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VEGETATION, SOILS, AND HYDROLOGY OF CENTRAL LOUISIANA BOTTOMLAND HARDWOOD FOREST TYPES

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The School of Forestry, Wildlife, and Fisheries

by
William Brown Patterson
B.A., Davidson College, 1983
M.S., University of Tennessee, 1989
December 1997

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ABSTRACT

Wetland delineation in bottomland hardwood forests is controversial due to uncertainty of the duration of inundation and soil saturation on seasonally dry sites. Wetland delineation requires an assessment of hydrophytic vegetation, hydric soils, and wetland hydrology.

The objectives were to: i) classify forest types in five Wildlife Management Areas in central Louisiana within Sharkey clay and Fausse clay soil mapping units, ii) compare site and soil variables between the forest types, iii) evaluate relationships between tree species distributions and soil/site factors, iv) characterize soils in the study area, v) evaluate differences in forest types for durations of inundation, soil saturation, and soil chemical reduction.

Five forest types were classified in the study area and named for their dominant species: Sugarberry (*Celtis laevigata* Willd.), Overcup Oak (*Quercus lyrata* Walt.), Water Hickory (*Carya aquatica* (Mich.f.) Nutt.), Black Willow (*Salix nigra* Marsh.), and Baldcypress (*Taxodium distichum* (L) L.C. Rich.). The Sugarberry forest type predominantly occurred on Sharkey clay soil mapping units with occasional flooding frequency, and the Black Willow and Baldcypress forest types occurred solely within the depressional Fausse clay soil mapping units having the longest inundation. Baldcypress forest type soils had the highest organic matter content and lowest pH among all the forest types.

All soils characterized were very fine or fine textured, and had high cation exchange capacities (30-50 cmol(+)/kg). The Sharkey soils were classified as very-

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fine, smectitic, thermic Chromic Epiaquerts, and met field indicators of hydric soils. Soils in identical landscape positions on Red River alluvium were classified as very-fine or fine, smectitic, thermic Aeric Epiaquerts, and mostly did not meet field hydric soil indicators.

Soils in the study area were episaturated during winter and spring. The Sugarberry forest type had the shortest durations of inundation, soil nitrate reduction, and soil iron reduction among the forest types. The Black Willow and Baldcypress forest types were inundated and chemically reduced longer than the other forest types.

All forest types were predominantly wetland, but the Sugarberry forest type had the least hydrophytic vegetation, met the fewest hydric soil indicators, and had the shortest duration of wetland hydrology among all five types.

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CHAPTER 1

INTRODUCTION

INTRODUCTION

Bottomland hardwood forests in Louisiana and the southern United States are a shrinking resource (Tiner, 1984; Conner et al., 1990), and portions of these bottomland hardwood forests are jurisdictional wetlands, which are protected from certain developmental activities. It is unclear now, however, how much of the bottomland hardwood forests are either jurisdictional or functional wetlands (Faulkner and Patrick, 1992). There are three criteria for identifying wetlands (Environmental Laboratory, 1987; Federal Interagency Committee for Identifying and Delineating Jurisdictional Wetlands, 1989): hydrophytic vegetation, hydric soil, and wetland hydrology. But, at this time, the relationship between the soils and vegetation of bottomland hardwood wetland and non-wetland areas is not well documented, except in rather general soil surveys. Collecting more data on vegetation-soil-hydrology relationships would aid in defining, identifying, delineating, evaluating and protecting bottomland hardwood wetlands (Touchet et al., 1990). With additional soil and hydrology data for bottomland hardwood forest types or communities, some predictions could be made as to possible species change or successional trends in response to a climate or hydrological change.

PROBLEM

The problem this study addresses is that the relationship between wetland characteristics such as hydrophytic composition of the vegetation, hydric nature of

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the soil, and the hydrology have not yet been investigated for southern bottomland forest community types. While there have been studies investigating soil and hydrology characteristics of the bottomland hardwood forests of the Mississippi River Alluvial Plain (Faulkner and Patrick, 1992), the approach has been conducted on wetland transition zones, and has not investigated the relationships of actual forest community types to wetland indicators. As previously mentioned, Scott et al. (1989) investigated the relationship of the hydric status of soils and the hydrophytic nature of vegetation in a wide variety of sites in the United States. They only measured herbaceous vegetation however, and did not sample any southeastern bottomland hardwood forests. Literature relating bottomland soil features to forest vegetation composition is limited (Wharton et al., 1982; Conner et al., 1990; Touchet et al., 1990; Larson et al., 1981; Huffman and Forsythe, 1981; and Patrick et al., 1981), and is in the form of literature reviews and workshop reports.

My research contributes new quantitative data to further evaluate conclusions reached by the above researchers. This study will also test important hypotheses of the relationships of the hydric nature and other features of soils to forest vegetation composition. Testing these hypotheses of wetland occurrence in forest community types and the association of hydric soils and hydrophytic vegetation would increase present knowledge of the status of the wetland nature of Mississippi River Alluvial Plain bottomland forest community types. The implications for wetland identification and delineation are enormous, given the current uncertainty over wetland status of southern bottomland hardwoods.

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OBJECTIVES

The overall goal and objective of this research is to evaluate the differences in wetland composition of several Louisiana Mississippi River Valley bottomland hardwood forest community types on the Sharkey (very fine, smectitic, thermic Vertic Haplaquept)-Fausse (very fine, smectitic, thermic Typic Fluvaquent) soil association, using vegetation, soil, and hydrology criteria. Differences in these characteristics were tested between selected forest community and soil combinations, rather than in transition zones used by Larson et. al (1981) and Touchet and Panel (1990). There are four main objectives: (i) classify the forest communities or forest types of the Sharkey-Fausse soil association; (ii) evaluate relationships between soil physical, chemical and morphological character and vegetation composition within the Sharkey-Fausse soil association in the Mississippi River Alluvial Plain in south-central Louisiana; (iii) characterize the typical pedons of the soils of each soil unit-forest type combination using chemical, physical and mineralogical methods; (iv) monitor water table depth and soil redox potential of typical (modal) sites of soil unit and forest type combinations over a two year period.

HYPOTHESES

To meet the objectives of this study, several hypotheses are tested. The general hypothesis is Louisiana Sharkey-Fausse bottomland hardwood forest types differ in vegetation composition, soil characteristics, and hydrology. Specific hypotheses to be tested for Objective 1 are: forest communities of the Sharkey-Fausse soil association differ in distribution of selected soil properties; forest communities differ in

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proportion having hydric soils; selected forest communities in the Sharkey-Fausse soil association are restricted to hydric soil; selected hydric soils are restricted to certain forest communities present in the study area. For the first objective of classification of forest community types, the hypothesis is vegetation forms separate clusters or groups of vegetation composition. The second objective's hypotheses are: forest types differ in soil physical, chemical, or morphological characteristics. Hypotheses for the third objective are: forest type-soil combinations differ in soil chemical, physical, or mineralogical characteristics. Hypotheses for the fourth objective are as follows: forest type-soil combinations differ in duration of high water-table depth; forest type-soil combinations differ in seasonal soil redox potential.

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CHAPTER 2

REVIEW OF LITERATURE

WETLAND DEFINITIONS

The National Food Security Act Manual (NFSAM)(Soil Conservation Service 1994) defines wetlands as lands that:

> have a predominance of hydric soil; and
> are inundated or saturated by surface water or groundwater at a frequency and duration sufficient to support a prevalence of hydrophytic vegetation typically adapted for life in saturated soil conditions; and
> under normal circumstances do support a prevalence of hydrophytic vegetation.
> (Soil Conservation Service 1994)

The NFSAM further states that wetlands have three criteria that must be met: hydrophytic vegetation, hydrology, and hydric soil (Soil Conservation Service 1994). Each criterion must be independently confirmed with data.

The following definition of a hydric soil was published in the Federal Register:

> Soil that is formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part. (Federal Register, February 24, 1995, Vol. 60, No. 37, page 10349)

The National Technical Committee on Hydric Soils developed criteria for hydric soils. Soil series and map unit components are classified as hydric by meeting one of these criteria:

1. All Histosols except Folists, or
2. Soils in aquic suborders, great groups, or subgroups, Albolls suborder, Aquisalids, Pachic subgroups, or Cumulic subgroups that are:

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a. Somewhat poorly drained with water table equal to 0.0 foot from the surface during the growing season, or,

b. poorly drained or very poorly drained soils that have either:

(1) water table at less than 0.0 foot from the surface during the growing seasons if textures are coarse sand, sand, or fine sand in all layers within 20 inches, or for other soils

(2) water table at less than 0.5 foot from the surface during the growing season if permeability is equal or greater than 6.0 inches/hour in all layers within 20 inches, or

(3) water table at less than 1.0 foot from the surface during the growing season if permeability is less than 6.0 inches/hour in any layer within 20 inches, or

3. Soils that are frequently ponded for long duration or very long duration during the growing season, or

4. Soils that are frequently flooded for long duration or very long duration during the growing season.
(Federal Register, February 24, 1995, Vol. 60, No. 37, page 10349)

The Natural Resources Conservation Service (NRCS, formerly Soil Conservation Service) staff have developed a set of field indicators of hydric soils to assist hydric soil classification (NRCS, 1996). These indicators are based on soil color morphology, especially redoximorphic features. Redoximorphic features are the signatures that oxidation, reduction, and movement of iron and manganese leave on the soil. Other field indicators are based on organic matter accumulation and sulfide presence.

The US Army Corps of Engineers (Environmental Laboratory, 1987) defines wetland hydrology as "periodical" inundation or having saturated soils during the

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growing season. This hydrology must, however, have an "overriding influence" on: vegetation due to anaerobic conditions, and soils due to "reducing" conditions. The 1987 wetland manual states that areas with less than 5 percent duration of inundation or soil saturation during the growing season are not wetlands. In addition, many areas with an inundation or saturation duration of 5 to 12 percent of the growing season are also not wetlands.

Hydrophytic vegetation is defined by the US Army Corps of Engineers as having 50 percent or more of the dominant species have obligate wetland or facultative wetland distributions. (Environmental Laboratory, 1987). The NRCS (Soil Conservation Service, 1995) defines hydrophytic vegetation as having a Prevalence Index (PI) of less than 3. Prevalence Index is an average of the species' wetland status or index, weighted by each species abundance or frequency. Wetland status categories of species are: Obligate (1), Facultative Wetland (2), Facultative (3), Facultative Upland (4), and Upland (5).

LOWER MISSISSIPPI RIVER ALLUVIAL PLAIN BACKSWAMP AND LOWER LEVEE SOILS

The Sharkey soil (very fine, smectitic, thermic Vertic Haplaquept) has the largest areal extent (36 percent) of all soils in the Mississippi River Alluvial Plain, and the Fausse soil (very fine, smectitic, thermic Typic Fluvaquent) has the third largest area (11 percent) in the alluvial plain (Schumacher et al., 1988). Sharkey is situated in clayey backswamps and low positions on natural levees, is poorly drained, and has very slow permeability. Fausse is located in backswamp interiors, is also formed from clayey alluvium, has very poor drainage and very slow permeability

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(Amacher et al. 1989). Sharkey is frequently mapped in phases such as: Sharkey clay, frequently flooded; Sharkey clay, occasionally flooded; and Sharkey clay, overwash. Sharkey and Fausse soils are found in association with each other in clayey backswamp soils and in Meander Belt No. 5 , the youngest meander belt of the Mississippi River Alluvial Plain (Shumacher et al., 1988).

The water table level is an important parameter in soils subject to saturation or inundation, and has been investigated in Louisiana by several researchers. Faulkner et al. (1991), using observation wells, found high water table durations critical to classifications of bottomland hardwood soils. Hudnall and Wilding (1992) and Hudnall et al. (1993), using piezometers, found that water table measurements of perched water tables differed from those of open bore holes or wells.

Faulkner et al. (1991), investigated saturated soil processes in wetland-nonwetland transition zones of the lower Mississippi River valley bottomland hardwoods in Louisiana and Mississippi, and concluded that large areas (5 of 24 soils monitored) of those forests exhibit dominantly aerobic soil processes during the growing season. They classified some sites as wetland, some as nonwetland, and others as transitional between the two classes. Sites were classified based on soil redox potential and soil oxygen content profiles and well water table fluctuations.

FLOODING EFFECTS ON SOIL CHEMISTRY

Flooding affects soil processes, mostly from the deprivation of oxygen in the soil. The exchange of oxygen from the air into the soil is slowed by 10,000 to 300,000 times because the exchange must go through water, and is limited to the

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very slow molecular diffusion (Greenwood, 1961; Stepniewski and Glinski, 1988). Also, the remaining oxygen in the flooded soil is rapidly consumed by aerobic and facultative anaerobic microorganisms (Gambrell et al., 1991). Thus anaerobic processes are established within a few hours to a few days (Turner and Patrick, 1968; Gambrell et al., 1991).

The top of the flooded soil profile (a few millimeters or centimeters) retains some oxygen. The presence of oxygen results from the relatively fast rate of oxygen transport from the atmosphere to the water, a small number of oxygen consuming microorganisms present, production of oxygen by algae in the water, and surface mixing by wind or convection current (Gambrell and Patrick, 1978).

Flooded soils, when anaerobic, have very different microbial activity from aerated soils. The aerobic microorganisms are replaced by facultative anaerobic and obligate anaerobic microorganisms. The anaerobic microbial utilization of soil organic matter is less efficient than that by aerobic microbes, so the soil organic matter decomposition is slowed, and there is a higher amount of organic material in the flooded soil than an aerobic soil (Reddy and Patrick, 1975; Delaune et al. 1981). The metabolic end products of aerobic soils result in carbon dioxide, nitrate, sulfate, and simple, low molecular weight, residual humic materials. Anaerobic microorganisms' metabolic endpoints formed are: carbon dioxide, methane, hydrogen, ammonia, amines, hydrogen sulfide, and complex, higher molecular weight organic acids and residual humus (Gambrell et al., 1980, Ponnamperuma, 1984).

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The redox potential (Eh) of a soil is the measure of electron availability or electrochemical potential, and a measurement of redox potential is used to indicate the oxidation-reduction state of a soil (Gambrell et al., 1991). Oxidized or aerobic soils have a redox potential in the normal range of 400 to 700 millivolts, whereas reduced soils have from 400 to -400 mV redox potential (Gambrell and Patrick, 1978). The following thresholds for soils at pH 7 were identified by Turner and Patrick (1968) and Gambrell and Patrick (1978). Oxygen (O_2) in the soil is reduced to water at 320 to 340 mV, nitrate (NO_3^-)is reduced from 340 to 220 mv, and will not be totally reduced until all the O_2 is depleted or reduced. At 200 mV, after all O_2 is depleted, manganic manganese (Mn^{+4}) is reduced to the manganous form (Mn^{+2}), and ferric (Fe^{+3}) iron starts reducing to the ferrous (Fe^{+2}) state at 120 mV. Mn^{+4} reduction may overlap with the last NO_3^- of to be reduced. There may be some Mn^{+4} reduction occurring after Fe^{+3} reduction is started. When the redox potential falls to -150 mV, sulfate (SO_4^{-2}) begins to reduce to sulfide (S^-) and at -250 to -300 mV, carbon dioxide (CO_2) is starting to reduce to methane (CH_4).

Gilmour and Gale (1988) examined data from 18 field, greenhouse, and laboratory studies relating metal concentrations to flooding. They found four typical curves of solution metal concentration varying with duration of flooding. Iron and Mn data usually followed the Type I response: a rapid increase in metal concentration in solution, followed by a slower decrease to somewhat more stable levels. Soil reduction and formation of chelates with fermentation products were thought to be the causes of the rapid increase. The decrease in metal concentration

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was attributed to: decreased chelation, solid phase formation, and adsorption by anaerobic condition created surfaces. Where low temperatures or lack of organic matter slowed reduction, a Type II curve resulted for Fe and Mn. This curve is characterized by a slow increase in Fe and Mn concentration, with no peak reached even after 100 days.

Soil pH is also affected by flooding or waterlogging. Acidic soils tend to have an increase in pH toward 6 or 7, whereas basic soils' pH usually decreases to around 7 (Ponnamperuma, 1984). Swarup et al. (1992) found that a Sharkey soil in Louisiana with an initial pH of 5.2 increased to pH 6.7 after four continuous weeks of waterlogging. The Eh in that soil decreased from about 400 mV to about -200 mV during that period. Acid soils low in organic matter and reducible Fe have a slower increase in pH in response to flooding than do soils with higher organic contents (Ponnamperuma, 1972).

Much N in flooded soils is tied up in organic matter, but some is mineralized to ammonium (NH_4^+). Ammonium is produced in both aerobic and anaerobic conditions. Ammonium that is not taken up by roots is oxidized to NO_3^- in the aerobic layer, and NH_4^+ diffuses up through the soil, because of the lower quantity in the oxidized horizon. If NO_3^- is not taken up by roots, or lost by leaching, it is reduced to ammonia (NH_3) or denitrified to gaseous molecular nitrogen (N_2) (Gambrell and Patrick, 1978; Mitsch and Gosselink, 1986). The reduction of Mn, Fe, S, and CO_2 has been mentioned already. Phosphorus occurs in soils in soluble and insoluble inorganic and organic forms. Anaerobic conditions in soils result in an

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increase in soluble P largely because of Fe reduction and the resulting dissociation of ferric phosphate forms, as well as hydrolysis of ferric and aluminum phosphates and anion exchange mediated release of P sorbed to clays and hydrous oxides (Ponnamperuma, 1972).

An example of forested floodplain soils experiencing both anaerobic and aerobic conditions is that of Faulkner and Patrick (1992). They found three different situations related to the duration of anaerobic conditions: nonwetland sites, wetland and transition sites. Nonwetland sites maintained high soil oxygen contents throughout the year, and the water table remained low. The redox potential of these sites also exhibited a flat response throughout the measurement time. None of the nonwetland soils developed enough hydric soil indicators to be classified as hydric. Wetland sites exhibited more than 68 days (25 % of growing season) of anaerobic conditions during the growing season, as evidenced by redox potentials below 300 mV, saturation, and low soil O_2 content (<5%). Gambrell et al. (1990) and Faulkner et al. (1991) in the same project, found extractable (largely reduced) Fe and Mn generally increased in wetter plots on transects as compared to the drier plots.

ANAEROBIC SOIL MORPHOLOGY FORMATION

Anaerobic conditions and the resulting reduction of iron from the ferric state to the ferrous form has great influence on the formation of soil colors. Soil scientists have long used soil color of the B horizon to assess drainage regimes. Parent material, geomorphology and hydrology influence the formation of soil color. The type (mineralogy) of Fe oxides formed, pattern and location in the soil ped give an

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indication of the pedogenesis (Richardson and Daniels, 1993; Mausbach and Richardson, 1994).

Aerated and oxidized soils have Fe in an immobile, slowly soluble oxide form. Mineralogy of the parent material can impart colors to the soil that formed from it (Schwertmann, 1993). Hematite (α-Fe_2O_3) exhibits a bright red color with a hue of 5YR to 5R. Lepidocrocite (γ-FeOOH), usually has a Munsell soil color hue of 7.5YR, and occasionally 5YR, and usually has a value ≥ 6, appearing as an orange color. Goethite (α-FeOOH), the most common soil Fe oxide, occurs mostly with hues ranging from 10YR to 2.5Y, and gives a yellow color. Ferrihydrite ($Fe_5HO_8 \cdot$ 4H2O) has a similar range of hue as lepidocrocite, but has values of 6 or less. Lepidocrocite formation requires reduced Fe to slowly oxidize during anaerobic-aerobic cycling conditions. Lepidocrocite is often concentrated as mottles, bands, pipestems, rootmats, and crusts (Fitzpatrick et al., 1985; Wang et al., 1993). Ferrihydrite has a smaller crystal size than lepidocrocite, so its value is less (darker). In contrast to lepidocrocite, reduced Fe is rapidly oxidized (Schwertmann, 1993).

When soils are anaerobic and reduced by microbes, the Fe oxides may be completely removed. The soil then generally retains the white, gray, or green-blue (gley) color of the mineral matrix. When reduced Fe is not completely removed from the soil, which may have differential zones of reduction intensity, characteristic patterns of morphology will arise. Vepraskas (1992) classified these patterns of mottling and low chroma colors into two general types of redoximorphic features. Redox concentrations are bodies of apparent accumulation of Fe-Mn oxides and

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include: nodules and concretions, masses, and pore linings. Redox concentrations typically have high chromas. Redox depletions are bodies of low chroma where Fe-Mn oxides and sometimes clay are apparently removed. Types of depletions are: Fe depletions, clay depletions, and reduced matrices. One must use caution in inferring current soil oxidation-reduction regimes because some soils have relict features such as: low chroma due to parent material alone, resistant concretions, and redoximorphic features from a previous different hydrological environment.

There are many examples of soil morphology related to site position, hydrologic, and soil reducing conditions. Simonson and Boersma (1972) correlated color morphology to water table regime in Willamette Valley soils of Oregon. Depths to faint and distinct mottling were strongly correlated with longer durations of saturation, although the depth to mottling was not a good indicator of saturation at depths above the mottled zone. Chromas of the dry, crushed soil increased at comparable depths for the sequence of somewhat poorly drained to well drained. Hues of 2.5Y and 5Y were associated with horizons of a perched water table, which were saturated nearly all the time from late fall to early spring.

In a central Ohio study (Zobeck and Ritchie, 1983), horizons at 25-50 cm depth with mottles of value/chroma of 4/2 were saturated longer than horizons with coatings of the same color (4/2). The low chroma mottles were found closer to the soil surface in the soils with the wettest moisture regimes (poorly drained). The matrix colors of the upper horizons of the two wettest soils had matrix chromas of 2 and 1. The moderately well drained and well drained soils had matrix chromas

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mainly of 4, as well as 3. All four soils in this study had perched water tables during winter or spring, but the very poorly drained, poorly drained, and moderately well drained soils all had perched water tables from mid-December through mid-April. The well drained soil had a perched water table only through February.

Franzmeier et al. (1983) related color patterns and water table levels of 14 Indiana soils within four particle-size families and drainage classes of well drained, moderately well drained, and somewhat poorly drained. They found that the horizons with dominantly gray (with chroma of 2 or less) matrix were saturated much of the year. Horizons with a brown matrix and gray mottles (depletions), and which were located above the gray matrix horizon, were saturated for a few months. Horizons with similar colors but located under the gray matrix layers were saturated most of the year. Horizons with a chroma of three in the matrix or mottles were also saturated for significant periods. Horizons with mottle chromas above 3, and matrix chroma of 5 or 7 were almost never saturated.

Evans and Franzmeier (1986) found that, for north-central Indiana soils, soils with no chromas of 2 or less could be saturated for several weeks but would not be reduced. Soils with chromas 2 or less had reduction durations consistent with the aquic moisture regime. Evans and Franzmeier proposed 3 classes of water and redox regimes: saturated-reduced, saturated-oxidized, and nonsaturated-oxidized.

Vepraskas and Wilding (1983a, 1983b, 1983c) studied seasonal saturation and reduction in Texas coastal plain soils and related those processes to soil morphology. These soils lacked the low chroma colors normally associated with saturation and reduction. The investigators found, however, eluvial concentrations of sand or silt

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located on ped surfaces and root channels. They called this feature an albic neoskeletan, as it is often a tongue or interfinger into an argillic horizon. Due to the depletion of iron and clay the chroma ranged from 2 to 4. Vepraskas and Wilding found that albic neoskeletan abundance was related more closely to duration of iron reduction than to duration of saturation.

A Chroma Index (CI) was developed by Evans and Franzmeier (1988) to relate the chroma of the soil to wet conditions. The CI is an average chroma of a soil horizon's matrix, redoximorphic concentrations, and redoximorphic depletions. The chromas are weighted by their abundance in that horizon. Megonigal et al. (1993) compared CI's of seasonally flooded South Carolina forest soils to water table, oxygen concentration and redox conditions. The CI was most strongly related to durations of saturation and reduction at 30 cm.

Bottomland hardwood soils examined by Faulkner and Patrick (1992) exhibited a wide range of soil morphology, saturation, and redox conditions. They found many soils in which the saturated and reduced conditions corresponded to chromas of 2 or less, but also found examples which deviated. Some soils had saturated and reducing conditions, but had higher chromas. Other soils were not saturated or reduced for significant periods during the study, and had apparent relict soil morphology indicators of wetness. Faulkner and Patrick concluded that if determinations of hydric soils were based on soil morphology alone, much more of the bottomland hardwoods would be delineated as wetlands than would be the case if hydrological and redox data were used.

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The texture and sequencing (stratigraphy) of parent material has a great influence on the water movement through the profile (Richardson and Daniels, 1993). Restricted water movement may lead to saturated or reduced conditions in some horizons. Clayey soils have finer pores, and a resulting lower hydraulic conductivity and longer water retention than sandy soils.

WETLAND HYDROLOGY

Leitman et al. (1983) investigated relationships between wetland hydrology and tree distribution of the Apalachicola River floodplain in Florida. They used four continuous recording gages over a one year period, and four long-term recording gages to record mean daily stage and mean daily discharge. These gages were located in several transects across the floodplain. In addition, several observation wells were measured monthly in the transects. Duration of inundation in the growing season was estimated from the river stage record. Duration of saturation was estimated by using the inundation duration or adding days to that time, depending on depth of water (above the soil) in the dry season (fall). Saturation level was judged as dry, damp or saturated. The water depth at a gage on a transect across the floodplain was related to vegetation plot elevation to assess duration of inundation and saturation. Leitman et al. (1983) found that three forest types dominated by baldcypress, tupelo, and by swamp tupelo and Ogeechee tupelo had longer hydroperiods than a water hickory - green ash - overcup oak -diamondleaf oak type. A sweetgum - sugarberry - water oak type had the least flooding frequency and saturation duration of all the forest types.

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Some relationships of trees in the White and Ouachita River basins to flooding were investigated by Bedinger (1979). Bedinger found that the duration of flooding for annually flooded sites was directly related to drainage area of the upstream basin. He used long term stream gaging records in the study areas to estimate flood frequency and duration, and relate them to species distribution.

Huffman (1979, 1980) also investigated timing of flooding and its relation to bottomland hardwood forest community structure in the Ouachita River Basin in Arkansas. His criteria for selecting study sites included: flooding duration of less than 30 days during the growing season, and sites located within 200 meters of U. S. Geological Survey continuous recording streamflow station, and adequately defined state-discharge relations of the site. Huffman limited the response variables to basal areas of trees having diameter at breast height of 2.5 to 15 cm, because they theoretically represented the study site vegetation of the 13 years that were on the hydrologic record. From the streamflow records, he used as variables: yearly frequency of flooding occurring early in growing season, frequency of early growing season flooding followed by midspring flooding, yearly frequency of two or more floods in variable parts of the growing season, and yearly frequency of late spring flooding. Cherrybark oak (*Quercus falcata* var. *pagodaefolia*) had a significant positive correlation with early spring flooding frequency, but was negatively correlated (as was blackgum (*Nyssa sylvatica*)) with late season flooding frequency. Sweetgum (*Liquidambar styraciflua*) was highly, positively correlated with the frequency of early spring flooding followed by midspring flooding. Variable timing

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of floods was significantly and positively correlated with ironwood (*Carpinus caroliniana*) basal area, but negatively correlated with that of water oak (*Quercus nigra*).

The relationship between ground-water fluctuations and canopy composition was investigated by Rheinhardt and Hershner (1992) in five tidal freshwater swamp sites in Virginia. They used 1 meter deep wells (slotted the whole length below ground) with potentiometer tide gauges to obtain water depth and water table depth. Depth of the water table / height of flooding was plotted against percent duration of flooding in hydrographs. Ash (*Fraxinus* spp.) - Blackgum (*Nyssa sylvatica* var. *biflora*) swamps had a shallower depth to mean water table than Maple (*Acer rubrum*)-Sweetgum (*Liquidambar styraciflua*) forests. Rheinhardt and Hershner stated that mean water-table depth in the root zone was more biologically appropriate than flooding duration, frequency, timing, or flood height for quantifying tidal system wetness.

Theriot (1993) used 10 to 20 year records of river stage or discharge at 17 sites across the Southeastern U.S. to establish flowrate boundaries of National Wetland Technical Council hydrologic zones (Larson et al., 1981), which were based on estimated growing season inundation and saturation duration and inundation frequency. Theriot employed a model that calculated inundation duration and frequency. The soil root zone was assumed to be a 25 cm deep bucket, and the model calculated a simplified water balance for this zone. Rates of filling, draining, and evapotranspiration were parameters in the model. Ponding was not included in

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the definition of inundation, and the bucket (soil) is only filled to overflowing by inundation. The hydrology at each site was related to the vegetation species composition of several bottomland hydrological zones. The study resulted in the assignment of a Flood Tolerance Index (FTI) for many southeastern U.S. forest tree, shrub, and herb species. The FTI of each species indicates the relative position of a plant's central distribution along the hydrologic zone gradient (zones 2-6).

Crownover et al. (1995) examined horizontal groundwater flow patterns through a cypress swamp - pine flatwoods landscape. On a grid system of a 42 ha study area, they used 120 one meter deep wells to determine water table levels every two weeks. Groundwater flow was assessed by comparing the water table depths at different locations within the grids to result in water table contours. The study demonstrated that the majority of water flow is through the cypress swamps, or out of the swamps, but not into the swamps from the surrounding flatwoods.

SOIL-VEGETATION CORRESPONDENCE

Several studies have evaluated the correspondence of plants, soils and soil properties or processes in areas with wetlands, uplands and transitions between wetland and upland. Josselyn et al. (1990) evaluated the relationships between vegetative cover of wetland list categories of plants, groundwater depth, soil oxygen, and redox potential in California. The hydrophytic nature of the vegetation was quantified by computing a weighted average ordination score, which took into account the cover of each species and weighted it by its wetland plant list category of Reed (1988). Obligate wetland plant occurrence with redox potential and soil oxygen

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content were the only significant correlations, as facultative wetland and facultative plants did not have clear associations with vegetative cover.

Scott et al. (1989) investigated the correspondence between vegetation (herb layer) and soils (hydric or not) for a variety of habitat types in the United States. As in Josselyn et al. (1990), weighted averages were computed for the vegetation. Scott et al. (1989) found good agreement between hydric status of soils and vegetation, as only 10 percent of the hydric soils sampled supported upland vegetation, and nonhydric soils supported only 15 percent wetland vegetation.

Christensen et al. (1988) examined soil-vegetation correlations in the pocosin communities (shrub bogs) in Croatan National Forest in North Carolina. They used weighted average ordination (weighting by hydrophytic categories of the Wetland Plant List) and detrended correspondence ordination to analyze the vegetation. Christensen et al., using the modern vegetation methods above on wetland vegetation and soil data of Woodwell (1956), found variations in peat depth and inundation frequency were related to the grading of pocosin communities into other community types. Christensen et al., however found a lack of clear relationships between vegetation types in the Croatan National Forest and soil series designations of the Soil Conservation Service. Two of the soil series investigated had great variation in vegetation composition. Although specific vegetation types were not well related to soil series, the wetland status (weighted average) of stands was significantly different among soil series, and the weighted average was highly correlated with a number of soil characteristics.

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Best et al. (1990), in northwest Florida, examined the correspondence of four hydric and two nonhydric soils with vegetation. Their results indicated significant differences in weighted average wetland index (for all strata of vegetation), and for plots or communities) among soils. Based on this community wetland index, the authors classified soils as either wet hydric, transitional hydric, or nonhydric.

Vegetation and soils were described by Light et al. (1993) for four north Florida floodplains with long-term hydrologic records. The determinations of wetlands were made first without using the hydrology information, then the long-term hydrology records were used to in order to make a comparison. On two floodplains, the high terrace forest vegetation indicated nonwetland conditions (using State of Florida wetland plant indices), but long-term hydrologic records suggested otherwise. Only one plot had its Federal wetland determination reversed when hydrology data was used. The State of Florida wetland plant index method was more liable than the Federal method to determine vegetation to be nonhydric in areas with documented wetland hydrology. The soil morphology of one of the high terrace soils was nonhydric; the other was marginally hydric. The hydrologic records of the problem sites of the high terraces indicate flooding of less than 10 percent of the growing season. All 10 sites had Federal hydrophytic vegetation; soil morphology of eight of these sites (one weakly) met Federal hydric soil criteria; eight sites had Federal indicators of wetland hydrology (one faint). Eight of the 10 sites were determined to be wetlands without using hydrologic records. Using hydrologic records, nine of the ten sites met wetland criteria.

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BOTTOMLAND HARDWOOD COMMUNITIES

There have been several recent classifications or groupings of Southeastern U.S. bottomland hardwood forests. Classifications since 1981 often are referenced to certain hydrologic zones of bottomland hardwoods. Larson et al. (1981) at a conference at Lake Lanier, Georgia (Clark and Benforado, 1981), designated six bottomland hardwood forest hydrological zones (Zones I to VI). Zone I is continuously flooded, Zone II is intermittently exposed (almost 100 percent of growing season has inundation), and Zone III is semipermanently flooded (greater than 25 percent of the growing season has flooding, and flooding frequency is greater than 50 percent of years). Zone IV is seasonally flooded, having a flooding duration of 12.5 to 5 percent of the growing season, and flooding frequency is greater than 50 percent of years. Zone V is temporarily flooded (duration of 2 to 12.5 percent of growing season, and frequency of 11 to 50 percent of years), and Zone VI, the transition to uplands, is intermittently flooded, having a flooding duration of less than 2 percent of the growing season, and a flood frequency of 1 to 10 percent of years (Larson et al., 1981).

Larson et al. (1981), Wharton et al. (1982), and Conner et al. (1990) are in agreement on the prevalence of certain species and their distribution in these hydrologic zones (ecological zones). For example, bald cypress (*Taxodium distichum* (L) L.C. Rich.) and water tupelo (*Nyssa aquatica L.*) are typical Zone II species (dominants), though they may also occur in Zone III. Zone III potential dominants are black willow (*Salix nigra* Marsh.), red maple (*Acer rubrum* L.), and cottonwood

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(*Populus deltoides* Bartr. ex Marsh.) in successional stands, as well as overcup oak (*Quercus lyrata* Walt.), water hickory (*Carya aquatica* (Michx.f.) Nutt.), and ash (*Fraxinus pennsylvanica* Marsh. and *F. caroliniana* Mill.). Dominant trees in Zone IV include sugarberry (*Celtis laevigata* Willd.), green ash (*F. pennsylvanica*), sweetgum (*Liquidambar styraciflua* L.), and elm (*Ulmus americana* L.), Water oak (*Quercus nigra* L.), cow oak (*Q. michauxii* Nutt.), and cherrybark oak (*Q. falcata* var. *pagodaefolia* Elliott), with many other species, occur in Zone V.

The previous zonal classification is not a community classification, but more an assemblage of species in hydrologic zones. Wharton et al. (1982), reviewed communities found by a number of studies in the Southeastern U.S., and grouped them into seven classes. Gum (water tupelo) - cypress (*Taxodium distichum* and *T. nutans* (*T. ascendans* Brongn.)) and swamp tupelo (*Nyssa sylvatica* var. *biflora*) associations are found in Zone II. There are three associations in Zone III: a pioneer dominance type of black willow, silver maple (*Acer saccharinum* L.), and cottonwood (*Populus deltoides*) on river banks and point bars; shrub - small tree types with willows and water elm (*Planera aquatica* J.F. Gmel); and on wet flats, overcup oak - water hickory. Floodplain flats with diamondleaf oak (*Quercus laurifolia* Michx.), green ash, American elm, sweetgum, and sugarberry. The Zone V dominance type occurs on flats and old levee ridges. The dominant species are cow oak, cherrybark oak, water oak, and either spruce pine (*Pinus glabra* Walt.) on wetter sites or loblolly pine (*P. taeda* L.) on drier sites.

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Klimas (1988) used a geographic information system (GIS) to find 23 forest cover types in the leveed floodplain of the lower Mississippi River. Ten of those cover types represented greater than 99 percent of the forest cover that was sampled in the field. Klimas classified cover types of tree plantation (cottonwood, sycamore (*Platanus occidentalis* L.)), black willow, cottonwood, sycamore-sweetgum-elm, sweetgum, sweetgum-oak, hackberry (sugarberry)-elm-ash, overcup oak - bitter pecan (water hickory), cypress-tupelo, and scrub.

Patterson and DeSelm (1989) classified the forest vegetation of the bottomlands of West Tennessee. They described 16 forest communities, and associated them with hydrologic zones of Larson et al. (1981) based on observed flood heights, and soil gleying depth classes. Baldcypress, water tupelo - baldcypress, and water tupelo communities were grouped into Zone II. Zone III communities were black willow, black willow - baldcypress, baldcypress hardwood, and water hickory - overcup oak. Red maple - mixed bottomland hardwood, green ash, and sweetgum - mixed bottomland hardwood communities were associated with Zone IV. Community types associated with Zone V were sugarberry - mixed bottomland hardwood, shellbark hickory (*Carya laciniosa* Michx. f.), cherrybark oak, willow oak (*Quercus phellos* L.), slippery elm (*Ulmus rubra* Muhl.) - mixed bottomland hardwood, and boxelder (*Acer negundo* L.).

White (1979) described several communities in the lower Pearl River Basin in Louisiana. His deep swamp community was dominated by water tupelo and baldcypress, and ashes were common. The mixed hardwood swamp had ironwood

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(*Carpinus caroliniana* Walt.), sweetgum, swamp red maple (*Acer rubrum* L. var. *drummondii* (H.&A. ex Nutt.) Sarg.) as dominants, with diamond leaf oak sometimes also being very important. The transition between the deep swamp and mixed hardwood swamp communities was marked by the occurrence of overcup oak and water elm. A shrub community consisting of *Iva frutescens* L., *Myrica cerifera* L., *Osmunda regalis* L., and *Amorpha fruticosa* L. also occurred.

Devall (1990) investigated the forest vegetation by quadrat analysis of Cat Island Swamp on the Mississippi River floodplain in West Feliciana Parish, Louisiana. Devall found that the vegetation formed patterns on six landform types. Baldcypress and water tupelo dominated the lowest area of the swamp, whereas overcup oak, followed by baldcypress and water hickory, was the main dominant in a slightly higher elevation. On an old natural levee, sugarberry was the dominant, with sweetgum following in importance. Sugarberry was the most important tree species on two other types: on ridges, in association with sycamore, and in swales, with the presence of pecan, and green ash. A community composed of black willow and cottonwood was situated on a new natural levee. There was a range of only 2 meters in elevation among all the quadrats in the swamp.

The Society of American Foresters (SAF) forest cover types (Eyre, 1980) for the southeastern U.S. include several baldcypress - gum (tupelo, swamp tupelo) types, both baldcypress dominated and with baldcypress and water tupelo sharing dominance, and one type with water tupelo dominating. Other forest cover types include a black willow type, an overcup oak - water hickory type, sweetgum - willow

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oak, sugarberry - American elm - green ash, willow oak - water oak , diamond leaf oak, and swamp chestnut oak - cherrybark oak.

VEGETATION COMPOSITION AND HYDROLOGY

Bedinger (1979) investigated relationships between forest species and flooding in the White and Ouachita River Basins in Arkansas. He found three groups of species related to flooding characteristics. The water hickory - overcup oak group was inundated annually from 29-40 percent duration. This group also included sugarberry, water locust, water elm, and swamp privet. The second group, the Nuttall oak group, was inundated in most years from 10-21 percent of the time. Its major species were overcup oak, Nuttall oak, sugarberry. ash, and water hickory. Willow oak and sweetgum are commonly present. Shagbark hickory (*Carya ovata*)- cherrybark oak (*Quercus falcata* var. *pagodaefolia* group occurred on sites flooded at intervals of every 2 to 8 years.

Huffman (1979), investigated the relation of sapling basal area to flooding frequency and timing in the Ouachita River Basin in Arkansas. Ironwood (*Carpinus caroliniana*) sapling basal area was positively correlated with repeated floods of short durations at variable times of the growing season. Sweetgum seedling' basal area developed well on areas flooded early in the growing season, followed by short duration midspring flooding. Cherrybark oak sapling basal area was positively correlated with short-term flooding in the early growing season, and negatively correlated with post-midspring flooding of short duration. Blackgum also developed

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poorly on areas with later flooding. Water oak basal area was negatively correlated with multiple flooding at various stages of the growing season.

Three swamp sites with differing flooding regimes in southern Louisiana were investigated by Conner et al. (1981). The hydrology of two of the sites (all contiguous) was altered by man 10 years before the study, but one site still has natural flooding. The naturally flooded area is inundated to a depth of up to 0.5 meter most of the year, and supports dominants of baldcypress and water tupelo. Water tupelo has the most importance in the permanently flooded (altered) site, but is not as important as in the naturally flooded site. Swamp red maple, baldcypress, ash, and buttonbush (*Cephalanthus occidentalis* L.) are much more prevalent than in the first site. On a crawfish farm site with controlled flooding (drained in the summer), swamp red maple and ash are dominants, with baldcypress remaining codominant.

Leitman et al. (1983) classified five forest types on the Apalachicola River floodplain in Florida. Sweetgum - sugarberry - water oak occurred on levees, ridges and high flats that received relatively infrequent flooding, and were saturated less than 20 percent of the growing season. A water hickory - green ash - overcup oak - diamondleaf oak type occurred on similar sites but with but on lower positions which were saturated longer and had a longer duration of flooding. The water tupelo - Ogeeche tupelo (*Nyssa ogeche* Bartr. ex Marsh.) - baldcypress, water tupelo swamp tupelo (*Nyssa sylvatica* var. *biflora*), and water tupelo - baldcypress types occurred on permanently saturated sites with the longest flooding duration.

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In tidal swamps of Virginia, Rheinhardt and Hershner (1992) related community canopy composition to flooding duration and water-table depth. They instrumented sites on two community types, Ash (*Fraxinus* sp.) - Blackgum (swamp tupelo)(*Nyssa sylvatica* var. *biflora*), and Red Maple - Sweetgum. The canopy composition of the plots had no association with flooding duration or tidal amplitude. Ash - Blackgum swamps had a shallower mean water-table depth than the Red Maple - Sweetgum swamps. The zone at which flooding occurred 20-80 percent of the time occurred at a greater depth in Red Maple - sweetgum swamps than Ash - Blackgum swamps.

Theriot (1993) used flood records to relate the frequency of Southeastern U.S. bottomland forest tree, sapling, shrub and herb layer species to National Wetland Technical Council (NWTC) hydrologic zones. The NWTC bottomland hydrologic zones are based on estimated inundation and saturation durations and frequencies (Larson et al., 1981). Water tupelo, black willow and baldcypress frequency peaked in Zone 2 (75-100 % growing season inundation/saturation duration, 90-100 years/100 years frequency), and water hickory, overcup oak, and swamp privet were most frequent in Zone 3 (25-75 % growing season inundation/saturation duration, 51-90 years/100 years frequency). Species having the most frequent distribution in Zone 4 (12.5-25 % growing season inundation/saturation duration, 51-90 years/100 years frequency) included sugarberry, willow oak, and American elm. Tree species with distribution centered around Zone 5 (5-25 % growing season inundation/saturation duration, 1-50 years/100 years frequency) included: water oak, blackgum and sweetgum. American hophornbeam (*Ostrya virginiana* (Mill) K. Koch.), loblolly

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pine (*Pinus taeda* L.), and mockernut hickory (*Carya tomentosa* (Poir.) Nutt.) were Zone 6 (<5 % growing season inundation/saturation duration, 1-10 years/100 years frequency) species.

Four bottomland hardwood forest dominance types were classified in the Cache River floodplain of Arkansas (Smith, 1996), and related to periods of overbank flooding, as determined by a link-node model (Walton et al., 1996). A tupelo and baldcypress forest type occupied backswamps with a mean flood duration of 194 days per year. The overcup oak - water hickory and Nuttall oak - green ash dominance types were found in floodplain depressions subject to 90 - 100 days of flooding per year. The sweetgum - willow oak community on terraces was only flooded an average of 73 days per year. The flooding of the tupelo - baldcypress type occurred throughout the growing season, but the flooding of the other three types was largely restricted to the nongrowing season. A bird community habitat study in the same floodplain (Wakeley and Roberts, 1996) found four similar zones of tree distribution: dominated by water tupelo and baldcypress having 297 days of inundation per year; dominated by overcup oak, water hickory and green ash flooded 77 days per year; dominated by Nuttall oak, willow oak, and sweetgum and inundated 28 days, and dominated by sweetgum, water oak, and pignut hickory (*Carya ovalis* [Wang.] Sarg.) having only 3 days of flooding per year. The study used the link-node surface-water model (Walton et al., 1996) to estimate cumulative annual duration of overbank flooding.

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EFFECTS OF FLOODING ON TREES

All trees are affected by flooding or anaerobic conditions, but some are more tolerant than others. Frequency, duration, and timing of the flood, as well as movement and height of the floodwater are important factors in determining effects of flooding on trees (Broadfoot, 1960; Harms, 1973; Bedinger, 1981). Flooding affects germination and viability of seeds, and growth of shoots, stems, and roots. Growth is inhibited by decreased photosynthesis, decreased macronutrient uptake, and altered amounts of hormonal growth regulators. Effects of flooding on seed germination, seedling growth, and physiology, as well as adaptations or tolerance mechanisms to flooding, influence species distribution.

The duration of flooding is important for germinating seeds, as saturated soil has little or no available oxygen, which is required for respiration. Baldcypress seeds can germinate after 30 months of flooding (Demaree, 1932). Water tupelo and swamp tupelo exhibit similar responses (Kozlowski et al., 1991). Cottonwood and black willow seeds germinated in water after only four days of soaking (Hosner, 1957). Red maple, silver maple, sycamore, and American elm showed no effect from 32 days of soaking, as they all germinated after removal from water (Hosner, 1957).

Shoot height and stem growth of red maple seedlings are reduced when flooded, but are increased for alder (McDermott, 1954) and water tupelo (Dickson et al., 1965) when growth is compared to that of unflooded controls. Cherrybark oak and Shumard oak show high shoot mortality under flooding during the growing season (Hosner and Boyce, 1962).

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The leaf growth timing and abscission may also be affected by flooding. Overcup oak and green ash delay leafing in the spring until the flooding level is down (Hook and Scholtens, 1978), but flooding induces premature leaf shedding in overcup oak, cherrybark oak, and swamp chestnut oak (Parker, 1950). Leaves of flooded sycamore seedlings expanded only 10% compared to unflooded seedlings (Tsukahara and Kozlowski, 1985).

Root growth is decreased by flooding in green ash (Sena Gomes and Kozlowski, 1980), sycamore (Tang and Kozlowski, 1982), and American elm (Newsome et al., 1982), but is increased in flooded tupelo and swamp tupelo (Hook and Scholtens, 1978). If roots cannot uptake oxygen because of death, injury, dormancy, or anoxia, the process of respiration is shut down, and water and ion uptake is inhibited by changing root cell membrane permeability and a reduction of the amount of energy available for membrane transport (Teskey and Hinckley, 1977).

The physiology of tree seedlings may be affected by flooding. Declining net photosynthesis (although stilll positive) of flooded sweetgum seedlings was associated with partial stomatal closing (Pezeshki and Chambers, 1985a). Cherrybark oak also experiences rapid stomatal closure and significant declines in net photosynthesis, and the average net daily photosynthetic rate was negative for the fourth through the sixth days of flooding (Pezeshki and Chambers, 1985b). Stomata close in green ash seedlings when flooded, and open after 15 days of inundation (Sena Gomes and Kozlowski, 1980; Tang and Kozlowski, 1984). Long-term reduction in photosynthesis (decrease in photosynthetic capacity) is caused by carboxylation

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enzyme activity decrease, chlorophyll loss, and reduced leaf area (Kozlowski and Pallardy, 1984). The closed stoma in the above studies were associated with reduced transpiration rates in the species involved (Sena Gomes and Kozlowski, 1980), which leave the tree species in various stages of drought-like stress (Teskey and Hinckley, 1977).

Flooding may alter the nutrition of tree species. Uptake of nutrients is related to waterlogging tolerance of a species, degree of reduction of soil and resulting toxic substances, and soil type (Ponnamperuma, 1972; Hook, 1984). Flood intolerant species are less able to take up macronutrients, as well as water (Teskey and Hinckley, 1977; Kozlowski et al., 1991). Sugarberry and American elm seedlings in saturated soil took up less N, P, K, Ca and Mg than nonsaturated seedlings (Hosner and Leaf, 1962). However, tupelo and baldcypress receive better nutrition and have greater growth in saturated soil than in nonsaturated soil (Dickson et al., 1972), and green ash and black willow seedlings had higher contents of N, P, K, Ca and Mg than their nonsaturated counterparts (Hosner and Leaf, 1962). Uptake of Fe and Mn is usually not increased on a net basis, due to reduced growth, but the absorption of Fe and Mn increases because of the conversion to reduced soluble forms (McKevlin et al., 1987; Kozlowski and Pallardy, 1984). In loblolly pine seedlings subjected to flooding, the Fe and P concentrations in the roots increased, but the Fe in the roots may have prevented P movement into the stem and leaves, leading to P deficiency (McKevlin et al., 1987).

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Phytotoxins are potentially injurious substances that accumulate either in the anaerobic soil environment, or in and around roots. Sulfides, CO_2, reduced and soluble Fe and Mn, ethanol, acetaldehyde, cyanide compounds, fatty acids, and ethylene are known and common phytotoxins (Kozlowski et al., 1991). Kozlowski (1991) states, however, that oxygen deficiency is the most important factor injuring and inhibiting flooded plants.

Jones and Etherington (1970) subjected two species of *Erica* to waterlogging and found that high Fe levels caused discoloration, desiccation. and ultimately death of leaves. Sanderson and Armstrong (1978, 1980) controlled the levels of several phytotoxins in the soil water culture of lodgepole pine and sitka spruce seedlings. Below a critical level of Fe^{2+} concentration of 5 mg/L in the soil solution culture there was no effect on root growth, but above this level root growth progressively declined. At a forest site in Britain, they found Fe^{2+} at 125 mg/L, exceeding the 100 mg/L levels they found, which causes root death. Sanderson and Armstrong (1980) suggest that Fe^{2+} may bind irreversibly with enzymes and thus immobilize them. Given iron's propensity to complex with organic acids, it seems possible. Reduced Fe in flooded soil around loblolly pine (McKevlin et al., 1987) was taken up by the roots and was concentrated in the roots more than that of the unflooded seedlings roots. The P concentration in roots that were flooded also increased, but the movement of P into the roots and stems was decreased, leading to foliage P deficiency. Waterlogged *Epilobium hirsutum* plants increase uptake of Fe^{2+} that catalyzes a reaction in the roots where super oxides radicals are produced, inducing

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superoxide dismutase and the formation of hydrogen peroxide, which causes lipid peroxidation and cellular damage (Hendry and Brocklebank 1985). Ferrous Fe has been shown to affect the photosynthetic rate and respiration of two waterlogged willow species (*Salix cinerea* and *Salix caprea*). In the latter species, 40 mg/L of Fe^{2+} caused almost total inhibition of photosynthesis as well as a significant reduction in respiration (Talbot and Etherington, 1987).

Ponnamperuma (1972) stated that Mn toxicity was not known to occur in flooded soils. Little appears to be known concerning Mn^{2+} toxicity in flooded soils. Despite the precipitation of black oxides (Fe/Mn = 2 to 3.1 / 1) on European larch, red pine, and white spruce, Mn^{2+} accumulated in the roots, thus was taken up and bypassed the oxidized rhizosphere (Levan and Riha, 1986). Levan and Riha suggest this oxidation is biological, as Mn oxidation is pH dependant. Mn oxidizes at pH above 7, but the soil pH was acidic (5.0). In the experiment by Jones and Etherington (1970), the effect of waterlogging on Mn uptake was much less evident than the effects of Fe on the plants. Waterlogging actually seems to have slightly decreased the Mn content in the leaves and shoots in one species. Manganese toxicity has been associated with the destruction of auxin in cotton and morning glory, leaf chlorosis and necrosis of various crop plants, and internal bark necrosis of apple trees (Foy et al., 1978).

Hydrogen sulfide in soil is highly toxic to plants (Gambrell et al., 1991). However, if Fe^{2+} is present, it will precipitate the sulfide into an immobile, nontoxic form. Hence, sulfide toxicity problems in flooded soils occur more in organic soils

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with little Fe^{2+} (Gambrell et al., 1991). Hydrogen sulfide may affect the roots directly (toxicity) or it can immobilize Zn and Cu (Ponnamperuma, 1972).

Some phytotoxins are generated as metabolic byproducts, such as volatile fatty acids (low molecular weight monocarboxylic acids (Sanderson and Armstrong, 1980a, 1980b). Sitka spruce and lodgepole pine root growth declined markedly upon treatment with several levels of acetic acid and butyric acid in an experiment conducted by Sanderson and Anderson (1980a). These researchers state that volatile fatty acids are known to increase membrane permeability by causing high lipid solubility. Sanderson and Armstrong (1980a, 1980b) concluded, however, that anoxia was the primary determinant in the root die-back in these trees. Membrane integrity is very important, as metabolic toxins like cyanide may enter the cell. Roe and Catlin (1971) found that plum roots had less cyanogenic glucoside than peach and apricot roots when waterlogged, and that plum had less hydrolyzing of the cyanogenic glucoside (thus less HCN evolved). The cyanide evolved creates cellular damage. Methane, ethane, propylene, unsaturated acids, aldehydes, ketones, and diamines have also been reported as byproducts of anaerobic metabolism (Kozlowski, 1985).

Ethanol has been considered as very toxic to the plant, and some (McMannon and Crawford, 1971) theorize that the accumulation of ethanol is characteristic of flood intolerant species. McMannon and Crawford (1971) speculated that the accumulation of nontoxic malate was characteristic of flood tolerant species. Ethanol, however, appears to readily diffuse out of *Spartina alterniflora* roots

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(Mendelssohn, McKee and Patrick, 1981). Jackson et al. (1982), however, subjected pea roots to 100 times the ethanol concentration normally found in flooded soil, and found no flooding injury. Ethylene may be produced both in the root (endogenous) or produced in flooded soil. Sanderson and Armstrong (1980a) reported permanent reduction and cessation of flooded lodgepole pine root growth when subjected to increased soil water ethylene concentrations of 20 mg/L. They suggest that toxic levels of ethylene may induce dormancy. Topa and McLeod (1988) reported retarded pond (*Pinus clausa*) pine root growth by ethylene, largely by reducing root extension.

Flood tolerant trees exhibit adaptations and tolerance mechanisms to avoid and tolerate anoxia. Some willow species transport oxygen from the leaves to the roots (Armstrong, 1968). Hypertrophied lenticels, extended openings on the stems, facilitate internal oxygen transport in tupelo (Hook et al., 1970). Green ash, black willow, cottonwood, and sycamore also exhibit hypertrophied lenticels, which may also function as vents for releasing the toxic ethanol, acetaldehyde, and ethylene, which may accumulate in the tree (Kozlowski et al., 1991). Swamp tupelo (Hook et al., 1971) and black willow roots (Dionigi al., 1985) diffuse oxygen into the soil, and oxidize the rhizosphere. The toxic reduced Fe and Mn will therefore be oxidized and rendered less soluble. Baldcypress, when flooded, developed aerenchyma, a porous tissue with large intercellular spaces, which facilitate the transport of oxygen (Pezeshki, 1991). The flooded roots of overcup oak developed a less dense exodermis and endodermis compared to nonflooded roots (Pezeshki, 1991). Tupelo (Hook et al., 1970) and green ash (Sena Gomes and Kozlowski, 1980) develop

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adventitious roots on the stem above the floodwater (Hook et al., 1970). These roots may increase the capacity to absorb water and nutrients (Kozlowski et al., 1991).

Flooded swamp tupelo and tupelo (Keeley, 1979), and green ash (Good and Patrick, 1987) increase activity of alcohol dehydrogenase (ADH), which catalyzes the conversion of aldehyde to the diffusible ethanol. Increased ADH activity levels indicate anaerobic respiration, an important metabolic adaptation (Mitch and Gosselink, 1986). Baldcypress (Pezeshki, 1991; Pezeshki et al., 1996), and green ash (Good and Patrick, 1987) also showed increased ADH levels induced by flooding, but water oak (Good and Patrick, 1987), overcup oak, and cherrybark oak (Pezeshki et al., 1996) showed no increase.

SUMMARY AND CONCLUSIONS

There are studies in the literature that rekate bottomland hardwood tree species distribution to inundation duration, frequency, and timing. There are also investigations relating the survival, growth, and physiology of bottomland tree species to flooded and waterlogged conditions. Many studies are published that investigate the development, processes, and expression of anaerobic soil conditions. Some investigations have correlated species hydrophytic composition to hydric soil status. There are, however, few or no quantitative studies relating bottomland hardwood community structure or species distribution to actual durations of soil saturation, high water table, and soil chemical reduction. There are also few or no studies relating the movement and type of water tables to bottomland hardwood community composition. Furthermore, the hydric status and taxonomic classification of clayey

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bottomland soils such as Sharkey is controversial (Pettry and Switzer, 1996). Further study of this type of soil would help to identify and characterize water table movement and chemical reduction processes, and relate those to soil morphology and bottomland hardwood species distribution.

Information relating bottomland hardwood species composition to soil inundation, saturation, and anaerobic processes would be very useful for future wetland classifications such as Hydrogeomorphic Classification (HGM) that evaluate wetlands based on fulfillment of wetland functions. Characterization of hydrologic process and geomorphic positions is an integral part of HGM (Brinson, 1993).

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CHAPTER 3

FOREST TYPES AND BOTTOMLAND HARDWOOD SPECIES DISTRIBUTION OF THE LOWER NATURAL LEVEES AND BACKSWAMPS OF THE MISSISSIPPI AND RED RIVERS IN CENTRAL LOUISIANA

INTRODUCTION

Wetlands are identified and delineated on the basis of meeting three criteria: hydrophytic vegetation, hydric soils, and wetland hydrology (Environmental Laboratory, 1987; FICWD, 1989). There has been disagreement on wetland classification and status of southeastern United States bottomland hardwood forests, due to uncertainty in the duration of seasonal inundation, saturation and anaerobic conditions. The hydrology of these forests has not been measured extensively, thus vegetation has been used as an indicator of the hydroperiod. Relating forest type composition to wetland conditions improves wetland classification and evaluation.

Individual species' distribution to wetlands have been related qualitatively by the National Wetlands Inventory (NWI) Wetland Plant Status (WPI)(Reed, 1988) and the resulting weighted average of WPI or Prevalence Index (PI) for a given site (Michener, 1983; Wentworth et al., 1988; Carter et al., 1988). Theriot's (1993) Flood Tolerance Index (FTI) related individual southeastern U.S. bottomland forest plants to computed duration of inundation and soil saturation. Basal areas of saplings of individual bottomland hardwood species were related to flood timing and duration in Arkansas (Huffman, 1980). Phipps (1979) computed optimal water table depths by simulation for bottomland hardwood species in Arkansas. Tree species in Louisiana virgin bottomland hardwood forests were related to geomorphic position by Tanner

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(1986). Several bottomland hardwood associations in the White and Ouachita River floodplains in Arkansas were related to flooding duration (Bedinger, 1979). Leitman (1983) compared durations of inundation and soil saturation for five bottomland hardwood forests in the Apalachicola River floodplain in western Florida. Smith (1996) found four bottomland hardwood types in the Cache River, Arkansas, and related them to geomorphic position and computed inundation duration. Bottomland hardwood forest type classification and characterization has been rare in Louisiana, and there are no or few studies relating bottomland forest types to hydric soil indicators.

The objectives of this study were to: i) classify forest types for backswamp and lower natural levee bottomland hardwoods for several central Louisiana Wildlife Management Areas (WMA's), ii) relate the forest types to soil and hydrology properties, and iii) examine relationships between species distribution and environmental gradients.

METHODS

The study areas were five Louisiana State Wildlife Management Areas in central Louisiana: Grassy Lake (GL), Pomme de Terre (PT), and Spring Bayou (SB) in Avoyelles Parish, and Red River (RR) and Three Rivers (TR) in Concordia Parish (Figure 1). Fifteen plots were randomly located within each of the three predominant soil mapping units in the Wildlife Management areas: Sharkey clay, occasionally flooded (SO); Sharkey clay, frequently flooded (SF); and Fausse clay (F), the most frequently flooded unit. Sharkey is classified as Vertic Haplaquept, very-fine,

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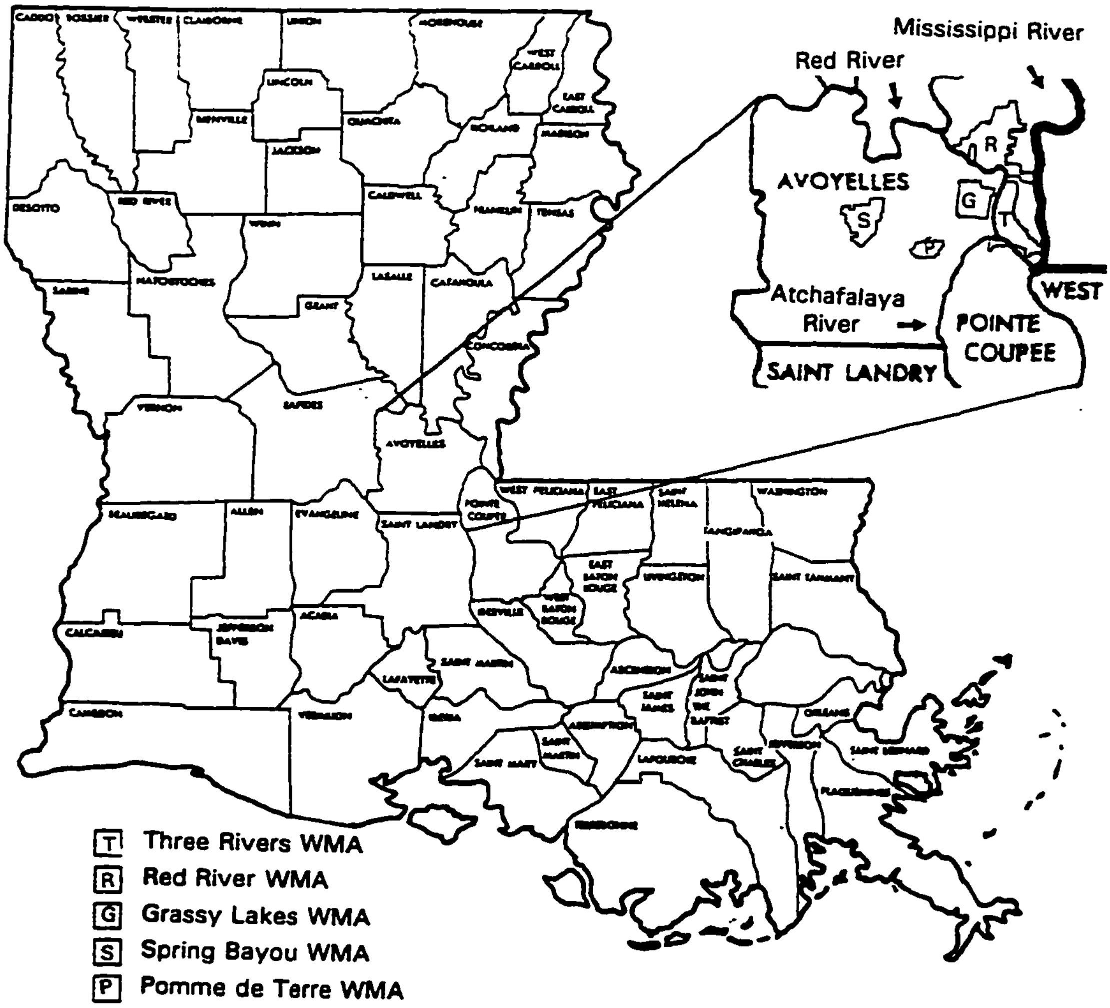

Figure 1. Location of study areas (Wildlife Management Areas (WMA's)) in Avoyelles and Concordia Parishes, Louisiana.

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nonacid, montmorillonitic, thermic. The Fausse classification is Typic Fluvaquent. very-fine, nonacid, thermic, montmorillonitic, thermic.

Field Measurements

Forty-five 0.04 ha. circular plots were located at random points on a grid of land within one mile of an all weather road. Several plots were located farther from the road due to small areas of the Fausse soil map unit. Diameters of trees were measured at diameter breast height (1.37 m) with a diameter tape. Trees with diameter ≥ 10 cm were classified as canopy trees; trees with diameter < 10 cm but ≥ 1 cm were classified as saplings. The latter were measured in a 0.004 ha circular subplot. Subsaplings, also measured in the 0.004 subplot, were < 1 cm in diameter, and > 0.5 m in height. Tree diameters were used to calculate basal area for each individual and species, and density was recorded for each species. Trees and shrubs were identified using Radford et al. (1968), Clewell (1985), and Duncan and Duncan (1990).

Soil morphology was described in each plot (Soil Survey Staff, 1993), and hydric soil field indicators (Soil Conservation Service, 1994 and 1996) were noted. An auger was used to obtain the soil to be described, usually to a depth of 1.5 meters or until the weight of the water sucked the soil out of the auger. The Chroma Index (CI) (Evans and Franzmeier, 1986), an average of Munsell soil chroma weighted by abundance of each color, was calculated for each soil horizon to assess average redoximorphic conditions of soil profiles. All horizons described from the auger holes were sampled for laboratory analysis. Wetland hydrology indicators from the

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1987 Corps of Engineers Wetland Delineation Manual (Environmental Laboratory, 1987) were also recorded.

Soil Laboratory Methods

Soil samples were air dried and crushed to pass a 2 mm sieve. Texture analysis was performed using the hydrometer method (Gee and Bauder, 1986). Percent clay was determined using hydrometer readings of the soil suspension, which was dispersed by overnight shaking with sodium hexametaphosphate solution. Percent sand was determined by sieving the dispersed sample through a 47 micrometer mesh. The LSU Soil Testing Laboratory performed routine soil tests on all the samples. Available phosphorus was extracted using the modified Bray 2 method (Brupbacher, 1970), where P is extracted using 0.03 M NH_4F and 0.1 M HCl. Phosphorus was measured by a Thermo Jerrel ICAP 61 inductively coupled plasma optical emission spectrometer (ICP). Ammonium acetate (pH 7) exhangeable calcium, magnesium, sodium, and potassium were determined by ICP, and were totaled for sum of bases (Thomas, 1982). Soil pH was determined in a 1:1 soil:water suspension allowed to equilibrate for two hours (McLean, 1982). KCl-exchangeable acidity, aluminum and hydrogen were determined titrimetrically (Thomas, 1982). Organic carbon percent was determined by the Walkley-Black technique, a wet digestion in potassium dichromate and sulfuric acid with a 16 hour equilibration (Nelson and Sommers, 1982). A Brinkmann PC 801 dip-probe colorimeter was used to measure the color associated with a known percentage of organic carbon.

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Vegetation Parameter Calculations

Relative basal area (RBA) for a species was computed as the total basal area of a species in a plot divided by the total basal area of all the species in the plot. Relative density (RD) was calculated as the total density of a species in a plot divided by the total density of all species in the plot. The RBA and RD values were converted to percent. and added to form an importance value (IV) with a maximum possible value of 200. The wetland plant indicator (WPI) status (Reed. 1988) and Flood Tolerance Index (Theriot, 1993) values were noted for each species in the proper vegetation strata. The five categories of the WPI are: obligate wetland (OBL = 1), facultative wetland (FACW = 2), facultative (FAC = 3), facultative upland (FACU = 4), and upland (UPL = 5). The WPI of each species was weighted by the importance of that species, which resulted in a Prevalence Index (PI) for each plot. Flood Tolerance Index (FTI) values for southeastern bottomland species are based on species prevalence within six hydrologic zones, and can be used to infer hydrologic regime (Theriot, 1993). The PI (FICWD, 1989; Soil Conservation Service. 1994) and the FTI were calculated for the canopy, subcanopy and shrub layers for each plot using species IV. These three values were averaged to obtain total PI or FTI for each plot.

$$\text{Plot PI or Plot FTI} = \frac{\sum(\text{IV of each species} * \text{WPI or FTI Status of each species})}{\text{Total plot IV}}$$

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Statistical Methods

The canopy species importance values for the 45 plots were used in a cluster analysis. The complete linkage method of cluster analysis (SAS Institute, 1990), a hierarchical, polythetic, agglomerative cluster algorithm (Gauch 1982; Johnson and Wichern. 1992) was used to produce a dendrogram (tree diagram), which illustrated a classification scheme. The cluster analysis dendrogram was used to classify the 45 vegetation plots into forest types, based on a dissection of the tree branches. Frequency of each species within a forest type was calculated as the percentage of plots having the occurrence of that species.

Canonical correlation analysis (SAS Institute, Inc., 1990) was used to directly relate the vegetation data set to the environmental data set (direct gradient analysis). The algorithm for canonical correlation analysis chooses scores (coefficients) for species and environmental variables so as to maximize the species-environment correlation. Species scores are parameters estimated by a multiple regression of the site scores and species variables. The numerous environmental variables were reduced to a few dimensions using canonical correlation. Twelve canopy level species were then plotted by their positions on these environmental gradients. The measured environmental variables themselves were plotted against these derived environmental axes. Canonical correlation analysis assumes linear species responses to environmental factors.

A similar method called canonical correspondence analysis (ter Braak 1990) assumes a unimodal species response. Therefore, canonical correspondence analysis

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was also used to relate species distributions to environmental gradients. It also provided information about site (plot) distribution with respect to the environmental factors. Canonical correspondence analysis is a technique that selects the linear combination of environmental variables that maximizes the dispersion of species scores.

Multiple regression was used to predict species' importance values from the environmental variables. A forward stepwise multiple regression technique (SAS Institute, Inc., 1990; Neter et. al, 1989) that adds one variable at a time to the model was used. The algorithm utilizes a maximum R^2 improvement method, which tries to find the best one variable model that produces the highest R^2, then adds a second variable that produces the highest improvement in R^2. The model was kept only when the R^2 of the overall model increased by 5 percent or more with an additional variable added to the model. When the coefficient of determination improved by less than 5 percent of the previous model, the previous model was used as the final model. Successive models with added variables usually had more variables with nonsignificant p-values (>0.05).

Means of the environmental variables by forest type were analyzed by an unbalanced one way analysis of variance (SAS Institute, Inc., 1990) using a completely randomized design. A two way ANOVA was also performed using classes of forest type, alluvium source (Mississippi or Red Rivers), and their interaction. The latter design used a completely random block design with forest types as treatments and alluvium source as blocks. All ANOVAs were determined to

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be significant at a p-value of less than 0.05. Significant differences between specific forest types were detected using Duncan's Multiple Range Test at the α=0.05 significance level. Duncan's Multiple Range Test was used for comparisons because it is a compromise between the power of the Fisher LSD procedure (but less protection) and the controlled experiment-wise significance level (but less power) of the Tukey procedure (Freund and Wilson, 1993). Means of Prevalence Index and Flood Tolerance Index for each vegetation layer and overall vegetation were also compared by forest type in a one way ANOVA with Duncan's multiple range test applied.

RESULTS

Five forest types were classified using the cluster analysis and indicated by the dendrogram (Figure 2). The forest types, which were named for the dominant species, are: Sugarberry (*Celtis laevigata*), Overcup Oak (*Quercus lyrata*), Water Hickory (*Carya aquatica*), Black Willow (*Salix nigra*), and Baldcypress (*Taxodium distichum*). Sugarberry (15 plots) and Water Hickory (17 plots) forest types were the most frequently found types in the study area. Overcup Oak and Baldcypress types were represented by five plots each, and only three plots were Black Willow forest type.

Overstory Vegetation

The main canopy layer dominant of the Sugarberry type was sugarberry (IV=76.6), however overcup oak, water hickory, and green ash (*Fraxinus pennsylvanica*) were very significant contributors of basal area and density (Table 1).

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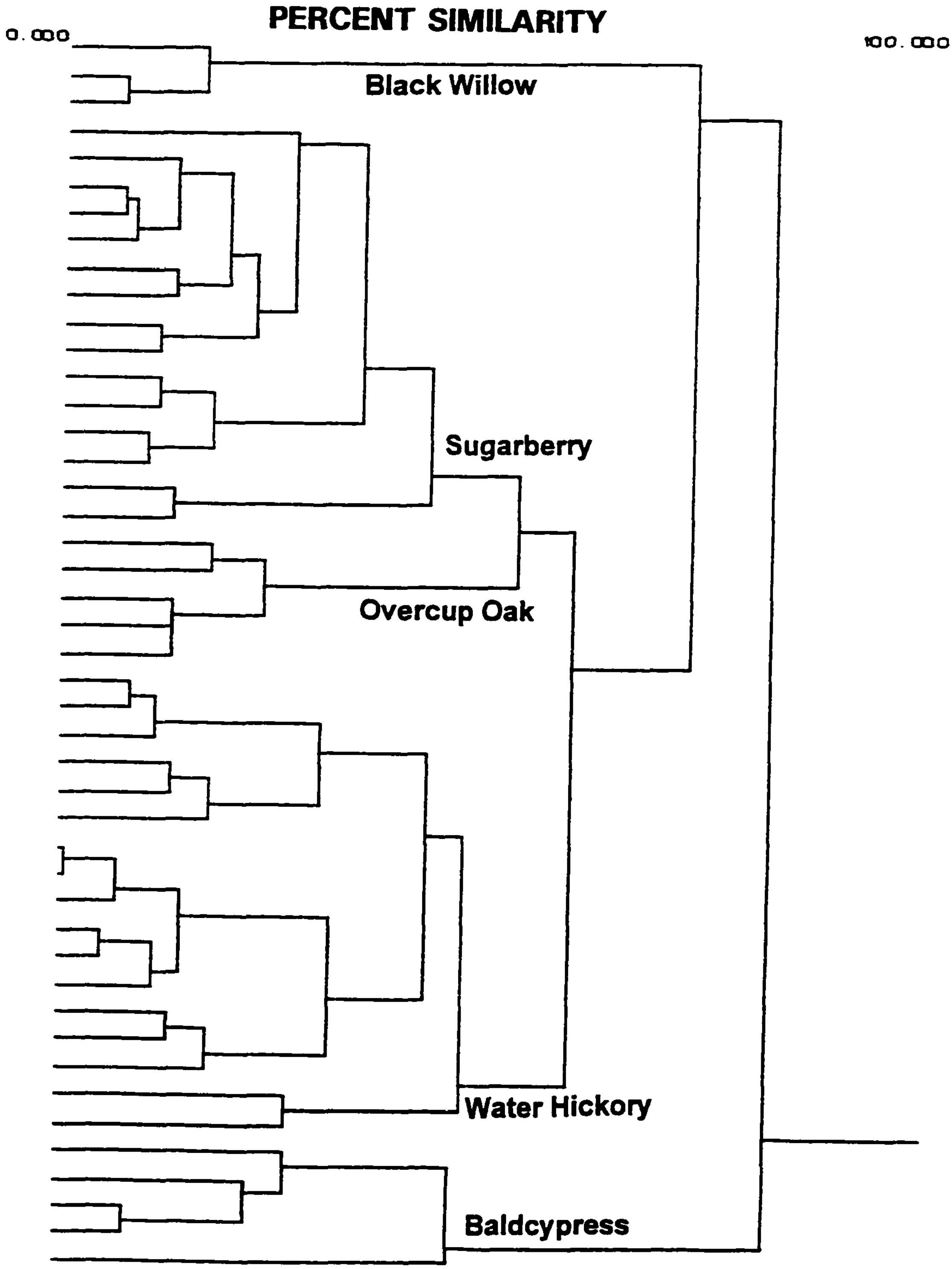

Figure 2. Dendrogram resulting from a complete linkage cluster analysis of species' importance values of 45 plots. Five forest types are delineated at 50 % similarity.

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Table 1. Plot mean values of structural characteristics for species in the canopy layer of the Sugarberry forest type (n=15 plots), and frequency of species within the forest type.

Species	Absolute Basal Area (m^2/ha)	Absolute Density (stems/ha)	Relative Basal Area (%)	Relative Density (%)	Importance Value (RBA+RD)	Frequency (%)
Celtis laevigata	11.05	185.0	36.3	40.3	76.6	100.0
Quercus lyrata	6.58	55.0	20.6	12.8	33.4	80.0
Carya aquatica	4.31	60.0	15.8	13.8	29.6	80.0
Fraxinus pennsylvanica	3.74	68.3	12.2	13.8	26.0	80.0
Quercus nuttalli	4.62	11.7	9.7	3.4	13.2	33.3
Forestiera acuminata	0.41	35.0	1.5	6.8	8.2	53.3
Acer negundo	0.30	10.0	0.5	3.6	4.1	6.7
Crataegus sp.	0.11	8.3	0.4	1.7	2.0	26.7
Salix nigra	0.43	1.7	1.5	0.4	1.8	6.7
Taxodium distichum	0.23	1.7	0.9	0.5	1.4	6.7
Gleditsia triacanthos	0.08	3.3	0.2	0.9	1.1	13.3
Diospyros virginiana	0.06	3.3	0.2	0.8	1.0	13.3
Platanus occidentalis	0.06	1.7	0.3	0.3	0.6	6.7
Gleditsia aquatica	0.02	1.7	0.0	0.6	0.6	6.7
Acer rubrum	0.02	1.7	0.1	0.3	0.4	6.7
Totals	32.01	448.3	100.0	100.0	200.0	

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Although Nuttall oak (*Quercus nuttalli*) had the third highest basal area (4.62 m^2/ha) of all species in this community type, its density (11.7 stems/ha) and frequency (33.3 %) within the type were much lower than the previously mentioned species. Swamp privet (*Forestiera acuminata*) was present in more than half the plots, but had rather low basal area (0.41 m^2/ha) and density (35 stems/ha).

Overcup oak was the sole dominant in the canopy stratum of the Overcup Oak forest type, as that species accounted for the highest relative basal area (66.8 %) and relative density (42.3 %) (Table 2). Water hickory had the second highest relative basal area (10.7 %), and swamp privet had the second highest relative density (18.7 %). Although baldcypress was very scattered throughout this community, it had the second highest absolute basal area (4.05 m^2/ha). Sugarberry was a frequent (60 %) species, but only comprised 4.4 % of the relative basal area.

Water hickory (59.8 % of the relative basal area) and swamp privet (40.7 % relative density) were the dominant species in the canopy stratum for the Water Hickory forest type (Table 3). Water elm (*Planera aquatica*) was frequently (64.7 %) a canopy constituent, and occasionally overcup oak would be a codominant or significant component of the crown. A few plots resembled a shrub-scrub type with swamp privet and water elm dominating, but with water hickory present.

Baldcypress was the sole dominant in the crown in the Baldcypress forest type (Table 4). Water elm, swamp privet, and water locust (*Gleditsia aquatica*) were frequent components in this layer, as each occurred in 60 % of the plots. Tupelo (*Nyssa aquatica*) was a codominant in one plot in Pomme de Terre WMA. One plot

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Table 2. Plot mean values of structural characteristics for species in the canopy layer of the Overcup Oak forest type (n=5 plots), and frequency of species within the forest type.

Species	Absolute Basal Area (m^2/ha)	Absolute Density (stems/ha)	Relative Basal Area (%)	Relative Density (%)	Importance Value (RBA+RD)	Frequency (%)
Quercus lyrata	18.43	180.0	66.8	42.3	109.1	100.0
Forestiera acuminata	1.02	80.0	3.9	18.7	22.5	60.0
Carya aquatica	3.70	45.0	10.7	9.5	20.2	60.0
Celtis laevigata	1.10	45.0	4.4	10.6	15.0	60.0
Taxodium distichum	4.05	10.0	9.5	2.1	11.6	40.0
Diospyros virginiana	0.34	30.0	1.6	7.7	9.3	40.0
Gleditsia aquatica	0.40	20.0	1.7	5.3	6.9	60.0
Liquidambar stryaciflua	0.19	5.0	0.7	1.3	2.0	20.0
Acer rubrum	0.11	5.0	0.4	1.3	1.7	20.0
Fraxinus pennsylvanica	0.06	5.0	0.2	1.3	1.5	20.0
Totals	29.40	425.0	100.0	100.0	200.0	

Table 3. Plot mean values of structural characteristics for species in the canopy layer of the Water Hickory forest type (n=17 plots), and frequency of species within the forest type.

Species	Absolute Basal Area (m^2/ha)	Absolute Density (stems/ha)	Relative Basal Area (%)	Relative Density (%)	Importance Value (RBA+RD)	Frequency (%)
Carya aquatica	14.60	142.6	59.8	29.3	89.1	100.0
Forestiera acuminata	2.87	208.8	13.7	40.7	54.3	88.2
Planera aquatica	2.46	60.3	10.7	10.9	21.6	64.7
Quercus lyrata	2.10	25.0	6.4	6.0	12.4	29.4
Gleditsia aquatica	1.33	20.6	5.6	3.6	9.2	35.3
Celtis laevigata	0.47	19.1	1.6	4.8	6.4	35.3
Fraxinus pennsylvanica	0.27	11.8	0.9	1.9	2.8	29.4
Salix nigra	0.17	10.3	0.8	1.3	2.1	5.9
Diospyros virginiana	0.05	4.4	0.2	0.9	1.1	5.9
Gleditsia triacanthos	0.07	2.9	0.3	0.6	0.9	11.8
Totals	24.39	505.8	100.0	100.0	200.0	

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Table 4. Plot mean values of structural characteristics for species in the canopy layer of the Baldcypress forest type (n=5 plots), and frequency of species within the forest type.

Species	Absolute Basal Area (m^2/ha)	Absolute Density (stems/ha)	Relative Basal Area (%)	Relative Density (%)	Importance Value (RBA+RD)	Frequency (%)
Taxodium distichum	40.76	135.0	69.6	42.0	111.7	100.0
Planera aquatica	3.17	125.0	4.4	18.0	22.4	60.0
Forestiera acuminata	1.19	100.0	1.4	14.6	16.0	60.0
Nyssa aquatica	2.79	10.0	9.7	3.3	13.1	20.0
Gleditsia aquatica	3.05	40.0	5.5	5.9	11.4	60.0
Salix nigra	1.36	15.0	4.5	4.5	8.9	40.0
Acer rubrum	0.30	15.0	1.1	5.0	6.1	20.0
Carya aquatica	2.74	20.0	3.2	2.6	5.8	40.0
Celtis laevigata	0.17	10.0	0.3	2.4	2.7	40.0
Fraxinus pennsylvanica	0.05	5.0	0.2	1.7	1.9	20.0
Totals	55.58	475.0	100.0	100.0	200.0	

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in this type had only two very large baldcypress trees, and no other live individuals in any other layer, besides water hyacinth (*Eichhornia crassipes*) floating in the water.

Only three species were represented in the three plots in the Black Willow forest type. Black willow comprised nearly all the basal area and density, but swamp privet was present in the canopy layer in two of the plots (Table 5). Water elm was less frequent.

Sapling Vegetation

The sapling stratum of the Sugarberry forest type was dominated by water hickory, which had the greatest relative density (32.5 %) and frequency (53.3 %), and two other species (Table 6). Sugarberry and green ash each had about half the density of water hickory.

Water hickory and swamp privet were the dominants of the sapling and subsapling layers of the Overcup Oak forest type (Table 7). Overcup oak was not very frequent (20 %) in the sapling layer, and was absent in the subsapling layer.

Swamp privet dominated the understory of the Water Hickory forest type (Table 8), and had a high sapling density (47.4 % relative density). Water hickory itself was not very frequent under the canopy (17.6 %), and even less abundant (10.8 % or less). Sugarberry was present in over a third of the plots.

Swamp privet was the dominant sapling species for the Baldcypress forest type, accounting for almost all the cover of that stratum (Table 9). Two of the five plots had no saplings represented.

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Table 5. Plot mean values of structural characteristics for species in the canopy layer of the Black Willow forest type (n=3 plots), and frequency of species within the forest type.

Species	Absolute Basal Area (m^2/ha)	Absolute Density (stems/ha)	Relative Basal Area (%)	Relative Density (%)	Importance Value (RBA+RD)	Frequency (%)
Salix nigra	41.23	483.3	94.5	85.0	179.4	100.0
Forestiera acuminata	0.57	50.0	2.2	12.5	14.7	66.7
Planera aquatica	0.67	8.3	3.3	2.6	5.9	33.3
Totals	42.47	541.6	100.0	100.0	200.0	

Table 6. Plot mean values of structural characteristics for species in the sapling and subsapling/shrub layers of the Sugarberry forest type (n=15 plots), and frequencies of species within those strata for the type.

	Sapling			Subsapling/Shrub		
Species	Absolute Density (stems/ha)	Relative Density (%)	Frequency (%)	Absolute Density (stems/ha)	Relative Density (%)	Frequency (%)
Carya aquatica	250.0	32.5	53.3	66.7	10.4	13.3
Celtis laevigata	350.0	16.8	40.0	216.7	11.8	26.7
Fraxinus pennsylvanica	266.7	15.9	40.0	416.7	31.9	33.3
Crataegus sp.	200.0	14.5	26.7	66.7	6.1	20.0
Forestiera acuminata	216.7	13.6	33.3	16.7	2.1	6.7
Ilex decidua	50.0	2.9	6.7	300.0	13.2	13.3
Quercus lyrata	50.0	1.8	13.3	16.7	1.0	6.7
Acer negundo	16.7	1.3	6.7	50.0	12.5	13.3
Cornus stricta	16.7	0.8	6.7	83.3	8.4	13.3
Ilex vomitoria				33.3	1.4	6.7
Ulmus americana				16.7	1.2	6.7
Totals	1416.7	100.0		1283.3	100.0	

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Table 7. Plot mean values of structural characteristics for species in the sapling and subsapling/shrub layers of the Overcup Oak forest type (n=5 plots), and frequencies of species within those strata for the forest type.

	-------------Sapling-------------			------Subsapling/Shrub------		
Species	Absolute Density (stems/ha)	Relative Density (%)	Frequency (%)	Absolute Density (stems/ha)	Relative Density (%)	Frequency (%)
Carya aquatica	550.0	36.4	40.0	100.0	50.0	40.0
Forestiera acuminata	500.0	29.8	40.0	50.0	25.0	20.0
Quercus lyrata	250.0	10.4	20.0			
Ilex decidua	200.0	9.1	20.0	50.0	3.6	20.0
Diospyros virginiana	100.0	5.6	40.0			
Gleditsia triacanthos	100.0	4.1	20.0			
Fraxinus pennsylvanica	50.0	2.2	20.0	50.0	3.6	20.0
Crataegus sp.	50.0	2.2	20.0	66.7	6.1	20.0
Celtis laevigata				50.0	3.6	20.0
Styrax americana				100.0	7.1	20.0
Taxodium distichum				50.0	3.6	20.0
Unknown				50.0	3.6	20.0
Totals	1800.0	100.0		500.0	100.0	

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Table 8. Plot mean values of structural characteristics for species in the sapling and subsapling/shrub layers of the Water Hickory forest type (n=17 plots), and frequencies of species within those strata for the forest type.

	Sapling			Subsapling/Shrub		
Species	Absolute Density (stems/ha)	Relative Density (%)	Frequency (%)	Absolute Density (stems/ha)	Relative Density (%)	Frequency (%)
Forestiera acuminata	1867.6	74.5	88.2	308.8	47.4	70.6
Celtis laevigata	250.0	10.4	35.3	279.4	31.0	52.9
Carya aquatica	73.5	3.0	17.6	132.4	10.8	17.6
Fraxinus pennsylvanica	102.9	2.4	11.8	73.5	6.8	17.6
Styrax americana	73.5	5.5	11.8	14.7	0.9	5.9
Quercus lyrata	29.4	1.5	11.8			
Acer rubrum	14.7	1.2	5.9	14.7	0.9	5.9
Cephalanthus occidentalis	14.7	0.5	5.9	44.1	2.3	5.9
Gleditsia aquatica	29.4	1.0				6.7
Totals	2455.9	100.0		867.6	100.0	

Table 9. Plot mean values of structural characteristics for species in the sapling and subsapling/shrub layers of the Baldcypress forest type (n=5 plots), and frequency of species within those strata for the forest type.

	Sapling			Subsapling/Shrub		
Species	Absolute Density (stems/ha)	Relative Density (%)	Frequency (%)	Absolute Density (stems/ha)	Relative Density (%)	Frequency (%)
Forestiera acuminata	1600.0	97.2	60.0	550.0	24.1	40.0
Planera aquatica	50.0	1.4	20.0	50.0	25.0	20.0
Cephalanthus occidentalis	50.0	1.4	20.0	450.0	50.9	60.0
Totals	1700.0	100.0		1050.0	100.0	

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Black willow, swamp privet, and water elm were the dominants in the sapling layer of the Black Willow forest type (Table 10).

Subsapling/Shrub Vegetation

Green ash (31.9 %), followed by deciduous holly (*Ilex decidua*)(13.2 %), and boxelder (*Acer negundo*)(12.5 %) dominated the relative density of the subsapling or shrub layer for Sugarberry forest type (Table 6). Swamp privet and sugarberry comprised much of the subsapling layer of the Water Hickory forest type (Table 8). A few plots were dominated in this stratum by water hickory, and green ash was a significant component in a few plots. For the Baldcypress forest type, buttonbush (*Cephalanthus occidentalis*) had the most relative density (50.9 %) in the subsapling/shrub stratum, and water elm and swamp privet each had about half that density (Table 10). Water elm was the sole dominant of one plot. No species were found in the subsapling layer in any of the Black Willow forest type plots (Table 9).

Vegetation Indices

Sugarberry forest type had the highest prevalence index for all three vegetation strata (Table 11), due to the prevalence of facultative wetland species such as sugarberry and green ash. The subsapling layer had the highest PI of 1.87, which is still hydrophytic (PI < 3.0). The Overcup Oak forest type had an overall mean PI of 1.24, as obligate wetland species were predominant over facultative wetland species. The canopy PI (1.07) of Water Hickory Type was lower than the sapling PI (1.21). The subsapling Prevalence Index was the highest (1.41) of the three layers, due to a higher abundance of sugarberry relative to the other layers. The

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Table 10. Plot mean values of structural characteristics for species in the sapling and subsapling/shrub layers of the Black Willow forest type (n=3 plots), and frequencies of species within those strata for the forest type.

	Sapling			Subsapling/Shrub		
Species	Absolute Density (stems/ha)	Relative Density (%)	Frequency (%)	Absolute Density (stems/ha)	Relative Density (%)	Frequency (%)
Salix nigra	666.7	45.8	66.7			
Planera aquatica	583.3	23.8	66.7			
Forestiera acuminata	916.7	26.2	33.3			
Gleditsia aquatica	83.3	4.2	33.3			
Totals	2250.0	100.0		0.0		

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Table 11. Mean Prevalence Index (PI) calculated for the canopy, sapling, subsapling/shrub, and total strata for the forest types.

	Prevalence Index[1]			
Forest Type	Canopy	Sapling	Subsapling/ Shrub	Overall
Sugarberry	1.58 a[2]	1.52 a	1.87 a	1.66 a
Overcup Oak	1.21 b	1.25 ab	1.21 b	1.24 b
Water Hickory	1.07 bc	1.21 ab	1.41 b	1.21 b
Baldcypress	1.02 c	1.00 b	1.00 b	1.01 b
Black Willow	1.00 c	1.00 b	_	1.00 b
p-value (ANOVA)	0.0001	0.0412	0.0005	0.0001

[1]PI is an average of hydrophytic plant status, weighted by abundance. Hydrophytic plant status is: obligate wetland =1, facultative wetland =2, facultative=3, facultative upland=4, upland=5.

[2]Means with same letters within the same stratum (column) are not significantly different at α=0.05 level, using Duncan's Multiple Range Test.

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Baldcypress forest type had a very low Prevalence Index (1.01), as almost every species present was in the obligate wetland category. The Black Willow forest type had the lowest Prevalence Index possible (1.00), as all species were obligate wetland.

Table 12 shows that the mean overall FTI (4.24) indicates that the Sugarberry forest type is located in the National Wetlands Technical Council (NWTC) Zone 4, which is characterized by seasonal inundation or saturation (12.5 to 25 percent duration of growing season), and a 51 to 90 years/100 years frequency) (Larson et al., 1981). The overall FTI of 3.81 for the Overcup Oak forest type (Table 18) indicates a hydrologic regime of the drier end of NWTC Zone 3 (regular inundation/saturation, or 51 to 90 years/100 frequency and 25 to 75 percent duration of the growing season (Larson et al., 1981)). The overall FTI for the Water Hickory forest type (3.69) indicates that this type shares the same hydrologic zone as the Overcup Oak Type. The overall FTI of 3.20 for Baldcypress forest type with a canopy FTI of 3.10 indicates that this type is on the wetter end of NWTC Zone 3 (regular inundation/saturation). The overall FTI (2.98) and the canopy FTI (2.88) for the Black Willow forest type were below 3.0, indicating semipermanent to permanent inundation/saturation for 75-100 percent of the growing season with an annual frequency (NWTC Zone 2).

Hydrogeomorphic Positions of the Forest Types

Most of the Sugarberry type plots occurred on the Sharkey clay, occasionally flooded mapping units, but a few plots were located on high or convex sites within the Sharkey clay, frequently flooded mapping unit. Both these mapping units

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Table 12. Mean Flood Tolerance Index (FTI) calculated for the canopy, sapling, subsapling/shrub, and total strata for the forest types.

Forest Type	Flood Tolerance Index[1]			
	Canopy	Sapling	Subsapling/ Shrub	Overall
Sugarberry	4.30 a[2]	4.05 a	4.44 a	4.24 a
Overcup Oak	3.75 b	3.85 ab	3.88 b	3.78 b
Water Hickory	3.55 c	3.68 b	3.72 b	3.69 b
Baldcypress	3.10 d	3.56 b	3.20 c	3.20 c
Black Willow	2.88 e	3.08 c	_	2.98 d
p-value (ANOVA)	0.0001	0.0001	0.0001	0.0001

[1]FTI corresponds to hydrologic zones: 2.5 = permanently flooded/saturated, 3.5 = semipermanently flooded/saturated, 4.5 = seasonally flooded/saturated, 5.5 = temporarily flooded/saturated, 6.5 = intermittently flooded/saturated.
[2]Means with same letters within the same stratum (column) are not significantly different at α=0.05 level, using Duncan's Multiple Range Test.

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included some soils derived from the Red River. This forest type occurred in nearly equal proportions on Mississippi River and Red River alluvial soils. Only a third of the plots of this forest type exhibited 1994 NRCS hydric soil indicators and a third showed 1987 US Army Corps of Engineers wetland hydrology indicators.

All the Overcup Oak plots were located on Mississippi River alluvium, but were represented equally by Sharkey clay, frequently flooded and the more frequently flooded Fausse clay soil mapping units. Three of the five plots showed 1994 hydric soil indicators but four plots had wetland hydrology indicators.

The majority of the plots of the Water Hickory Type occurred on Red River alluvium, which imparted red-colored masking of hydric soil indicators. The majority of plots of this forest type occurred on the Sharkey clay, frequently flooded mapping unit, but over a third were on Fausse clay, on backswamp depressions. A few plots were on low, ponded microsite positions on the occasionally flooded Sharkey clay mapping unit. Only 41.2 % of the plots had 1994 hydric soil indicators, but 76.5 % of the plots showed wetland hydrology indicators.

The Baldcypress forest type was largely restricted to the wettest soil mapping unit, the Fausse clay. One plot, which may have been a Fausse, occurred in a flooded Sharkey clay, frequently flooded mapping unit. Four of the five plots were on soils with Mississippi River alluvium at the surface. All the sites of this type exhibited wetland hydrology evidence, but one plot did not show the 1994 hydric soil indicators.

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The Black Willow type was found exclusively on the wettest (most frequently flooded and longest flooded) map unit, the Fausse clay. Of the three plots in this type, the two with the Mississippi River alluvium at the surface had hydric soil indicators. All the plots showed wetland hydrology indicators.

Analyses of Variance of Environmental Variables

The one way (forest type) ANOVAs of environmental variables indicated significant (p-value less than 0.05) differences between forest types for only four of the upper horizons' soil chemical and physical variables (Table 13): organic matter percent, exchangeable sodium, pH, and hydrogen ion concentration. The organic matter content for the Baldcypress forest type (4.3 %) within the upper two soil horizons was significantly greater than that for the other types. The Black Willow type had an exchangeable Na content of 0.4 cmol(+)/kg, which was significantly higher than epipedon Na contents for the Baldcypress, Water Hickory, and Sugarberry forest types. The Black Willow type also had a significantly higher pH (6.40) as compared with that for Overcup Oak and Baldcypress. The Baldcypress forest type had a significantly lower pH of 4.98 than the pH for the Water Hickory type, which was 5.98. When pH was converted to hydrogen ion activity or concentration, the only significant difference revealed was that the Baldcypress type had the highest H concentration (1.54×10^{-5}) of the five forest types.

Six soil morphology and landscape variables had significant differences between forest types (Table 13). The chroma index average (of the upper two horizons) for the Water Hickory (2.74) and Sugarberry (2.52) forest types was

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Table 13. Means of soil chemistry, morphology, and landscape variables, by forest type of upper two horizons.

Variable	Forest Type: Sugarberry	Overcup Oak	Water Hickory	Black Willow	Baldcypress	p-value
Clay, %	63.4	71.1	63.9	66.2	73.7	0.3211
Sand, %	2.3	1.5	1.1	1.0	3.4	0.1612
OM, %	2.4 a[1]	2.8 a	2.2 a	2.2 a	4.3 b	0.0060*
P, mg/kg	176.1	171.4	203.9	243.8	199.8	0.3685
Ca, cmol(+)/kg	24.9	23.9	24.6	30.2	22.1	0.1294
Mg, cmol(+)/kg	9.3	10.5	10.0	10.3	12.2	0.0628
K, cmol(+)/kg	0.8	0.9	0.8	0.7	1.0	0.1591
Na, cmol(+)/kg	0.2 a	0.3 ab	0.2 a	0.4 b	0.2 a	0.0153*
pH	5.8 abc	5.2 bc	6.0 ab	6.4 a	5.0 c	0.0145*
H concentration ($\times 10^{-5}$)	0.299 a	1.04 ab	0.355 a	0.224 a	1.54 b	0.0058*
Sum of bases, cmol/kg	34.8	35.5	35.6	41.6	35.6	0.2508
Chroma 1, %	15.9	37.8	20.1	45.3	33.0	0.4213
Chroma 2, %	48.0 a	41.6 a	3.4 b	18.0 ab	37.6 ab	0.0014*
Chroma 1+2, %	63.9 ab	79.4 a	23.5 b	63.3 ab	70.6 a	0.0019*
Chroma Index, Avg.	2.52 a	2.23 ab	2.74 a	1.83 b	1.88 b	0.0041*
Chroma Index, below A	2.69 ab	2.28 ab	3.01 a	1.92 b	2.33 ab	0.0269*
Flood frequency unit[2]	1.2 a	2.0 b	2.2 b	3.0 c	2.8 bc	0.0001*
Hydrology indicators[3]	1.3 a	1.6 ab	1.8 ab	2.0 b	2.0 b	0.0033*
Hydric soil indicators[4]	1.3	1.6	1.4	1.7	1.8	0.2405

[1]Values with the same letter within the same row are not significantly different at $\alpha=0.05$, using Duncan's Multiple Range Test. Rows with no letters indicate no significant ($\alpha=0.05$) difference between forest types by a one way ANOVA.
[2]Flood frequency units are coded: 3=Fausse (highest frequency), 2=Sharkey clay, frequently flooded, 1=Sharkey clay, occasionally flooded
[3]Presence of Corps of Engineers' wetland hydrology indicators. No=1, Yes=2
[4]Presence of 1994 NRCS field indicators of hydric soil. No=1, Yes=2
*significant at $\alpha<0.05$

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significantly higher than the CI average for Baldcypress (1.88) and Black Willow (1.83) types. The chroma index of the horizon below the A layer was significantly higher for Water Hickory (3.01) than for Black Willow (1.92). The Black Willow type was situated lower on the landscape (higher flooding frequency, poorer drainage) than Water Hickory, Overcup Oak, and the Sugarberry types. The Sugarberry type was situated significantly higher on the landscape. Black Willow and Baldcypress forest types exhibited significantly more wetland hydrology evidence than did the Sugarberry forest type. There were no significant differences between forest types in the proportion of soil color with chroma 1 or less. The abundance of soil color with a chroma of 2 was different between forest types, as Sugarberry (48.0 %) and Overcup Oak (41.6 %) types exhibited greater chroma 2 abundance, when compared with the Water Hickory, which only had a chroma 2 proportion of 3.4 %. Chroma 1 and 2 anundance was expressed more by Overcup Oak (79.4 %) and Baldcypress (70.6 %) forest types than by Water Hickory forest type (23.5 %).

A two way ANOVA was computed using classes of forest type, river alluvium type, and their interaction. Only four variables were significantly different among forest types (Table 14). The Black Willow forest type had the highest mean flood frequency unit (3.0), and Sugarberry forest type had the lowest (1.2). Black Willow and Baldcypress had the highest mean value for presence of wetland hydrology indicators (2.0), and Sugarberry forest type had the lowest mean value (1.3). Water Hickory forest type showed the lowest abundance of chroma 2 (3.4 %),

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Table 14. P-values of effects in a two way ANOVA (with interaction) of soil chemistry, morphology and landscape position variables.

Variable	Source			
	Overall Model	Forest Type	River	Forest Type * River
Clay, %	0.5586	0.5168	0.7835	0.6212
Sand, %	0.3435	0.3997	0.3789	0.4684
OM, %	0.0006*	0.1253	0.3097	0.0061*
P, mg/kg	0.1573	0.1533	0.8238	0.0635
Ca, cmol(+)/kg	0.0396*	0.0863	0.0049*	0.6790
Mg, cmol(+)/kg	0.0847	0.1427	0.2231	0.3218
K, cmol(+)/kg	0.5994	0.3938	0.8962	0.9852
Na, cmol(+)/kg	0.0001*	0.1334	0.0002*	0.0176*
Sum of Bases, cmol(+)/kg	0.3527	0.2031	0.0805	0.7130
pH	0.0001*	0.0307*	0.0001*	0.3073
H concentration, (x 10^{-5})	0.0007*	0.2566	0.0089*	0.1964
Chroma 1, %	0.0003*	0.3764	0.0004*	0.0051*
Chroma 2, %	0.0009*	0.0130*	0.0540	0.1575
Chroma 1+2, %	0.0001*	0.1085	0.0001*	0.1484
Chroma Index below A	0.0074*	0.3774	0.0066*	0.0436*
Chroma Index Avg.	0.0001*	0.1835	0.0003*	0.0059*
Flood frequency unit	0.0001*	0.0001*	0.7923	0.5544
Hydrology indicators	0.0211*	0.0034*	0.5699	0.6952
Hydric soil indicators	0.0013*	0.2395	0.0003*	0.0667

*significant at $\alpha<0.05$

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and Baldcypress, Overcup Oak. and Sugarberry forest types had higher percentages. ranging from 37.6 to 48.0 %. The mean pH of the Black Willow (6.4) and Water Hickory (6.0) forest types was higher than that of Overcup Oak (5.2) and Baldcypress (5.0) types.

River alluvium source differed for four soil chemistry variables. The Red River alluvial soils had a higher mean pH (6.3) than those derived from Mississippi River sediments (5.3). Likewise, the Mississippi River alluvial soils had a higher hydrogen ion concentration than that of Red River derived soils. Although the Mississippi River soils had a statistically significant higher content of Na (0.3 cmol(+)/kg) than that for the Red River soils (0.2 cmol(+)/kg), they are both very low compared to the lower level of detection, so the difference is probably not important. Red River soils had higher mean content of Ca (26.5 cmol(+)/kg) than Mississippi River soils (23.5 cmol(+)/kg). Five soil color variables showed differences between river alluvium source. Mississippi River soils showed 37.3 % chroma of 1, but Red River soils only showed 5.3 % chroma 1. Mississippi River soils also had a higher mean percentage of chroma of 1 and 2 together (78.0 %) than Red River soils (14.2 %). Red River soils had a higher mean Chroma Index beow the A horizon (3.0) than did the Mississippi River soils (2.5). The mean CI average of the upper 30 cm also was higher for Red River soils (2.7) than for the Mississippi River soils (2.2). Mississippi River soils had a higher mean value of hydric soil indicator presence (1.7) than did the Red River soils (1.2).

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Five variables showed an interaction effect of forest type and river alluvium source: organic matter, Na, Chroma 1, CI below the A horizon, and average upper 30 cm CI (Table 14). Because of the significant interaction effects, means of the soil chemistry and morphology variables for forest types were computed for each river alluvium source separately.

A one way ANOVA by forest type on Mississippi River alluvial soils showed significant differences for nine variables (Table 15). Baldcypress forest type had the highest organic matter content (4.3 %) among forest types, and Black Willow forest type had the highest exchangeable Na content (0.5 cmol(+)/kg) among all forest types. Baldcypress also had the highest Hydrogen ion concentration (1.862×10^{-5}) of all the forest types. Black Willow (67.5 %) and Water Hickory (66.0 %) forest types had the highest expression of chroma of 1, but Sugarberry forest type had the highest percentage of color as chroma 2 (62.0 %) whereas Water Hickory showed no chroma of 2. Average 30 cm CI was highest for Sugarberry (2.6) and Water Hickory (2.5) forest types, but Black Willow had the lowest mean value (1.2). Below the A horizon, the CI exhibited the same trend. Mean flood frequency unit was higher for Black Willow (3.0) and Baldcypress (2.8) than for the Sugarberry forest type (1.3). The Water Hickory, Black Willow, and Baldcypress forest types had all their plots meet the hydric soil field indicators (mean presence value = 2.0), but Sugarberry forest type had a lower mean hydric soil indicator presence value of 1.3.

On Red River alluvium, only two forest types had more than one plot, so a T-Test was employed to test differences between forest types for the soil chemical and

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Table 15. Means of soil chemistry and morphology of upper two soil horizons, and landscape variables, by forest type within Mississippi River alluvium.

Variable	Forest Type					p-value
	Sugarberry	Overcup Oak	Water Hickory	Black Willow	Baldcypress	
Clay, %	63.0[1]	71.1	69.5	68.3	72.3	0.7159
Sand, %	2.0	1.5	1.3	1.2	4.0	0.5103
OM, %	1.9 b[2]	2.8 b	2.4 b	2.6 b	4.7 a	0.0053*
P, mg/kg	190.8	171.4	185.3	199.5	218.0	0.8433
Ca, cmol(+)/kg	23.8	23.9	22.4	27.7	20.6	0.1525
Mg, cmol(+)/kg	9.2	10.5	11.3	11.2	12.2	0.0984
K, cmol(+)/kg	0.8	0.9	0.8	0.8	1.0	0.2998
Na, cmol(+)/kg	0.2 b	0.3 b	0.3 b	0.5 a	0.2 b	0.0062*
pH	5.6	5.2	5.2	5.8	4.8	0.0745
H concentration (x 10^{-5})	0.361 b	1.040 ab	1.022 ab	0.335 b	1.862 a	0.0440*
Sum of bases, cmol/kg	34.1	35.5	34.8	40.2	34.1	0.4814
Chroma 1, %	15.0 b	37.8 ab	66.0 a	67.5 a	41.2 ab	0.0133*
Chroma 2, %	62.0 a	41.6 ab	0.0 b	27.0 ab	44.2 ab	0.0190*
Chroma 1+2, %	76.9	79.4	66.0	94.5	85.5	0.1430
Chroma Index, Avg.	2.57 a	2.23 ab	2.47 a	1.24 c	1.66 bc	0.0071*
Chroma Index, below A	2.77 a	2.28 ab	2.78 a	1.38 b	2.06 ab	0.0479*
Flood frequency unit[3]	1.3 b	2.2 ab	2.0 ab	3.0 a	2.8 a	0.0051*
Hydrology indicators[4]	1.4	1.6	1.8	2.0	2.0	0.1723
Hydric soil indicators[5]	1.3 b	1.6 ab	2.0 a	2.0 a	2.0 a	0.0129*

[1]Rows with no letters indicate no significant ($\alpha=0.05$) difference between forest types by a one way ANOVA.
[2]Values with the same letter within the same row are not significantly different at $\alpha=0.05$, using Duncan's Multiple Range Test.
[3]Flood frequency units are coded: 3=Fausse (highest frequency), 2=Sharkey clay, frequently flooded, 1=Sharkey clay, occasionally flooded
[4]Presence of Corps of Engineers' wetland hydrology indicators. No=1, Yes=2
[5]Presence of 1994 NRCS field indicators of hydric soil. No=1, Yes=2
*significant at $\alpha<0.05$

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morphology variables (Table 16). Sugarberry forest type had a higher OM content (3.5 %) than the Water Hickory type (2.2 %), but the latter forest type had a higher available P content (211.6 mg/kg) than the Sugarberry type (146.5 mg/kg). Water Hickory forest type had a higher mean CI upper 30 cm average (2.8) than Sugarberry (2.4). Water Hickory forest type had a higher mean flood frequency unit compared with Sugarberry, and also a higher proportion of plots with wetland hydrology indicators.

Multivariate Analyses of Species and Environmental Variables

Canonical correlation, canonical correspondence, and multiple regression were used to relate individual forest canopy tree species distributions to environmental variables. Table 17 shows the abbreviations or computer codes used for species in these analyses. Table 18 lists the abbreviations and explanations of the environmental variables also used in these analyses. Canonical discriminant analysis was employed to depict the relationship of the forest types with the environmental variables.

Canonical Correlation Analysis

The overall canonical correlation analysis (COR) was significant using four measures of multivariate F tests (Wilk's Lambda, Pillai's Trace, Hotelling-Lawley-Trace, and Roy's Greatest Root). Only the first two sets of canonical variables (VEG 1, VEG 2, and ENVIR 1 and ENVIR 2) were significant at $\alpha = 0.05$ (Table 19). The first vegetation canonical variable explained 14.9 % of the variance in the vegetation data set (Table 20), and the first environmental canonical variable

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Table 16. Means of soil chemistry and morphology of upper two soil horizons, and landscape variables, by forest type within Red River alluvium.

Variable	Forest Type Sugarberry	Forest Type Water Hickory	p-value
Clay, %	64.2[1]	61.5	0.4578
Sand, %	2.8	1.0	0.0947
OM, %	3.5 a[2]	2.2 b	0.0011*
P, mg/kg	146.5 b	211.6 a	0.0421*
Ca, cmol(+)/kg	27.0	25.4	0.5307
Mg, cmol(+)/kg	9.6	9.5	0.9075
K, cmol(+)/kg	0.9	0.8	0.8585
Na, cmol(+)/kg	0.1	0.2	0.5209
pH	6.2	6.3	0.6554
H concentration (x 10^{-5})	0.175	0.077	0.4473
Sum of bases, cmol/kg	36.3	36.0	0.9070
Chroma 1, %	17.8	0.9	0.3969
Chroma 2, %	20.0	4.8	0.4361
Chroma 1+2, %	37.8	5.8	0.2030
Chroma Index, Avg.	2.43 b	2.85 a	0.0114*
Chroma Index, below A	2.53	3.10	0.0521
Flood frequency unit[3]	1.0 b	2.3 a	0.0001*
Hydrology indicators[4]	1.0 b	1.8 a	0.0001*
Hydric soil indicators[5]	1.2	1.2	0.8793

[1]Values with no letter within the same row are not significantly different at α=0.05, using a T-Test.
[2]Values with different letters are significantly different at α=0.05, using a T-Test.
[3]Flood frequency units are coded: 3=Fausse (highest frequency), 2=Sharkey clay, frequently flooded, 1=Sharkey clay, occasionally flooded
[4]Presence of Corps of Engineers' wetland hydrology indicators. No=1, Yes=2
[5]Presence of 1994 NRCS field indicators of hydric soil. No=1, Yes=2
*significant at α<0.05

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Table 17. Scientific names, common names, and computer codes of species occurring in the canopy, sapling, and subsapling/shrub strata in the study area.

Scientific Name	Common Name	Computer Code
Acer negundo	boxelder	ACNE
Acer rubrum	red maple	ACRU
Carya aquatica	water hickory (bitter pecan)	CAAQ
Celtis laevigata	sugarberry (hackberry)	CELV
Cephalanthus occidentalis	buttonbush	CPOC
Cornus stricta	swamp dogwood	COST
Crataegus sp.	hawthorn	CRSP
Diospyros virginiana	persimmon	DIVI
Forestiera acuminata	swamp privet	FOAC
Fraxinus pennsylvanica	green ash	FRPN
Gleditsia aquatica	water locust	GLAQ
Gleditsia triacanthos	honey locust	GLTR
Ilex decidua	possumhaw (deciduous holly)	ILDE
Ilex vomitoria	yaupon	ILVO
Liquidambar stryaciflua	sweetgum	LQST
Nyssa aquatica	tupelo gum	NYAQ
Planera aquatica	water elm	PLAQ
Platanus occidentalis	sycamore	PTOC
Quercus lyrata	overcup oak	QULY
Quercus nuttallii	Nuttall oak	QUNU
Salix nigra	black willow	SANI
Styrax americana	storax (American snowbell)	STAM
Taxodium distichum	baldcypress	TADI
Ulmus americana	American elm	ULAM

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Table 18. Computer code and description of environmental variables used in canonical analyses.

Code	Variable Description
CHROMA 1	Percent of soil color of upper 30 cm having Munsell chroma 1
CHROMA 2	Percent of soil color of upper 30 cm having Munsell chroma 2
CHROMA 12	Percent of soil color of upper 30 cm having Munsell chroma of 1 and 2
CI bel A	Chroma Index of horizon below A horizon
CI Avg	Chroma Index of average of upper 2 horizons within 30 cm
CLAY	Percent clay, average of upper two horizons
SAND	Percent sand, average of upper two horizons
OM	Percent organic matter of upper two horizons
P	Available P, mg/kg of upper two horizons
Ca	Exchangeable Ca, cmol(+)/kg of upper two horizons
Mg	Exchangeable Mg, cmol(+)/kg of upper two horizons
Na	Exchangeable Na, cmol(+)/kg of upper two horizons
K	Exchangeable K, cmol(+)/kg of upper two horizons
SUM	Sum of bases, cmol(+)/kg of upper two horizons
pH	Soil/water pH, 1:1 of upper two horizons
H	Hydrogen ion concentration of upper two horizons
FLOOD	Flood frequency map unit (Fausse=3, Sharkey Frequently Flooded=2, Sharkey Occasionally Flooded=1
HYDROL	Presence of wetland hydrology indicators (No=1, Yes=2)
HYDRIC	Presence of field indicators of hydric soils (No=1, Yes=2)
RIVER	River alluvium source (Mississippi River=1, Red River=2)

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Table 19. Results of canonical correlation analysis between a dataset of vegetation species importance values and a data set of environmental variables.

Canonical Correlation	Canonical Correlation Coefficient	Squared Canonical Correlation	Proportion of Variance Common	Cumulative Proportion of Variance	p-value[1]
1	0.9749	0.9505	0.4985	0.4985	0.0003
2	0.9383	0.8803	0.1909	0.6894	0.0471
3	0.9020	0.8136	0.1132	0.8027	0.3223
4	0.8383	0.7027	0.0613	0.8640	0.7118

[1]P-value is the significance of the Likelihood Ratio test of null hypothesis (canonical correlations in the current row and all that follow are zero).

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Table 20. Results from canonical correlation analysis. Correlations (loadings) of species with the first four vegetation canonical variables (VEG 1 - VEG 4).

	Canonical Variate				
	VEG 1	VEG 2	VEG 3	VEG 4	Communality
Species					
Taxodium distichum	0.326	-0.091	0.170	0.509	0.403
Salix nigra	0.456	-0.094	-0.138	-0.089	0.244
Planera aquatica	0.528	-0.144	0.302	-0.456	0.598
Gleditsia aquatica	0.170	0.031	0.138	0.087	0.056
Forestiera acuminata	0.065	0.653	0.401	-0.372	0.730
Carya aquatica	-0.042	0.666	0.199	-0.146	0.507
Quercus lyrata	-0.131	-0.511	-0.119	0.390	0.444
Celtis laevigata	-0.645	-0.342	-0.484	0.008	0.767
Fraxinus pennsylvanica	-0.649	-0.088	-0.262	0.048	0.500
Gleditsia triacanthos	-0.274	-0.047	-0.019	-0.210	0.122
Diospyros virginiana	0.358	0.341	-0.351	0.129	0.269
Quercus nuttalli	-0.327	-0.170	0.060	-0.316	0.240
Variance extracted	0.149	0.111	0.067	0.080	0.407 (Total)
Redundancy	0.142	0.097	0.054	0.056	0.350 (Total)

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explained 14.2 % of the variance in the same data set to yield a canonical R^2=0.95 (Table 19). The second vegetation canonical variable explained an additional 11.1 % of the variance of the importance value data set. The second environmental canonical variable explained an additional 9.7 % of the vegetation data set (Table 20), giving a canonical R^2 = 0.88 (Table 19).

The first vegetation canonical variable (VEG 1) was loaded highest negatively on sugarberry and green ash, and highest positively on black willow and baldcypress (Table 20). Axis one is interpreted as a flood tolerance gradient. With COR, one can also directly relate this dimension to the environmental data set's first canonical dimension (ENVIR 1). ENVIR 1 itself is highly positively loaded on flood frequency map unit and hydrology evidence (Table 21), so the interpretation of this axis is a flooding frequency or duration and/or drainage gradient. The correlations between the individual species' importance values and the first environmental canonical variable show a similar pattern to the presumed flood tolerance gradient (VEG 1). VEG 2 is highly positively weighted on water hickory and swamp privet, and is highly negatively weighted on sugarberry and overcup oak (Figure 3). ENVIR 2 is highly positively loaded on river number (Red vs Mississippi) and pH, and highly negatively weighted on percent chroma 2 or less percent clay, and percent chroma 1. The second environmental canonical dimension is interpreted as the alluvial parent material gradient. When the species' importance values are correlated with ENVIR 2, they are ordinated on this gradient (Figure 4 and Table 22). Overcup oak has the highest negative position on this gradient (on the Mississippi River side),

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Table 21. Results from canonical correlation analysis. Correlations (loadings) of environmental variables with the first four environmental canonical variables (ENV 1 - ENV 4).

	---------------Canonical Variate---------------				
	ENV 1	ENV 2	ENV 3	ENV 4	Communality
Environmental Variables					
Clay, %	-0.013	-0.417	0.576	0.351	0.629
Sand, %	0.074	-0.054	-0.473	0.093	0.241
OM, %	0.264	0.037	-0.087	0.416	0.252
P, mg/kg	0.230	0.183	-0.146	-0.290	0.191
Ca, cmol(+)/kg	-0.086	0.130	0.021	-0.178	0.056
Mg, cmol(+)/kg	0.325	-0.195	0.247	0.302	0.296
K, cmol(+)/kg	0.031	-0.318	0.329	0.128	0.227
Na, cmol(+)/kg	0.456	-0.385	0.014	0.242	0.415
pH, 1:1	0.019	0.395	-0.107	-0.613	0.544
Sum of bases, cmol/kg	0.092	0.011	0.202	-0.026	0.050
H concentration	0.236	-0.290	0.044	0.568	0.464
Chroma Index, avg	-0.334	0.198	0.166	-0.479	0.408
Chroma Index below A	-0.259	0.201	0.173	-0.499	0.387
Flood frequency unit	0.744	0.124	0.320	0.017	0.672
Hydric soil indicators	0.240	-0.317	0.167	0.478	0.414
Hydrology indicators	0.617	0.020	0.148	0.008	0.402
River	-0.010	0.651	0.255	-0.478	0.718
Chroma 1, %	0.353	-0.408	-0.015	0.236	0.347
Chroma 2, %	-0.287	-0.313	-0.318	0.350	0.405
Chroma 1 and 2, %	0.036	-0.616	-0.296	0.508	0.728
Variance extracted	0.095	0.101	0.064	0.133	0.392 (Total)
Redundancy	0.090	0.089	0.052	0.093	0.324 (Total)

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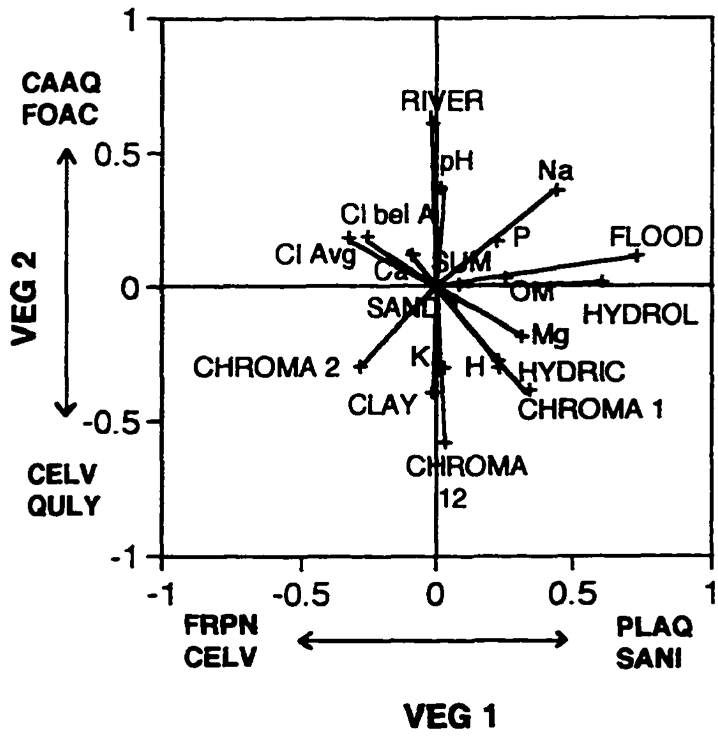

Figure 3. Vectors representing the direction and magnitude of relationships of environmental variables to the canonical vegetation variables. Labels of gradients on axes are interpretations based on the canonical loading structure. Species abbreviations are: CAAQ=*Carya aquatica*, CELV=*Celtis laevigata*, FOAC=*Forestiera acuminata*, FRPN=*Fraxinus pennsylvanica*, PLAQ=*Planera aquatica*, QULY=*Quercus lyrata*, SANI=*Salix nigra*.

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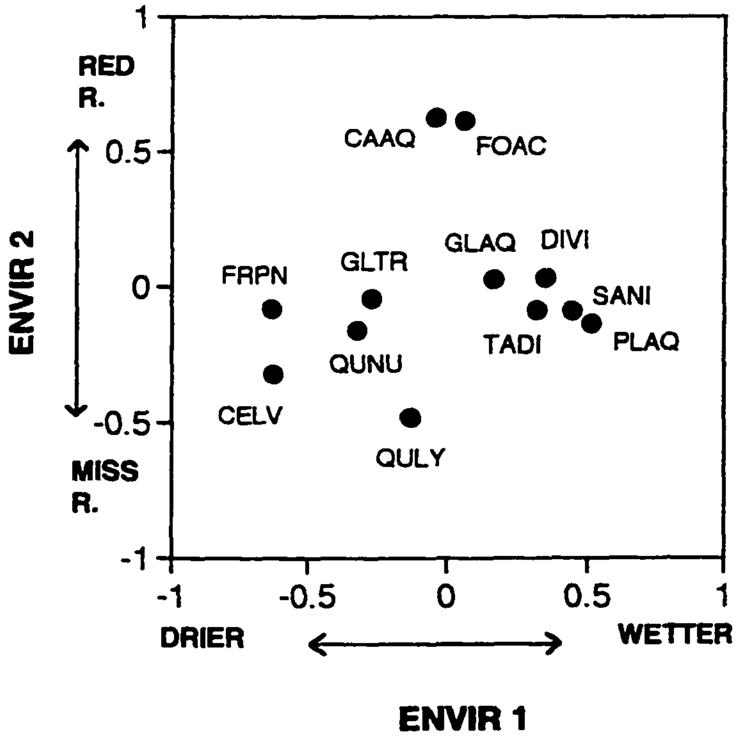

Figure 4. Scatterplot of correlations between species' importance values and the first two canonical (correlation) variables of the environmental characteristics data set. Labels of gradients on axes are interpretations of the loading structure of original variables on the canonical variables. CAAQ=*Carya aquatica*, CELV=*Celtis laevigata*, DIVI=*Diospyros virginiana*, FOAC=*Forestiera acuminata*, FRPN=*Fraxinus pennsylvanica*, GLAQ=*Gleditsia aquatica*, GLTR=*Gleditsia triacanthos*, PLAQ=*Planera aquatica*, QULY=*Quercus lyrata*, QUNU=*Quercus nuttalli*, SANI=*Salix nigra*, TADI=*Taxodium distichum*.

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Table 22. Results from canonical correlation analysis. Correlations (loadings) of species with the first four environmental canonical variables (ENV 1 - ENV 4).

	Canonical Variate				
	ENV 1	ENV 2	ENV 3	ENV 4	Communality
Species					
Taxodium distichum	0.318	-0.085	0.153	0.427	0.314
Salix nigra	0.444	-0.088	-0.124	-0.075	0.278
Planera aquatica	0.515	-0.135	0.272	-0.382	0.503
Gleditsia aquatica	0.165	0.029	0.125	0.073	0.049
Forestiera acuminata	0.064	0.612	0.362	-0.312	0.607
Carya aquatica	-0.041	0.623	0.180	-0.122	0.440
Quercus lyrata	-0.127	-0.480	-0.107	0.327	0.365
Celtis laevigata	-0.629	-0.321	-0.436	0.007	0.689
Fraxinus pennsylvanica	-0.632	-0.082	-0.237	0.040	0.464
Gleditsia triacanthos	-0.267	-0.044	-0.017	-0.176	0.104
Diospyros virginiana	0.350	0.032	-0.316	0.108	0.235
Quercus nuttalli	-0.319	-0.160	0.054	-0.265	0.200
Variance extracted	0.142	0.097	0.054	0.056	0.350 (Total)
Redundancy	0.135	0.086	0.049	0.039	0.304 (Total)

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and is followed by sugarberry. Water hickory and swamp privet are at the other extreme (Red River). Several species are centered near zero (Table 22): black willow, baldcypress, green ash, honeylocust, water locust, and persimmon.

Table 23 shows the relationship of the environmental variables to the derived vegetation canonical variables. The vegetation canonical variable explaining the most variance (VEG 1) has high positive loadings for flood frequency unit (0.726) and presence of wetland hydrology indicators (0.601). These high loadings indicate that flooding characteristics are the primary orderer of vegetation species distribution in the study area. The second vegetation canonical variable accounts for almost as much variation, but is highly loaded on river alluvium (Mississippi vs Red River) (0.611) and percent chroma 1 and 2 (-0.578). The third vegetation canonical variate is highy loaded on clay and sand, so it reflects a texture gradient.

Canonical Correspondence Analysis

Canonical correspondence analysis (CCA) resulted in four axes, or linear combinations of species and environmental variables. The first canonical axis, which had a correlation of 0.88 between species and environmental variables, accounted for 33.1 % of the species-environment relation. Flood frequency-drainage regime (FLOOD) and presence of wetland hydrology evidence (HYDROLGY) were the environmental variables weighted highest on the first axis (Figure 5). This axis had high positive weights for the flood tolerant species black willow and water elm, and high negative weights for less flood tolerant species Nuttall oak, green ash, and sugarberry (Figure 6). Black willow is highly loaded on the second axis, with all

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Table 23. Results from canonical correlation analysis. Correlations (loadings) of environmental variables with the first four vegetation canonical variables (VEG 1 - VEG 4).

	---------------Canonical	Variate---------------			
	VEG 1	VEG 2	VEG 3	VEG 4	Communality
Environmental Variables					
Clay, %	-0.012	-0.391	0.520	0.294	0.510
Sand, %	0.073	-0.050	-0.427	0.078	0.196
OM, %	0.257	0.035	-0.079	0.349	0.195
P, mg/kg	0.224	0.172	-0.131	-0.243	0.156
Ca, cmol(+)/kg	-0.084	0.122	0.019	-0.149	0.044
Mg, cmol(+)/kg	0.316	-0.183	0.223	0.254	0.247
K, cmol(+)/kg	0.031	-0.299	0.296	0.107	0.189
Na, cmol(+)/kg	0.445	-0.361	0.013	0.203	0.370
pH, 1:1	0.019	0.370	-0.097	-0.514	0.411
Sum of bases, cmol/kg	0.090	0.010	0.182	-0.021	0.042
H concentration	0.231	-0.272	0.039	0.476	0.355
Chroma Index, avg	-0.325	0.186	0.150	-0.402	0.324
Chroma Index below A	-0.253	0.189	0.156	-0.418	0.299
Flood frequency unit	0.726	0.116	0.288	0.014	0.624
Hydric soil indicators	0.234	-0.297	0.150	0.401	0.326
Hydrology indicators	0.601	0.019	0.133	-0.007	0.379
River	-0.010	0.611	0.230	-0.401	0.587
Chroma 1, %	0.344	-0.382	-0.014	0.198	0.304
Chroma 2, %	-0.280	-0.294	-0.287	0.294	0.334
Chroma 1 and 2, %	0.035	-0.578	-0.268	0.426	0.589
Variance extracted	0.090	0.089	0.052	0.093	0.324 (Total)
Redundancy	0.086	0.078	0.042	0.066	0.272 (Total)

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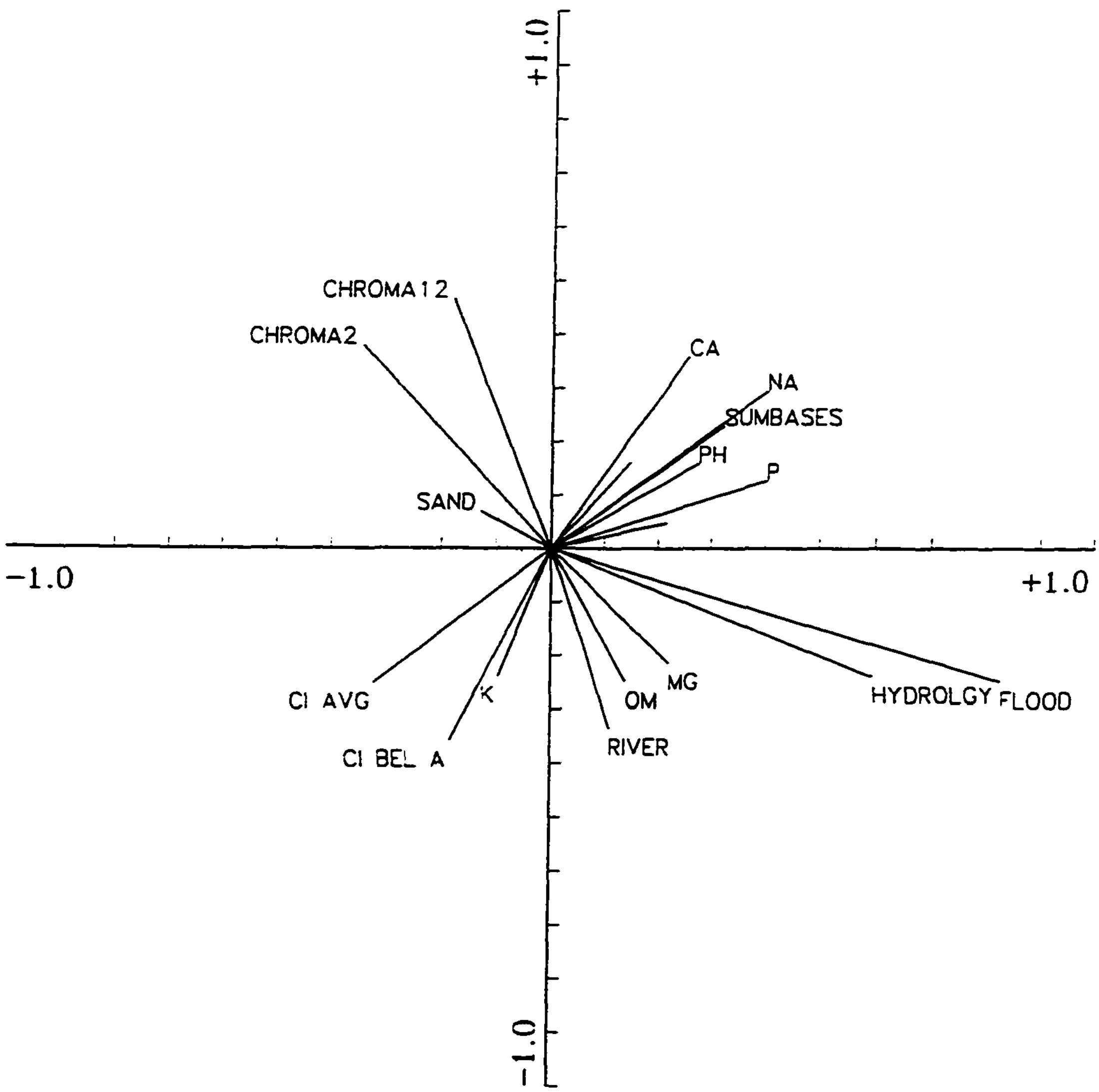

Figure 5. Canonical correspondence analysis results showing the magnitude and direction of environmental variables across the first two canonical axes.

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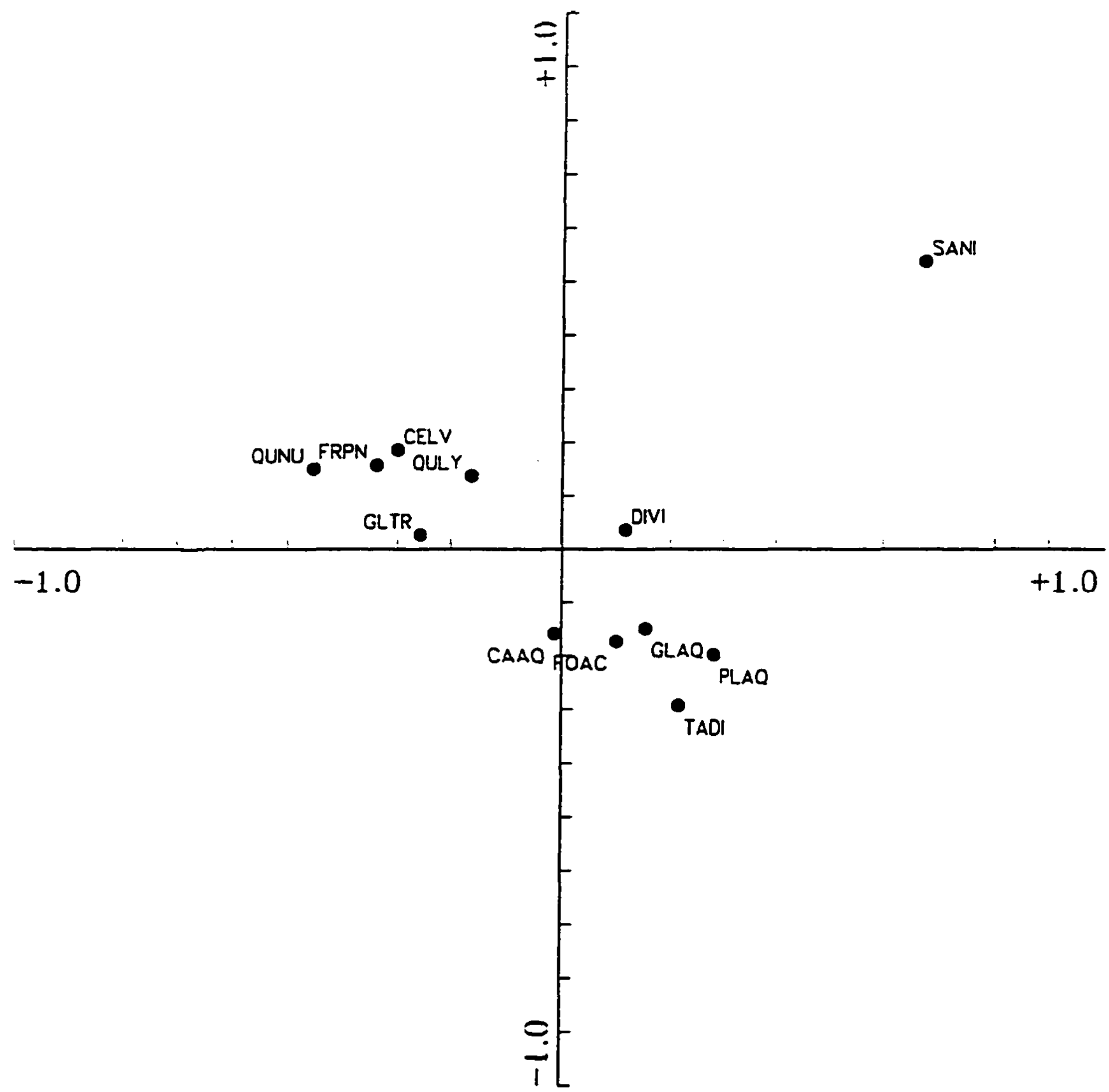

Figure 6. Species distribution across the first two canonical (correspondence) axes. Species abbreviations are: CAAQ=*Carya aquatica*, CELV=*Celtis laevigata*, DIVI=*Diospyros virginiana*, FOAC=*Forestiera acuminata*, FRPN=*Fraxinus pennsylvanica*, GLAQ=*Gleditsia aquatica*, GLTR=*Gleditsia triacanthos*, PLAQ=*Planera aquatica*, QULY=*Quercus lyrata*, QUNU=*Quercus nuttalli*, SANI=*Salix nigra*, TADI=*Taxodium distichum*.

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other species having much lower weights. The second axis only explains 4.2 % of the environmental data, and although Chroma 12 has the highest weight, its correlation with that axis is only 0.366. Chroma 12, pH and river source were highly correlated with the third axis, which explained 13.1 % of the environmental data. Baldcypress, persimmon, and overcup oak were positively loaded on this axis, indicating more presence on Mississippi River alluvium. Water hickory and swamp privet were loaded high negatively, reflecting a positive correlation with Red River alluvium.

When the individual plots' vegetation and environment attributes are depicted in a graph of the first two canonical correspondence axes (Figure 7), it is clear that the Sugarberry forest type occupies a drier space than the Water Hickory, Baldcypress, and Black Willow types.

Canonical Discriminant Analyses

Canonical variate analysis (CVA), a variant of CCA where the species data are binary coded forest types, was used to assess the relationship between forest types and environmental variables. Flood frequency-drainage and hydrology evidence were the variables highest correlated (positive) with the first axis (Figure 8). Sugarberry type was situated on the negative end of the axis, and Baldcypress and Black Willow forest types were loaded highly positive (Figure 9). The second axis was weighted positively toward calcium, sodium, pH, and sum of bases, and negatively correlated with organic matter (Figure 8), but only accounted for 4.1 % of the environmental data. The species-environment correlation, however was 0.76. The second axis contrasted Black Willow and Baldcypress forest types. The third axis contributed

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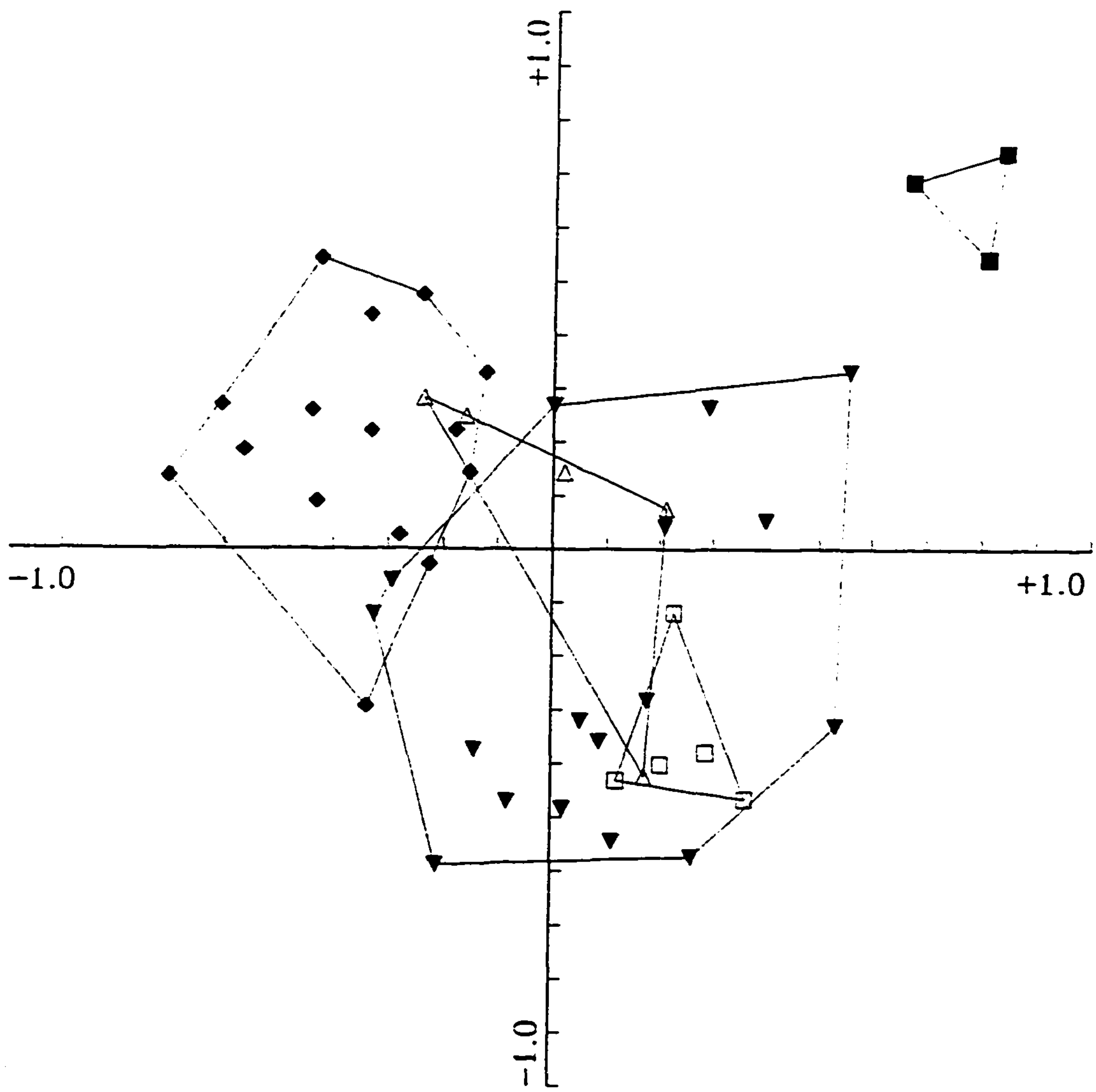

Figure 7. Location of plots identified by forest type across the first two canonical correspondence axes. ◆ = Sugarberry, Δ = Overcup Oak, ▼ = Water Hickory, ■ = Black Willow, and □ = Baldcypress.

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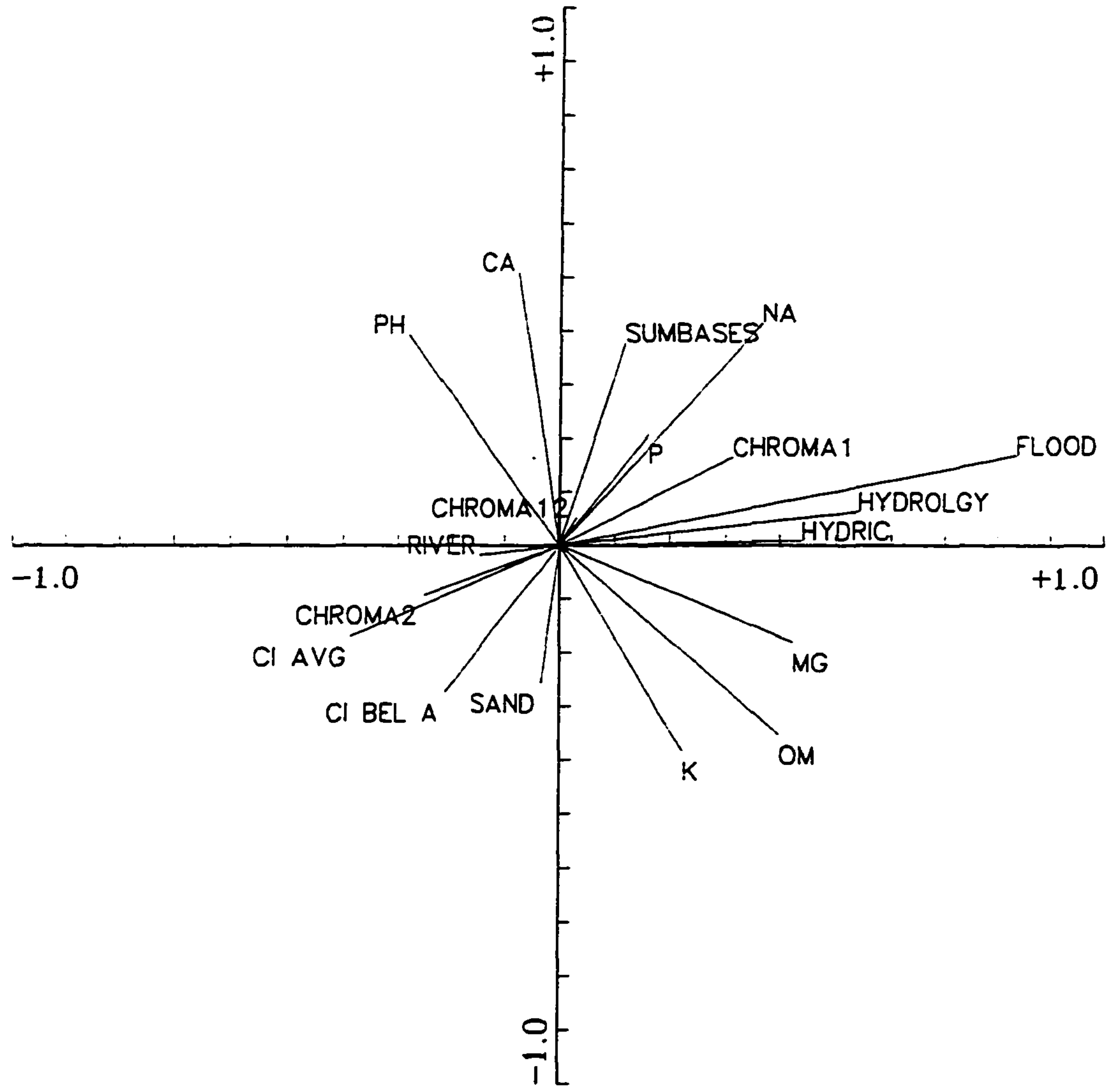

Figure 8. Environmental variables' vectors plotted against the first two canonical variate analysis axes.

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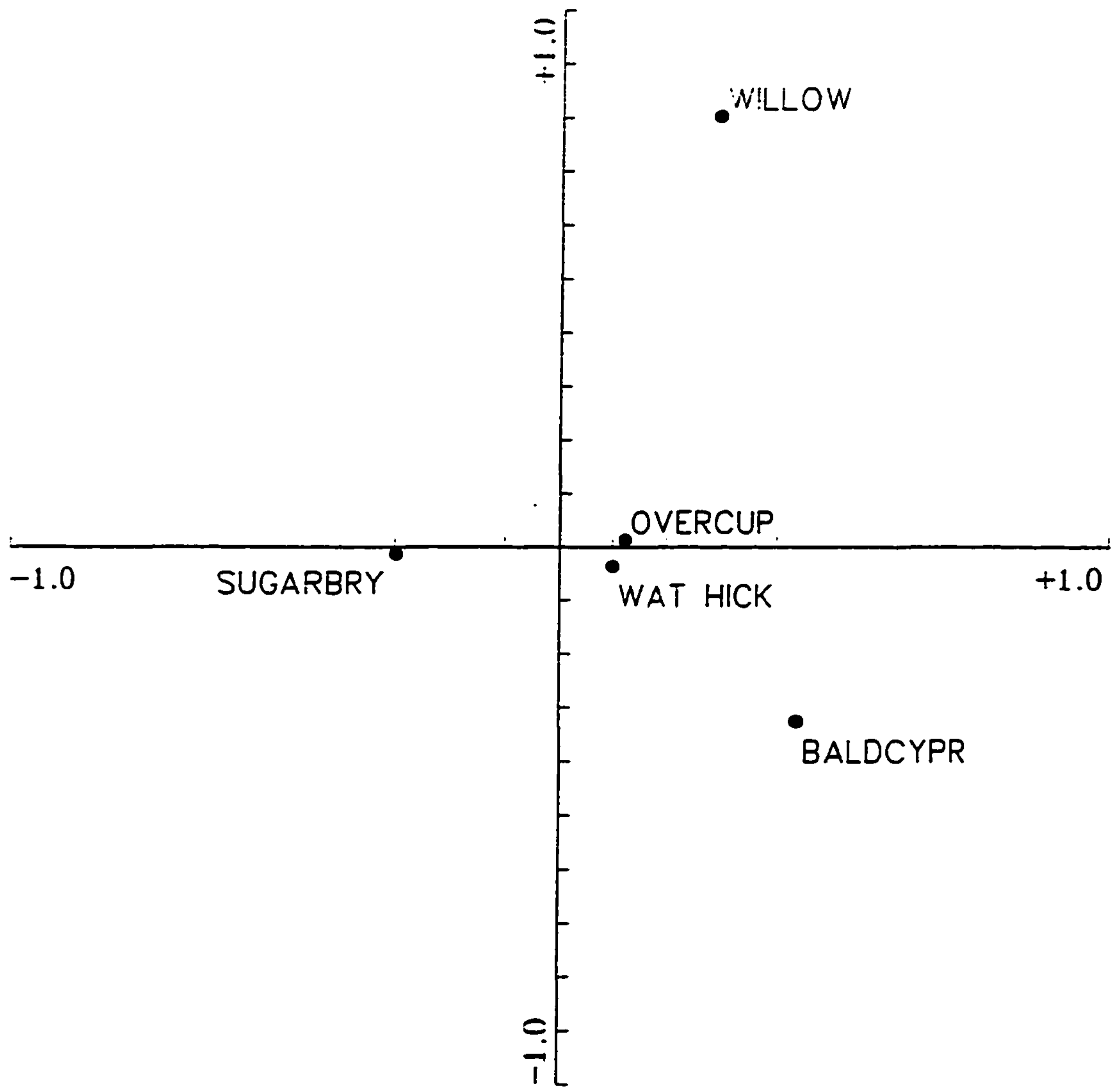

Figure 9. Centroids of the forest types plotted on the first two canonical variate analysis axes. Sugarbry=Sugarberry, Overcup=Overcup Oak, Wat Hick=Water Hickory, Willow=Black Willow, Baldcypr=Baldcypress.

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more to the environmental variance, and soil color variables and river source were the most heavily weighted variables. Water Hickory type was positively correlated with this axis, opposite Baldcypress and Overcup Oak on the other extreme (Mississippi River).

Canonical discriminant analysis is equivalent to a canonical correlation analysis of binary coded forest types and environmental data. Canonical axis one accounted for 58.3 % of the forest type-environment variance. As in other analyses, flood frequency map unit and hydrology indicators were loaded very heavily on that axis, which was a contrast between Sugarberry (weighted negatively) and Black Willow and Baldcypress (weighted positively) forest types. The second canonical axis, together with the first axis, accounted for 79 % of the species-environment variance. Organic matter had a high positive loading on Axis 2, but pH was loaded high negatively. This axis separated Baldcypress and Black Willow types. As in the CVA, the third axis, loaded heavily on soil colors and river source, was a contrast between Water Hickory type and the Overcup Oak and Baldcypress forest types. The Mahalanobis distances (squared distances between class means, based on pooled within-class covariance matrix) of the forest types indicate that, overall, Sugarberry type is significantly different (at α=0.05) from Water Hickory, Black Willow, and Baldcypress forest types. The latter three are not significantly different from each other. Overcup Oak is not significantly different from any forest type.

Multiple Regression of Species' Importances and Site Variables

Ten species were chosen for multiple regression analysis with the variables in the environmental data set (Table 24). All except for Nuttall oak had highly

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Table 24. Results of stepwise multiple regression analysis of species importance with environmental variables.

Species	Overall Regression R^2	Overall Regression p-value	Variable name	Variable coefficient	Variable p-value
Celtis laevigata	0.596	0.0001	Floodmap	-28.67	0.0001
			Chroma 2	0.44	0.0001
Fraxinus pennsylvanica	0.442	0.0001	Floodmap	-10.05	0.0003
			Chroma 2	0.20	0.0033
			H_conc.	-579082.0	0.0470
Quercus lyrata	0.381	0.0002	Chroma 12	0.73	0.0001
			CI Avg	25.14	0.0306
			P	-0.13	0.1255
Carya aquatica	0.402	0.0001	Chroma 12	-0.77	0.0001
			Ca	-3.33	0.0141
Forestiera acuminata	0.540	0.0001	Chroma 12	-0.57	0.0001
			Floodmap	8.62	0.0409
Gleditsia aquatica	0.358	0.0030	Chroma 1	0.24	0.0009
			CI below A	14.07	0.0079
			CI Avg	-13.66	0.0290
			Na	-32.28	0.1173
			Floodmap	3.13	0.1927
Planera aquatica	0.459	0.0004	Floodmap	10.01	0.0017
			Chroma 2	-0.30	0.0034
			K	45.35	0.0182
			Ca	-1.51	0.0427
			pH	12.49	0.0436
			Chroma 12	0.15	0.1760
Taxodium distichum	0.417	0.0001	OM	13.3	0.0059
			Floodmap	16.33	0.0090
			pH	-15.05	0.0354
Salix nigra	0.465	0.0001	pH	54.1	0.0001
			Na	173.55	0.0074
			H conc.	2376344.0	0.0275
			Chroma 12	0.40	0.0503

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significant (p-value < 0.001) overall regressions. Most of the variables entered into the models attained a significance level of p-value < 0.05. Sugarberry had only two environmental variables entered into the regression when the coefficient of determination stabilized at 0.596. Both variables were highly significant, as was the overall regression. Floodmap, the flooding frequency-soil drainage landscape map unit, had a negative coefficient and was highly significant. Percent chroma of 2 has a positive coefficient. Green ash had floodmap, percent chroma 2 and hydrogen concentration entered into the regression equation, and as with sugarberry, the coefficient for the first variable was negative and the that of the second was positive. Overcup oak had a lower R^2 than the previous two species, and only the first two variables in the model, percent chroma 1 or 2 and chroma index average were significant. Both had positive coefficients. Water hickory had a coefficient of determination of 0.402, and percent chroma 1 or 2 and exchangeable calcium were negatively related to importance value. The R^2 of the regression of swamp privet was the second highest at 0.540. Percent chroma 2 or below was negatively related to importance, but the value of floodmap was positively related to IV. Although waterlocust had five variables entered into the regression equation, the overall R^2 was the lowest with the exception of Nuttall oak : 0.358. The overall regression had a p-value of 0.003, not highly significant. Percent chroma 1 and chroma index below A were significantly and positively related to waterlocust importance, but the chroma index average of the top two horizons was significantly negatively related with IV. Sodium and floodmap were not significant. Floodmap, potassium, and pH were

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significantly positively related to water elm importance value. Percent chroma of 2 and calcium had significant negative coefficients. Baldcypress importance value had a significant positive relationship with percent organic matter and floodmap, but also had a significant negative coefficient for pH. Black willow was strongly related to higher pH levels and higher concentration of exchangeable sodium. Percent chroma 2 or below and sum of bases had positive coefficients, but were just outside the range of significance.

DISCUSSION

Characteristics of Forest Types

All vegetation characterized in this study on the backswamps and lower natural levees is hydrophytic based on PI and FTI. Forest types range from Sugarberry type concentrated on Sharkey clay, occasionally flooded soils to the Baldcypress and Black Willow types, which are restricted to the longest flooding backswamp positions on the Fausse clay. In between the lower natural levee and backswamp positions, Overcup Oak and Water Hickory forest types are concentrated, and have an intermediate flooding duration and frequency. These types are situated on Sharkey clay, frequently flooded and Fausse clay soil map units.

The range in PI among three vegetation strata for all plots in all forest types was narrow, from 1.00 to 1.83. Thus obligate wetland and facultative wetland species dominated all strata. As expected, the higher PI and FTI's were on the lower natural levee positions mapped occasionally flooded and high microsite positions.

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The lowest PI and FTI's were found in depressional areas with frequent flooding for long duration.

A greater diversity and range in flood tolerance would probably have been encountered if the middle and upper levee positions in the study area were still under bottomland hardwood forest vegetation. Most of these positions are currently farmed for production of soybeans and cotton.

Soils with the upper part of the soil profile developed from Mississippi River alluvium showed a trend of increasing redoximorphic features (oxidized iron concentrations or orange mottles, and iron depletions or gray mottles derived from reduced iron) with increased flood frequency and duration. Sugarberry forest type had a higher CI than Overcup Oak type, indicating a higher mean Munsell soil chroma (brightness) color. Mississippi River derived epipedons of the Baldcypress and Black Willow forest types also showed this trend. Soils mapped as Sharkey or Fausse clay on the transitional Red River sediment did not exhibit the trend in redoximorphic features due to the masking by the red-colored parent material. Soils of the Red River valley and similarly red-colored parent materials are exempt from meeting the color requirements of hydric soil indicators (Environmental Laboratory, 1987).

There is a trend in exhibited wetland hydrology evidence. Evidence included drift lines, water stains on leaves, sediment on trees, and direct observation of flooding or a high water table (Environmental Laboratory, 1987). Sugarberry forest type had the lowest proportion of plots showing evidence, whereas Overcup Oak and

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Water Hickory predominantly had the indicators. All Baldcypress and Black Willow type plots had wetland hydrology evidence.

DeVall (1990) investigated the vegetation of Cat Island Swamp on the Mississippi River floodplain in West Feliciana Parish, Louisiana, and found sugarberry to be dominant on the old natural levee, and on ridges and in swales. Black willow and cottonwood (*Populus deltoides*) formed a community on a new natural levee, and overcup oak, along with baldcypress and water hickory were situated higher than a community of baldcypress and tupelo in the lowest area.

Succession of Forest Types

Putnam et al. (1960) and Hodges (1993) discussed successional pathways of southern bottomland hardwood forest types on poorly drained soils. Black willow colonizes exposed new fine-textured sediments of long flooding duration, but this shade intolerant species cannot succeed itself, and after 30 years, the even-aged stand begins to deteriorate. If sedimentation is fast, sugarberry, elm and ash may come in. Under slower sedimentation rates, overcup oak and water hickory will take advantage of the former willow sites. These trees are more tolerant of shade, and will compete better for less wet sites than will black willow. Willow stands may, however, develop into a scrub-shrub type with swamp privet, water elm, and buttonbush if there is little or no deposition. Baldcypress can develop a stand if there is a seed source and the hydrology prevents reproduction and growth of competitors while drawing down intermittently to allow seed germination. Overcup oak and water hickory forests will form from the scrub-shrub type if deposition remains slow. The

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latter three successional types may last for centuries if sedimentation rates remain slow. Sugarberry, elm and green ash replace overcup oak and water hickory under continued slow deposition.

In the study areas in central Louisiana, black willow is not reproducing itself in the subsapling layer, as it had no subsaplings encountered in any plots. Baldcypress in the Baldcypress forest type was not present in the sapling or subsapling layers. All the species for those two forest types in the sapling and subsapling layers are obligate wetland. The Water Hickory forest type has a very large component of swamp privet in the sapling and subsapling strata, but sugarberry is the second most numerous species in those layers. Water hickory is only the third most numerous species in the understory layers in this forest type named for its dominant canopy status. Water hickory and swamp privet are the two most numerous and frequent sapling and subsapling layer species for the Overcup Oak forest type, which may be a transition to the Water Hickory type. Since overcup oak was not encountered in any of the subsapling layer plots in the Overcup Oak forest type, and sugarberry had a very small presence in the understory, this forest type does not seem to be changing to a drier vegetation. The Sugarberry forest type sapling layer is dominated by water hickory, but sugarberry and green ash are the second and third most numerous species. Green ash and sugarberry are the two most frequent subsapling layer species, and deciduous holly (*Ilex decidua*) and boxelder (*Acer negundo*) with the first two species are most numerous in that layer. All four

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of those species are facultative wetland, so the Sugarberry appears to be maintaining its current canopy level hydrophytic nature (not getting wetter).

Species-Environment Relations

Sugarberry was most important on sites with less frequent (occasional) flooding. Often these were on low ridges, and the lower natural levee landscape positions. In virgin Louisiana bottomland forests, sugarberry was common on first bottom ridges (river or bayou, low, and flat) and high flats alluvial landscape positions (Tanner, 1986). The distribution of larger trees peaked on first bottom flat ridges. Baker and Broadfoot (1979) rated the soil-site conditions for important southern hardwoods. The best soil-site conditions for sugarberry growth include: silty or loamy soil texture, water table between 2 and 6 feet depth during the growing season, concave microsites, winter or spring floods, Mississippi River geologic source, organic matter > 2%, wet in winter only, and no mottling within 18 inches depth. Sugarberry was present on sites in the lower White River, Arkansas, which had flooding regimes ranging from not flooded to 40 % of the year (Bedinger, 1979). The distribution of sugarberry, however, peaked on sites having flooding duration of 10 to 21 percent of the year. Theriot (1993) found sugarberry to be most important in the seasonally flooded (12.5-25 percent duration) hydrologic zone. Sugarberry is classified by Hook (1984) as weakly tolerant to waterlogging, and by Reed (1988) as having a facultative wetland distribution.

Green ash importance, like that of sugarberry, was successfully predicted by landscape positions with less frequent flooding, as well as a high percent of chroma 2

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soil color. Lower soil hydrogen ion concentration also favored ash importance. In a site near the northern terminus of the southern floodplain (Mississippi River) forest in southern Illinois, green ash attained its highest importance in areas with prolonged flooding, mottling near the soil surface, and more sand and less clay in the most permeable horizon (Robertson et al., 1978). Green ash importance peaked on first bottom medium flats characterized by heavy clay in virgin Louisiana bottomland forests (Tanner, 1986). In that study, however, as in that of Theriot (1993), green ash exhibits a very wide ecological amplitude. Putnam et al. (1960) described the bottomland distribution of green ash to be wide on new sediments and on first bottoms, and most common in flats and shallow sloughs. Baker and Broadfoot (1979) listed the same optimal soil-site conditions for green ash as were reported for sugarberry. Green ash is rated by Hook (1984) as moderately tolerant to waterlogging, and has same NWI status (Reed, 1988) and similar floodplain zone distribution (Theriot 1993) as sugarberry. Green ash develops adventitious roots in response to flooding, as well as hypertrophied lenticels (Sena Gomes and Kozlowski, 1980; Hosner 1958). Another adaptation to flooding is reopening of stomates after 2 weeks of inundation (Sena Gomes and Kozlowski, 1980; Tang and Kozlowski, 1984). Green ash also delays leafing out in spring (Putnam et al., 1960), thus avoiding some stress from flooding conditions. The seeds of green ash, however, lose viability when subjected to more than short term flooding (Hosner, 1957).

Although Nuttall oak importance was not predicted well, presumably because it was rarely dominant in the study area, it was restricted to occasionally flooded

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positions on Mississippi River alluvium. Nuttall oak typically grows well on poorly drained clay flats and low ridges in the Mississippi delta, with shallow flooding (8-20 cm depth) during the winter (Putnam et al. 1960; Filer, 1990). Nuttall oak distribution in the lower White River valley in Arkansas was concentrated on sites with 10 to 21 % flooding duration (Bedinger, 1979). In Louisiana virgin bottomland forests (Tanner, 1986), Nuttall oak occurred on all site types except the second bottom ridge or terrace. Although not dominant, Nuttall oak distribution peaked on first bottom high flat sites. Baker and Broadfoot (1979) found Nuttall oak grew best on soils with a pH of 4.5 to 5.5. Although it is classified by Reed (1988) as an obligate wetland species, Nuttall oak is rated as only moderately waterlogging tolerant (Hook, 1984), and has a similar bottomland hydrology zone distribution as sugarberry and green ash (Theriot, 1993). Nuttall oak breaks dormancy relatively late in the spring (Chambers et al., 1993)

Overcup oak importance was best on frequently flooded backswamp flat position Mississippi River alluvial soils with high percentage of soil color with chromas ≤ 2, indicating long reduction hydroperiods. Overcup oak is found on poorly drained, low position first bottom clay flats, sloughs, and edges of swamps in southern floodplains (Putnam et al. 1960, Solomon 1990). Best growth, however, can be attained on sites with better drainage and lighter soil texture (Morris, 1965). Overcup oak was a dominant, with water hickory on sites with 29-40 % flooding duration in the White and Ouachita River floodplains, Arkansas (Bedinger, 1979). The optimal water table depth (in May and June) for overcup oak in the White River

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floodplain was simulated to be 60 cm (Phipps, 1979). In virgin bottomland forests in Louisiana, overcup oak was present in small quantities on many landforms, but was dominant on first bottom low flats which are estimated to be flooded or saturated more than 25 % of the growing season (Tanner, 1986). Near the northern range of the southern floodplain in southern Illinois, overcup oak occupied sites which had winter and spring inundation with moderate to deep floodheights, and shallow depths to the least permeable horizon (Robertson et al., 1978). Overcup oak is considered highly tolerant of waterlogging by Hook (1984), and is classified as an obligate wetland species by Reed (1988). Overcup oak delays leafing out in the spring (Hook and Scholtens, 1978; Chambers et al., 1993), as well as seedling height and diameter growth (Chambers et al., 1993). Although this species does not develop aerenchyma, the stem tissue after flooding treatment is less dense than that of cherrybark oak (*Quercus falcata* var. *pagodaefolia*) (Pezeshki, 1991).

Water hickory was most important on frequently flooded backswamp flat and depression, Red River alluvium soils with a low percentage of low chroma soil colors. These sites also had lower contents of exchangeable calcium than other sites. Water hickory distribution in the Mississippi River delta is concentrated on backwater basin flats, but can also occur commonly in sloughs and swamp margins, and occasionally on low clay ridges (Putnam et al., 1960). Vertic Haplaquepts (wet, clayey soils which dry out and crack) are the most common subgroup this species occurs on, but water hickory growth is best on loamier, drier soils (Francis, 1990). Water hickory occurs in several bottomland hydrologic zones, but Theriot (1993)

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found its importance peaked in Zone III (regularly flooded or saturated). In the White River valley in Arkansas, water hickory was dominant with overcup oak in areas flooded 29-40 % of the time (Bedinger, 1979). It had a significant presence also in forests with a flooding duration of 10 to 21 %. Phipps (1979) simulated the optimal May-June water table depth for White River water hickory to be 30 cm. Hook (1984) ranked water hickory as highly tolerant to waterlogging, and Reed (1988) assigned obligate wetland distribution to this species. Water hickory leafs out late in the spring to avoid stressful flooding conditions (Putnam et al., 1960). When flooded in a shallow water impoundment until July 1, however, radial growth increased 45 % over that on nonflooded conditions (Broadfoot, 1967).

Water elm was most important in the study area on sites with more frequent flooding, but higher exchangeable potassium, lower calcium, and higher pH. Waterlocust and water elm in the White River valley, Arkansas were limited to sites flooded 29-40 % of the time (Bedinger, 1979). Their optimal water table depth there was estimated to be 30 cm (Phipps, 1979). Theriot (1993) found water locust most prevalent in Zone III hydrologic zone (regular inundation/saturation). Water locust is highly tolerant of waterlogging (Hook, 1984), and has an obligate wetland frequency of occurrence (Reed, 1988). Waterlocust can develop hypertrophied lenticels in response to flooding (Environmental Laboratory, 1987). Water elm, also an obligate wetland species, was rated by Hook (1984) as most tolerant to waterlogging, and had a lower FTI value (Theriot, 1993) than water locust. Water elm may develop

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multiple stems, considered an adaptation to flooding (Environmental Laboratory. 1987).

Black willow importance was best predicted by high pH and exchangeable Na. Its distribution was largely restricted to the most frequently flooded sites in backswamp depressions with the poorest drainage. Baldcypress occurred mostly in similar positions . but was also present on backswamp flats (in Overcup Oak forest type) and the lower natural levee (in Sugarberry type). Baldcypress importance was greatest on sites with high organic matter content, highest flood frequency, and lowest pH. Black willow and baldcypress are rated obligate wetland plants (Reed, 1988) and most tolerant of waterlogging (Hook, 1984). In Louisiana virgin bottomland forests, their distribution was limited to swamps (Tanner, 1986). The most common soil subgroups associated with black willow are Haplaquents and Fluvaquents (Pitcher and McKnight, 1990). Black willow is a shallow rooted pioneer species of bottomlands with continous and abundant soil moisture, and is very shade intolerant (Pitcher and McKnight, 1990). Black willow requires bare mineral soil to germinate, though it can germinate under water (Putnam et al., 1960). Black willow seeds cannot withstand even a few days of dry conditions (Pitcher and McKnight, 1990). This species develops adventitious and soil water roots in response to flooding (Kozlowski, 1982), as well as adaptations of hypertrophied lenticels (Environmental Laboratory, 1987), aerenchyma (Kozlowski, 1984), rapid stomatal reopening (Pereira and Kozlowski, 1977), and ability to oxidize the rhizosphere (Dionigi et al., 1981). Baldcypress reproduction is erratic since the seed must

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germinate under unflooded conditions on moist soil (Dubarry. 1963). This species is often restricted to the wettest sites, but if competition is controlled, may thrive on much drier conditions. Baldcypress exhibits the following adaptations to flooded conditions: adventitious and soil water roots, oxidizing rhizosphere, aerenchyma, rapid recovery of gas exchange (Pezeshki, 1993), prolonged seed viability, pneumatophores, and buttressed tree trunks (Environmental Laboratory, 1987), and delayed spring leafing (Putnam et al., 1960).

CONCLUSIONS

Although all the bottomland hardwood canopy, sapling and subsapling vegetation encountered in this study qualifies as hydrophytic, vegetation indices indicate that the Sugarberry forest type is less hydrophytic and flooded less frequently than the Overcup Oak, Water Hickory, Black Willow and Baldcypress forest types. The Water Hickory, Black Willow and Baldcypress forest communities show more soil and hydrology indicators of wetland function than the Sugarberry type. Baldcypress forest type has more organic matter content and is more acid than the other four forest types. Multivariate analyses show that the most important gradient influencing vegetation species distribution in these bottomland hardwood forests is the flooding frequency and duration. The river alluvium source and soil chemistry related to it is the second most important gradient in determining community structure. The Sugarberry forest type exhibits less evidence of wetland function than the other four forest types.

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CHAPTER 4

SOIL CHARACTERIZATION OF BOTTOMLAND HARDWOOD FORESTS

INTRODUCTION

Wet Vertisols were not recognized at the suborder level of the USDA Soil Taxonomy until 1992 (Soil Survey Staff, 1992), when Aquerts were classified based on soil color and aquic conditions. Wet Vertisols have been problematic in characterizing saturation, water tables, and water movement (Comerma, 1985) due to cracks resulting from shrinkage and swelling. The Sharkey soil series (proposed classification: Chromic Epiaquert, very fine, smectitic, thermic) has a primary hydric soil component (NRCS, 1997), based on color morphology and/or frequent flooding or ponding. The hydric nature of the Sharkey soil and similar soils in Mississippi has been challenged (Pettry and Switzer, 1996) on the basis that the aquic soil colors are relict, and the soils are neither saturated nor reduced. There has also been controversy surrounding the delineation of wetlands in bottomland hardwood soils due to uncertain hydroperiods of inundation and saturation (Faulkner et al., 1992, Faulkner et al., 1993).

The primary objective was to relate soil morphology, texture, and chemical properties to the factors of soil formation and soil forming processes including i) floodplain geomorphic position and hydrologic regime, ii) parent material (specific river alluvium), and iii) forest community composition. A second objective was to classify soils by *Keys to Soil Taxonomy* in the Sharkey-Fausse soil association

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mapped in central Louisiana, using morphology descriptions, particle size distributions, and hydric conditions monitoring.

Hypotheses are: i) soils of lower, wetter floodplain positions have different morphology, physical, and chemical properties than soils of higher, drier floodplain positions; ii) Mississippi River and Red River derived soils have different soil morphology, physical, chemical, and mineralogical features; and iii) forest types have different soil composition.

METHODS

The study areas were in Avoyelles and Concordia Parishes in central Louisiana, in the Mississippi River and Red River floodplains. Five Louisiana Wildlife Management Areas (WMA's) were selected for the project: Three Rivers (TR) and Red River (RR) in Concordia Parish; and Grassy Lake (GL), Spring Bayou (SB) and Pomme de Terre (PT) (combined) in Avoyelles Parish. Five 0.04 ha plots were randomly selected within each of the three soil map units of the WMA's: Sharkey clay, occasionally flooded (SO); Sharkey clay, frequently flooded (SF), and Fausse (F) clay. Vegetation was described for 45 circular 0.04 ha. plots within three groups of WMA's. Soils were described and sampled from an auger hole in the center of each of the 45 plots. The forest species composition of the plots was used in a complete linkage cluster analysis (SAS Institute, 1992) that resulted in a classification of forest types. Seventeen of these plots were selected as typical or modal within the forest types and were instrumented with piezometers and redox electrodes for hydrological monitoring (Chapter 5). Pits were dug for 12 of these

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sites and the soil morphology and redoximorphic features were described in more detail, using terminology of Vepraskas (1993) and the National Technical Committee on Hydric Soils (NTCHS) (1993). Horizons were sampled for laboratory characterization.

Bulk density was determined using the saran clod method on field moist, air dry and oven dry clods (Soil Survey Staff, 1992). Coefficient of Linear Extension (COLE) was calculated from the oven dry and field moist bulk densities. Soils were air dried for the following analyses. The hydrometer method and sieving for sands (Gee and Bauder, 1986) was used for particle size analysis, to determine clay, silt and sand content. Organic carbon was oxidized by the Walkley-Black acid dichromate method, and its content is estimated using a colorimeter (Allison, 1965). Soil pH was determined on a 1:1 soil to water weight basis, using an Orion pH meter. Available P was extracted by the Bray 2 method (Brupbacher et al., 1970). The exchangeable cations Ca, Mg, Na, and K were displaced by ammonium acetate (Thomas, 1982), and determined by an inductively coupled plasma emission spectrophotometer (ICP). Exchangeable H and Al were determined using KCl as an extractant (Thomas, 1982), and extractable acidity was determined by the $BaCl_2$ Triethanolamine (TEA) method (Thomas, 1982). Effective cation exchange capacity (ECEC) was calculated by adding the sum of the bases (Ca, Mg, Na, K) to the KCl exchangeable Al and H. The cation exchange by sum (sum CEC) was calculated as the sum of bases plus the $BaCl_2$ - TEA extractable acidity. Percent base saturation was calculated as the sum of bases divided by the sum CEC (multiplied by 100 %).

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Calcium carbonate equivalent (CCE) was titrimetrically measured on samples having a pH greater than 7.4 by digestion with HCl (Soil Survey Staff, 1972). Free Fe oxides, as well as oxides of Mn and Al, were extracted by the dithionite-citrate-bicarbonate method (Mehra and Jackson, 1960) and determined by ICP. Clay mineralogy was determined on four horizons using X-ray diffraction (Moore and Reynolds, 1989) employing five soil treatments: K saturated (air dry, 300°C, 550°C), and Mg saturated (air dry, and ethylene glycolated). A semi-quantitative analysis of the abundance of clay minerals was obtained using peak intensity of minerals' first order peaks for the Mg saturated, ethylene glycolated and the K saturated 300°C and 550°C X-ray diffractograms.

A one way (by soil group: Sharkey, Fausse, red-colored surface Sharkey, and red-colored surface Fausse) analysis of variance (ANOVA) was used to statistically analyze the surface horizons and control sections of the chemical and texture data of the 45 augerholes. A one way ANOVA by forest type was computed to determine significance of the forest type on soil properties. Significance was determined at α=0.05 level. Duncan's Multiple Range Test was used to make multiple mean comparisons. All statistical analysis was performed using SAS GLM procedure (SAS Institute, Inc., 1990).

RESULTS

Soil Morphology

The Sharkey clay, occasionally flooded (SO) and frequently flooded (SF) and Fausse (F) clay mapping units in the study area included some soils with Red River

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sediments overlying Mississippi River alluvium. Thus these mapping units provide a basis to compare backswamp soils developed primarily from Red River alluvium and Mississippi River alluvium with similar geomorphic positions. Properties of the soils investigated include color morphology, specifically the matrix hue, value and chroma, and the redoximorphic concentrations and depletions, vertic properties, and the presence of hydric soil field indicators.

Color Morphology and Redoximorphic Features

The Sharkey soils developed from Mississippi River alluvium had A horizons with a 10YR hue. Seventy-six percent of all the A horizons were 10YR4/2 or 10YR 3/2. Almost all the A horizons had redoximorphic concentrations (mottles due to oxidation of Fe), and 73 % of these were 7.5YR4/6, 7.5YR5/8, 7.5YR4/4, or 10YR4/6, with abundance of common to many. About half of the A horizons had redoximorphic depletions (mottles due to reduction of Fe), and 10YR4/1 was the most common. Almost all the depletions were common or many, chroma 1 or less.

Seventy-five percent of the transitional AB or BA horizons of the Mississippi River alluvium Sharkey soils had a matrix color of 10YR3/2 or 10YR4/2. All horizons had common to many redoximorphic concentrations of mostly 7.5YR5/8, 7.5YR4/6, and 7.5YR4/4. Other concentrations were: 7.5YR4/3, 7.5YR3/3, 5YR4/4, 5YR4/6, and 10YR4/6. Sixty-seven percent of the transitional horizons had depletions, of which 10YR4/1 alone comprised 62 %.

The B horizons were grouped for the purpose of evaluating soil colors, since almost all had a similar clay content and structure. Matrix colors of 10YR5/1,

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10YR4/1, and 10YR4/2 comprised 88 % of the matrix colors of 59 B horizons of 20 Sharkey soils. Seventy-five percent of the matrix chromas were 1 or less. Every horizon had common to many redoximorphic concentrations, of which 7.5YR4/6, 7.5YR5/8, and 7.5YR4/4 represented 69 % of the occurrences. Only 33 % of the profiles had depletions, mostly having common abundance, of which 10YR4/1 and 10YR4/2 were the most prevalent (73 %).

Almost all the A horizons of Fausse clay map unit soils derived from Mississippi River alluvium had a matrix chroma of 1. The most common matrix colors were 10YR4/1, 10YR5/1, and 2.5Y4/1. Six of the 10 Fausse soils had common redoximorphic concentrations, of which 7.5YR4/6 was the most frequent Two of the three pits had A horizons with pore and root linings (oxidized rhizoshperes), which were 7.5YR4/6 and 7.5YR5/8. Three soils had depletions of varying abundance: N5/ and 10YR5/1.

Sixty percent of the Fausse B horizons had a matrix chroma of 1 or less. The most frequent matrix colors were 10YR5/1 and 10YR4/2. All B horizons except one had common to many redoximorphic concentrations. The most frequent concentration color was 7.5YR4/6, which together with 7.5YR5/8, 5YR4/6, and 7.5YR4/4 comprised 89 % of the concentrations. Seventy percent of the horizons also had depletions which were mostly common to many. Sixty-seven percent of these depletions were 10YR5/1 and N5/. All the B horizons of the pits and detailed auger holes had pore and root linings (7.5YR4/6 and 5/8, and 5YR4/6). Two horizons had root linings with the reduced color N5/.

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The Sharkey clay, frequently flooded and occasionally flooded map units in Avoyelles and Concordia parishes included some soils with overlying Red River alluvium. The matrices of the A horizons of these soils had hues of 5YR or 7.5YR. The most frequent matrix colors were 5YR3/2 and 5YR4/3. Other matrix colors occurring more than once were 7.5YR3/2, 7.5YR4/2, and 5YR3/3. Less than half of the A horizons had redoximorphic concentrations, which were mostly common 5YR 4/3 and 5YR4/6, along with 7.5YR5/8 and 7.5 YR4/6. Only five of the 16 A horizons had redoximorphic depletions, which were 5YR4/2, with 7.5YR5/2 and 7.5YR4/1 also represented.

The red-colored surface Sharkey clay mapping unit soils included 15 transitional horizons, either AB or BA. The colors 5YR3/3 and 5YR4/3 together comprised 73 % of the matrix colors found. Some matrix colors having a value of four and chromas of 2 or 1 were also described. More than half of the transitional horizons had redoximorphic concentrations, with common 5YR4/3 and 5YR4/4 represented most, and 7.5YR and 5YR4/6 also occurring. A third of the horizons had depletions, with 5YR4/2 occurring in four of the five horizons with depletions.

Of the 54 B horizons that occurred in the red-colored Sharkey clay mapping unit soils, 80 % of the matrix colors were 5YR4/3, 5YR4/4, or 5YR3/3. Lower B horizons often had matrix colors with lower chromas, such as 2.5Y5/1, 5YR4/2, 10YR4/1, and 5YR4/1. About half of the horizons had common to many redoximorphic concentrations, of which 85 % were 7.5YR5/8, 5YR4/4, 7.5YR4/6, or 5YR4/3. Redoximorphic depletions occurred in 57 % of the B horizons. The most

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prevalent depletion colors were 5YR4/2 and 7.5YR5/1. Other frequent depletions were 5YR4/1 and 7.5YR4/2. The pit profiles included two horizons with pore linings with reduced colors.

The red-colored soils in the Fausse clay mapping unit had a variable matrix color in the A horizons. Colors occurring were: 5YR3/2, 7.5YR3/2, 10YR3/2, 5YR3/3, 5YR4/2, and 5YR4/3. Half of the A horizons had redoximorphic concentrations, which included 7.5YR4/6, 5YR4/3, 5YR4/4, 5YR3/3, 7.5YR4/3, and 5YR5/8. Half of the horizons had depletions, which were 7.5YR4/1, 10YR5/1 and 4/1, and 5YR4/2. One horizon also had pore and root linings of 5YR4/1.

The transitional horizons of the red-colored Fausse clay map unit soils had matrix colors of 5YR4/3, 3/3, and 3/4, as well as 7.5YR4/3. Five of the 7 horizons had commonly abundant redoximorphic concentrations, of which 7.5YR4/4 and 5YR 4/4 were most common. Five horizons also had mainly common depletions, which were 7.5YR4/1, 5/1 and 4/2, and 5YR4/1, 5/1 and 4/2.

The B horizons of the red-colored Fausse map unit soils showed many matrix colors, but about half the horizons had 5YR4/3. Other matrix colors included 5YR 3/3, 7.5YR4/2, and 7.5YR4/3. Lower B horizons sometimes had lower chroma matrix colors such as 10YR4/1 and 4/2, and 7.5YR5/1. Sixty-one percent of the B horizons showed redoximorphic concentrations. More than 75 % of these were 5YR 4/4, 5YR4/6, 7.5YR5/8, and 7.5YR4/4. Many (81 %) of the horizons had common redoximorphic depletions, of which the most common were: 5YR4/2, 5YR4/1,

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5YR5/1, 7.5YR4/2, and 7.5YR5/1. The profiles from pits showed frequent pore and root linings of 7.5YR5/1 and 4/1, and 5YR5/1 and 4/1.

Field Indicators

Table 25 shows NRCS (1996) hydric soil indicators present in the detailed profiles adjacent to hydrology monitoring plots (Chapter 5). Depleted Matrix (F3) (NRCS 1996) hydric soil field indicator was found in all the Sharkey soils which had detailed pit profile descriptions. Four of the 7 Sharkey soils had Delta Ochric (F11) present. Delta Vertic (TF11), a testing indicator, was also present for four of the Sharkey pedons, and all were on Red River WMA, on Saucier's (1994) Mississippi River Meander Belt 3 geomorphic unit. The Three Rivers WMA Sharkeys either had 10YR 4/2 matrix colors, or did not have prominent concentrations and did not make TF11. The three Fausse profiles all had Depleted Matrix (F3), Depleted Ochric (F11), and the proposed Delta Vertic (TF11). The only indicator the red-colored Sharkey map unit soils had was TF2 (Red Parent Material), a testing indicator. All three of the red-colored Sharkeys met this indicator, but only two of the four red-colored soils in the Fausse map units had this indicator present. The only reason RR-F-2 and GL-F-2 did not meet the indicator was that these two soils had a matrix value of 3, instead of the required value of 4 or above. The two soils would have made the original TF2, which did not stipulate a value of 4.

Vertic Morphology

Most of the soils in the Sharkey clay mapping units on both the Mississippi and Red River alluvium displayed vertic morphology, such as slickensides, pressure

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Table 25. Presence (X) of field indicators of hydric soils (NRCS 1996) present for detailed soil morphology profiles adjacent to hydric soil instrumentation.

	Field Indicators of Hydric Soils				
Profile	F3 Depleted Matrix	F11 Delta Ochric	F4 Depleted Below Dark Surface	TF11 Delta Vertic	TF2 Red Parent Material
Sharkey					
TR[1]-SF[2]-5[3]	X				
TR-SO-1	X	X			
TR-SF-1	X		X		
RR-SF-5	X	X		X	
RR-SO-3	X	X		X	
RR-SO-2	X	X		X	
RR-SO-5	X			X	X
Fausse					
TR-F-3	X	X		X	
TR-F-4	X	X			
SB-F-2	X	X		X	
Red-colored Sharkey					
GL-SO-3					X
GL-SF-4					X
RR-SF-4					X
Red-colored Fausse					
RR-F-1					X
RR-F-2					
RR-F-4					X
GL-F-2					

[1]TR=Three Rivers WMA, RR=Red River WMA, SB=Spring Bayou WMA, GL=Grassy Lake WMA.
[2]SO=Sharkey clay, occasionally flooded; SF=Sharkey clay, frequently flooded; F=Fausse clay (most flooded)
[3]Plot identification

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faces, and strong angular blocky structure (wedge-shaped peds). Most of these features were described in Bss or Bssg horizons. The BC or BCg horizons often had a smaller expression of these features. The surfaces cracked in September and October. The red-colored Sharkey map unit soils often had thin horizons of silty clay loam between higher clay Bss horizons, and the horizon would be in cracks or between slickensides. The wetter Fausse mapping unit soils in the Mississippi River alluvium had more variation in soil morphology. Many profiles lacked cracks, slickensides, and pressure faces, and were Inceptisols. TR-F-3, however had slickensides and Bssg horizons. The red-colored soils in the Fausse map units also displayed cracks, strong angular blocky structure, slickensides, and pressure faces when described in the summer after drying.

Physical and Chemical Properties

Plot Soil Samples

Texture and chemical data for the surface horizons of Sharkey clay and Fausse clay mapping unit soils, and the red colored soils in those map units are shown in Table 26. The Sharkey clay surface horizons showed a greater mean clay content (73.0 %) than that of the Fausse clay (60.6 %) and the red-colored soils within Sharkey clay mapping units (62.4 %). The Sharkey surfaces also had significantly lower silt contents (25.5 %) versus the the Fausse (36.8 %) and the red-colored Sharkey counterparts (35.2 %). The Fausse surface horizons contained a higher percentage of organic matter (4.0 %) than the Sharkey surfaces (2.6 %). The red colored Sharkey and Fausse map unit soils were intermediate in organic matter

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Table 26. Surface horizon texture and chemical properties. Results of a one way ANOVA by soil mapping unit (Sharkey clay, Fausse clay, and red-colored inclusions in those mapping units).

		Mean Value by Soil Type				
Property	n	Sharkey 17	Fausse 12	Red Sharkey 14	Red Fausse 9	p-value
clay, %		73.0 a[1]	60.6 b	62.4 b	66.0 ab	0.0055
sand, %		1.5[2]	2.6	2.3	1.0	0.0714
silt, %		25.5 b	36.8 a	35.2 a	33.0 ab	0.0144
organic matter, %		2.6 b	4.0 a	3.6 ab	2.9 ab	0.0340
pH, 1:1		5.4 b	5.2 b	6.0 a	6.1 a	0.0015
P, mg/kg		163.6	208.8	164.3	220.0	0.0637
Ca, cmol(+)/kg		24.9	22.5	26.0	24.7	0.1978
Mg, cmol(+)/kg		9.9	10.9	9.9	9.4	0.3222
Na, cmol(+)/kg		0.2 b	0.3 a	0.2 b	0.2 b	0.0031
K, cmol(+)/kg		1.0 a	1.0 a	0.7 b	0.9 a	0.0090
Exchangeable Acidity, cmol(+)/kg		0.5 b	1.2 a	0.2 b	0.3 b	0.0137
Sum of Bases, cmol(+)/kg		35.9	34.7	36.9	35.0	0.6369
ECEC, cmol(+)/kg		36.8	35.7	37.2	35.2	0.7474
Base Saturation, %		98.6 a	96.7 b	99.3 a	99.2 a	0.0278
Ca/Mg		2.6	2.2	2.6	2.7	0.1163

[1]Mean values with same letter within row are not significantly different at α=0.05 level, by Duncan's Multiple Range Test.
[2]Mean values with no letters within same row are not significantly different at α=0.05 level

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content. The mean pH for the Sharkey (5.4) and Fausse (5.2) surface horizons was significantly lower than that for their red-colored counterparts (6.0 for red-colored Sharkey and 6.1 for red-colored Fausse). Available phosphorus values for all the soils were high, and mean P values ranged from 163.6 to 220.0 mg/kg. Exchangeable calcium values for all four soil groups were very similar, and means ranged from 22.5 to 26.0 cmol(+)/kg. The four groups also had very similar exchangeable Mg contents ranging from 9.91 to 10.88 cmol(+)/kg. Fausse clay map unit soil surfaces had significantly higher exchangeable Na content (0.3 cmol(+)/kg) than the other three soil groups. The red-colored Sharkey mapping unit soil surfaces had lower exchangeable K values (0.7 cmol(+)/kg) than those of the Sharkey, Fausse, and red-colored Fausse mapping units, which ranged from 0.9 to 1.0 cmol(+)/kg. The Fausse surface horizons had significantly higher exchangeable acidity (1.2 cmol(+)/kg) than the other three groups (0.2 - 0.5 cmol(+)/kg). The surface soils had a narrow range of mean effective cation exchange capacity (ECEC), as four soil groups had ECEC values ranging from only 35.2 to 36.9 cmol(+)/kg. The Fausse surface horizons had a significantly lower base saturation (on an ECEC basis) percentage (96.7) than the other three soil groups, which were 98.6 % or greater. The Ca/Mg ratio was not significant among the soil map unit-alluvium groups, and ranged from 2.2 to 2.7.

Table 27 shows the particle size and chemical characteristics of the control sections of the 45 auger holes sampled, grouped by soil mapping unit. The control section values are a weighted (by horizon thickness) average of all horizons within

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Table 27. Control section (25-100 cm) texture and chemical properties. Results of a one way ANOVA by soil mapping unit (Sharkey clay, Fausse clay, and red-colored inclusions in those mapping units).

	Mean Value by Soil Type				
Property n	Sharkey 15	Fausse 9	Red Sharkey 13	Red Fausse 7	p-value
clay, %	73.0 a[1]	73.1 a	58.3 b	63.1 b	0.0009
sand, %	0.9[2]	1.1	1.2	0.4	0.5562
silt, %	26.2 b	25.8 b	40.5 a	36.5 a	0.0006
organic matter, %	1.0 b	1.4 a	1.0 b	1.2 ab	0.0167
pH, 1:1	6.2 b	6.5 b	7.4 a	7.2 a	0.0001
P, mg/kg	197.1	195.2	227.0	239.1	0.3147
Ca, cmol(+)/kg	26.8	26.1	26.8	27.4	0.9262
Mg, cmol(+)/kg	11.0 a	12.3 a	7.4 b	8.7 b	0.0001
Na, cmol(+)/kg	0.6	0.5	0.4	0.4	0.1595
K, cmol(+)/kg	0.7 ab	0.8 a	0.5 c	0.6 b	0.0001
Exchangeable Acidity, cmol(+)/kg	0.2	0.2	0.0	0.1	0.1927
Sum of Bases, cmol(+)/kg	39.1	39.7	35.1	37.0	0.0531
ECEC, cmol(+)/kg	39.3	39.8	36.2	37.1	0.0860
Base Saturation, %	99.5	99.5	100.00	99.8	0.2407
Ca/Mg	2.5 b	2.2 b	3.8 a	3.2 a	0.0001

[1]Mean values with same letter within row are not significantly different at α=0.05 level, by Duncan's Multiple Range Test.

[2]Mean values with no letters within same row are not significantly different at α=0.05 level.

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the 25 to 100 cm soil depth. The Sharkey (73.0 % clay) and Fausse soils (73.1 % clay) developed from Mississippi River alluvium had significantly higher clay content than their red-colored counterparts (58.3 % for red-colored Sharkey and 63.1 % for red-colored Fausse) developed from Red River alluvium. The sand fraction of each group was 1.2 % or lower. Silt contents for the red-colored Sharkey (40.5 %) and Fausse (36.5 %) mapping unit control sections were significantly higher than those of the Sharkey (26.2 %) and Fausse (25.8 %) counterparts developed in Mississippi River alluvium. The Fausse control sections had a higher mean organic matter content (1.4 %) than soils in both Sharkey (1.0 %) and red-colored Sharkey (1.0 %) mapping units. The red-colored Fausse soils had an intermediate mean organic matter content. The mean pH of the red-colored Sharkey (7.4) and Fausse (7.2) control sections was higher than that of the Sharkey (6.2) and Fausse (6.5) mapping units. As in the surface soils, available phosphorus was not significantly different between groups, and ranged from 195.2 to 239.1 mg/kg. Exchangeable Ca content was similar across all groups, and means ranged from 26.1 to 27.4 cmol(+)/kg. The Sharkey clay and Fausse clay mapping unit soils derived from Mississippi River alluvium, however, had significantly higher mean control section exchangeable Mg contents (11.0 and 12.3 cmol(+)/kg) than the Sharkey and Fausse soils derived from Red River alluvium (7.4 and 8.7 cmol(+)/kg). This resulted in significantly higher mean Ca/Mg ratios for the red-colored Sharkey and Fausse soils. The Fausse clay mapping unit control sections had the highest mean exchangeable K amount (0.8 cmol(+)/kg) and the red-colored Sharkey clay mapping unit had the lowest mean K

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content at 0.5 cmol(+)/kg. None of the groups had much exchangeable acidity in the control sections, as they ranged from mean values of 0.0 to 0.2 cmol(+)/kg. The control sections of all the groups had similar mean ECEC's falling in a range of 36.2 to 39.8 cmol(+)/kg. The control section percent base saturation of all groups was very high, with a range of means from 99.5 to 100.0 %.

Profiles From Pits

Twelve soil pits provided additional opportunities for sampling and analysis. Particle size and bulk density results for profiles described in pits are shown in Table 28. Chemical characterization data are reported in Tables 29 and 30. TR-SF-5, TR-SF-1, and TR-SO-1 were sampled in Sharkey clay mapping units in Three Rivers WMA. Each was characterized by very-fine texture in the surface and control sections, and slickensides in the B horizons. Organic matter only dropped to 0.7 or 0.8 percent in the lowest horizons sampled. The pH of the profiles ranged from 5.5 to 5.8 for the surface horizons, and declined to 4.9 to 5.5 in the first Bss horizon, before increasing to 6.8 to 7.3 in the lower Bss horizons and BCg and Cg horizons. Although KCl-exchangeable acidity was rather low in the upper horizons, A, AB/BA, and Bss1/Bssg1 horizons (0.4 to 1.8 cmol(+)/kg) the $BaCl_2$ TEA acidity for the same horizons ranged from 13.2 to 19.2 cmol(+)/kg. The lower horizons had little or no KCl exchangeable acidity, and $BaCl_2$ acidity was also mostly lower than the upper horizons, ranging from 7.8 to 15.0 cmol(+)/kg. The cation exchange capacity by sum (CEC) ranged from 44.9 to 59.9 cmol(+)/kg. Base saturation (by sum CEC) percentages were 66.5 to 72.5 % in the upper horizons, and increased to 75.0 to 82.7

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Table 28. Texture, bulk density, and Coefficient of Linear Extension (COLE) of pit profiles for Sharkey clay and Fausse clay soil mapping units.

Horizon	Depth	Clay	Silt	Sand	Texture Class	Bulk Density field moist	air dry	oven dry	COLE
	(cm)	--------(%)--------				-------(g/cm^3)-------			
TR[1]-SF[2]-5[3]									
A	0-7	75.3	23.5	1.2	clay				
BA	7-21	69.8	29.2	1.0	clay				
Bss1	21-48	70.0	29.5	0.5	clay				
Bss2	48-71	70.1	29.6	0.3	clay				
Bss3	71-100	87.7	11.9	0.4	clay				
Bss4	100-114	87.9	11.7	0.4	clay				
TR-SF-1									
A	0-8	75.3	23.5	1.2	clay	1.2	1.8	1.8	0.14
AB	8-19	80.6	18.8	0.6	clay	1.3	1.8	1.9	0.13
Bssg1	19-40	75.8	23.6	0.6	clay	1.2	1.8	1.8	0.14
Bssg2	40-63	87.8	11.9	0.3	clay	1.2	1.8	1.8	0.15
Bssg3	63-90	88.2	11.2	0.6	clay	1.2	1.8	1.9	0.16
BCg	90-125	87.5	12.1	0.4	clay	1.2	1.8	1.8	0.15
TR-SO-1									
A	0-6	69.7	27.8	2.5	clay	0.9	1.4	1.6	0.19
AB	6-15	64.2	34.6	1.2	clay	1.2	1.7	1.8	0.15
Bssg1	15-37	69.7	29.8	0.5	clay	1.2	1.8	1.8	0.14
Bssg2	37-63	75.5	24.0	0.5	clay	1.3	1.8	1.8	0.12
BC1	63-90	75.8	23.7	0.5	clay	1.3	1.8	1.8	0.13
BC2	90-110	65.1	34.6	0.3	clay				
Cg	110-120	70.3	28.4	1.3	clay				
RR-SF-5									
A	0-7	78.6	20.2	1.2	clay				
BA	7-21	76.2	22.9	0.9	clay				
Bssg1	21-43	76.4	22.8	0.8	clay				
Bssg2	43-74	64.8	34.2	1.0	clay				
Bssg3	74-121	76.5	22.6	0.9	clay				
BCg	121-150	82.5	16.9	0.6	clay				

[1]TR=Three Rivers WMA, RR=Red River WMA, GL=Grassy Lake WMA, SB=Spring Bayou WMA
[2]SO=Sharkey clay, occasionally flooded; SF=Sharkey clay, frequently flooded; F=Fausse clay
[3]Plot identification number

table con'd.

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Horizon	Depth	Clay	Silt	Sand	Texture Class	Bulk Density field moist	air dry	oven dry	COLE
	(cm)	---------(%)---------				-------(g/cm^3)-------			
TR[1]-F[2]-4[3]									
Ag	0-12	33.9	65.3	0.8	silty clay loam				
Bg1	12-25	51.5	48.0	0.5	silty clay				
Bg2	25-32	61.0	38.0	1.0	clay				
Bg3	32-45	31.1	66.6	2.3	silty clay loam				
Bssg1	45-70	36.6	62.8	0.6	silty clay loam				
Bssg2	70-90	48.0	51.5	0.5	silty clay				
Bssg3	90-110	70.8	28.9	0.3	clay				
TR-F-3									
A	0-10	63.0	35.8	1.2	clay				
BAg	10-20	51.9	48.1	1.3	silty clay				
Bssg1	20-50	63.1	36.6	0.3	clay				
Bssg2	50-80	74.0	25.7	0.3	clay				
Bssg2	80-105	74.0	25.4	0.6	clay				
BCg	105-120	62.8	35.2	2.0	clay				
Cg	120-140	62.6	36.3	1.1	clay				
SB-F-2									
A	0-6	71.5	25.5	3.0	clay				
BA	6-18	82.1	16.4	1.5	clay				
Bg	18-29	76.7	22.3	1.0	clay				
2Bg1	29-50	82.0	17.3	0.7	clay				
2Bg2	50-70	93.2	6.3	0.5	clay				
3C	70-100	87.6	12.0	0.4	clay				

[1]TR=Three Rivers WMA, RR=Red River WMA, GL=Grassy Lake WMA, SB=Spring Bayou WMA

[2]SO=Sharkey clay, occasionally flooded; SF=Sharkey clay, frequently flooded; F=Fausse clay

[3]Plot identification number

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Horizon	Depth	Clay	Silt	Sand	Texture Class	Bulk Density field moist	air dry	oven dry	COLE
	(cm)	--------(%)--------				-------(g/cm^3)-------			
RR[1]-F[2]-4[3]									
A	0-7	58.4	41.0	0.6	silty clay				
BA	7-22	53.0	46.7	0.3	silty clay				
Bss1	22-38	58.5	41.2	0.3	silty clay				
Bss2	38-74	58.1	41.6	0.3	silty clay				
Bss3	74-100	52.4	47.3	0.3	silty clay				
BCg1	100-140	47.5	52.2	0.3	silty clay				
BCg2	140-150	53.0	46.5	0.5	silty clay				
RR-F-1									
A	0-3	64.3	34.1	1.6	clay				
BA	3-21	53.1	46.5	0.4	silty clay				
Bss1	21-38	69.7	30.1	0.2	clay				
Bss2	38-54	69.7	30.0	0.3	clay				
Bssg1	54-96	61.4	38.3	0.3	clay				
Bssg2	96-150	64.4	32.4	3.2	clay				
GL-SO-3									
A	0-5	52.9	45.0	2.1	silty clay	1.3	1.6	1.8	0.12
AB	5-15	58.0	41.6	0.4	silty clay	1.4	1.8	1.9	0.09
Bss1	15-29	57.9	41.9	0.2	silty clay	1.4	1.8	1.9	0.09
Bw1	29-41	41.7	57.7	0.6	silty clay	1.4	1.7	1.7	0.05
Bw2	41-50	58.4	41.3	0.3	silty clay	1.4	1.7	1.8	0.07
Bss2	50-80	47.4	52.0	0.6	silty clay	1.5	1.7	1.8	0.07
BCg1	80-92	47.1	51.1	1.8	silty clay	1.4	1.7	1.8	0.09
BCg2	92-104	58.2	40.2	1.6	silty clay	1.3	1.7	1.7	0.10

[1]TR=Three Rivers WMA, RR=Red River WMA, GL=Grassy Lake WMA, SB=Spring Bayou WMA

[2]SO=Sharkey clay, occasionally flooded; SF=Sharkey clay, frequently flooded; F=Fausse clay

[3]Plot identification number

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Horizon	Depth	Clay	Silt	Sand	Texture Class	Bulk Density field moist	Bulk Density air dry	Bulk Density oven dry	COLE
	(cm)	---------(%)---------				-------(g/cm^3)-------			
GL[1]-SF[2]-4[3]									
A	0-8	68.6	29.1	2.3	clay				
BA	8-25	63.2	36.1	0.7	clay				
Bss1	25-40	63.2	36.3	0.5	clay				
Bss2	40-52	68.9	30.7	0.4	clay				
Bss3	52-75	57.6	42.0	0.4	silty clay				
Bss4	75-88	74.4	24.5	1.1	clay				
BC	88-108	74.9	24.5	0.6	clay				
Cg	108-	80.5	18.6	0.9	clay				
GL-F-2									
A	0-9	81.0	17.6	1.4	clay				
BA	9-18	70.0	29.5	0.5	clay				
Bss1	18-43	58.5	41.3	0.2	silty clay				
Bss2	43-74	63.8	35.7	0.5	clay				
Bss3	74-91	53.1	46.6	0.3	silty clay				
BCg1	91-116	70.2	29.4	0.4	clay				
BCg2	116-150	76.3	23.3	0.4	clay				

[1]TR=Three Rivers WMA, RR=Red River WMA, GL=Grassy Lake WMA, SB=Spring Bayou WMA

[2]SO=Sharkey clay, occasionally flooded; SF=Sharkey clay, frequently flooded; F=Fausse clay

[3]Plot identification number

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Table 29. Selected chemical characteristics for soil profiles from pits within Sharkey clay and Fausse clay soil mapping units.

Horizon	Depth	OM	Available P	pH	Ca	Mg	Na	K	H	Al	Extractable Acidity	Effective CEC	Sum CEC	Base Saturation	Ca/Mg	CCE
	(cm)	(%)	(mg/kg)	(1:1)	(cmol(+)/kg)									(%)	(%)	(%)
TR-SF-5 (Three Rivers WMA, Sharkey clay, frequently flooded)																
A	0-7	2.2	147	5.8	22.8	7.1	0.1	1.0	0.2	0.2	14.4	31.4	45.4	68.3	3.2	-
BA	7-21	1.3	173	5.5	23.9	8.8	0.1	0.9	0.2	0.2	13.8	34.0	47.4	70.9	2.7	-
Bss1	21-48	1.1	234	5.2	23.8	10.3	0.2	0.8	0.1	0.4	16.2	35.7	51.4	68.5	2.3	-
Bss2	48-71	0.9	327	5.9	26.7	11.2	0.4	0.8	0.2	0.0	11.4	39.3	50.5	77.4	2.4	-
Bss3	71-100	0.9	190	6.8	29.3	11.2	0.7	0.8	0.0	0.0	9.6	42.0	51.6	81.4	2.6	-
Bss4	100-114	0.8	166	6.9	33.4	12.5	0.8	0.8	0.0	0.0	10.2	47.6	57.8	82.4	2.7	-
TR-SF-1 (Three Rivers WMA, Sharkey clay, frequently flooded)																
A	0-8	2.7	113	5.5	22.0	9.2	0.2	0.8	0.2	0.2	16.2	32.6	48.4	66.5	2.4	-
AB	8-19	1.6	155	5.5	22.5	10.0	0.3	0.8	0.2	0.2	16.2	33.9	49.7	67.4	2.3	-
Bssg1	19-40	1.2	141	4.9	23.9	11.2	0.4	0.8	0.4	1.4	19.2	38.2	55.6	65.5	2.1	-
Bssg2	40-63	1.0	153	5.5	30.4	12.9	0.7	0.9	0.4	0.0	15.0	45.3	59.9	75.0	2.4	-
Bssg3	63-90	0.8	189	6.6	32.8	12.5	1.0	0.9	0.0	0.0	12.0	47.3	59.3	79.8	2.6	-
BCg	90-125	0.7	188	6.8	32.0	12.2	1.1	0.8	0.0	0.0	10.8	46.2	57.0	81.1	2.6	-
TR-SO-1 (Three Rivers WMA, Sharkey clay, occasionally flooded)																
A	0-6	4.3	213	5.8	28.6	8.2	0.1	1.0	0.2	0.0	14.4	38.1	52.3	72.5	3.5	-
AB	6-15	1.7	214	5.6	22.8	7.4	0.1	0.8	0.4	0.0	13.8	31.5	44.9	69.3	3.1	-
Bssg1	15-37	1.1	214	5.5	23.4	9.2	0.2	0.7	0.2	0.2	13.2	33.9	46.7	71.1	2.5	-
Bssg2	37-63	0.7	308	6.1	25.9	10.4	0.2	0.7	0.0	0.0	7.8	37.2	45.0	82.7	2.5	-
BC1	63-90	0.9	312	6.3	26.1	10.3	0.2	0.7	0.0	0.0	7.8	37.4	45.2	82.7	2.5	-
BC2	90-110	1.2	347	7.3	24.1	9.2	0.4	0.6	0.0	0.0		34.2			2.6	-
Cg	110-120	1.9	319	7.3	26.0	9.2	0.4	0.6	0.0	0.0		36.2			2.8	-

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Horizon	Depth	Available OM	Available P	pH	Exchangeable Ca	Exchangeable Mg	Exchangeable Na	Exchangeable K	Exchangeable H	Exchangeable Al	Extractable Acidity	Effective CEC	Sum CEC	Base Saturation	Ca/Mg	CCE
	(cm)	(%)	(mg/kg)	(1:1)	(cmol(+)/kg)									(%)	(%)	(%)
RR-SF-5 (Red River WMA, Sharkey clay, frequently flooded)																
A	0-7	2.2	104	5.0	24.8	11.4	0.2	1.0	0.3	0.5	17.5	38.3	54.9	68.3	2.2	-
BA	7-21	1.5	95	4.6	25.3	11.8	0.4	0.9	2.0	0.2	19.5	40.6	57.9	66.3	2.2	-
Bssg1	21-43	0.9	89	5.7	35.5	13.8	0.6	1.0	0.0	0.2	13.5	50.3	64.5	79.0	2.6	-
Bssg2	43-74	0.6	142	6.9	33.2	11.9	0.9	0.8	0.0	0.0	9.5	46.9	56.4	83.2	2.8	-
Bssg3	74-121	0.6	107	7.3	37.9	13.7	1.2	0.8	0.0	0.0	9.8	53.6	63.4	84.5	2.8	-
BCg	121-150	0.4	65	7.4	38.4	14.1	1.3	0.9	0.0	0.0	10.0	54.7	64.7	84.5	2.7	-
TR-F-4 (Three Rivers WMA, Fausse clay)																
Ag	0-12	1.6	216	5.9	16.5	7.0	0.2	0.6	0.1	0.0	9.5	24.4	33.8	71.9	2.3	-
Bg1	12-25	1.2	215	7.3	21.7	8.3	0.4	0.7	0.0	0.0	7.2	31.1	38.3	81.2	2.6	-
Bg2	25-32	0.9	269	7.6	26.3	10.0	0.4	1.0	0.0	0.0	5.7	37.6	43.3	86.8	2.6	3.9
Bg3	32-45	0.8	278	7.7	16.9	5.9	0.2	0.5	0.0	0.0	3.7	23.6	27.3	86.4	2.9	2.6
Bssg1	45-70	0.8	302	7.7	21.2	6.2	0.2	0.7	0.0	0.0	4.9	28.2	33.1	85.2	3.4	3.0
Bssg2	70-90	0.9	255	7.4	24.7	8.1	0.3	0.8	0.0	0.0	6.9	33.9	40.8	83.1	3.0	1.8
Bssg3	90-110	0.7	224	7.5	29.9	10.4	0.4	1.0	0.0	0.0	9.5	41.7	51.2	81.4	2.9	1.7

table con'd.

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Horizon	Depth	OM	Available P	pH	Exchangeable Ca	Exchangeable Mg	Exchangeable Na	Exchangeable K	Exchangeable H	Exchangeable Al	Extractable Acidity	Effective CEC	Sum CEC	Base Saturation	Ca/Mg	CCE
	(cm)	(%)	(mg/kg)	(1:1)	(cmol(+)/kg)									(%)	(%)	(%)
TR-F-3 (Three Rivers WMA, Fausse clay)																
A	0-10	1.2	194	6.1	25.6	10.5	0.3	1.1	0.0	0.0	12.6	37.5	50.1	74.9	2.4	-
BAg	10-20	0.7	335	7.2	23.0	10.0	0.2	0.9	0.0	0.0	10.0	34.2	44.2	77.4	2.3	-
Bssg1	20-50	0.5	266	7.4	27.3	11.3	0.3	1.0	0.0	0.0	11.5	39.9	51.4	77.6	2.4	-
Bssg2	50-80	0.7	216	7.4	33.1	13.0	0.4	1.2	0.0	0.0	11.8	47.7	59.5	80.2	2.5	-
Bssg3	80-105	0.6	223	7.7	33.2	11.9	0.5	1.1	0.0	0.0	10.9	46.7	57.6	81.1	2.8	1.8
BCg	105-120	0.7	288	7.8	30.7	10.3	0.5	1.1	0.0	0.0	9.8	42.5	52.3	81.3	3.0	1.5
Cg	120-140	0.7	330	7.9	30.7	10.3	0.5	1.1	0.0	0.0	9.5	42.7	52.2	81.8	3.0	1.9
SB-F-2 (Spring Bayou WMA, Fausse clay)																
A	0-6	4.9	103	4.8	20.3	13.4	0.3	1.4	0.7	0.8	28.1	36.8	63.4	55.7	1.5	-
BA	6-18	3.2	106	4.8	22.5	17.5	0.3	1.5	0.5	0.8	23.0	43.0	64.8	64.4	1.3	-
Bg	18-29	1.4	116	5.1	18.3	13.5	0.2	0.9	0.1	0.4	18.1	33.5	51.1	64.6	1.4	-
2Bg1	29-50	1.6	102	5.9	22.2	13.9	0.4	0.8	0.1	0.0	14.4	37.4	51.7	72.1	1.6	-
2Bg2	50-70	0.8	63	7.1	28.6	15.9	0.8	0.8	0.0	0.0	9.8	46.1	55.9	82.5	1.8	-
3C	70-100	0.8	115	7.0	28.1	15.0	0.7	0.9	0.0	0.0	9.8	44.6	54.4	82.0	1.9	-

table con'd.

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Horizon	Depth	OM	Available P	pH	Ca	Mg	Na	K	H	Al	Extractable Acidity	Effective CEC	Sum CEC	Base Saturation	Ca/Mg	CCE
	(cm)	(%)	(mg/kg)	(1:1)	(cmol(+)/kg)									(%)	(%)	(%)
RR-F-4 (Red River WMA, Fausse clay)																
A	0-7	3.1	335	7.5	27.8	6.9	0.1	0.6	0.0	0.0	10.2	35.5	45.7	77.7	4.0	3.8
BA	7-22	1.4	299	7.9	33.6	6.2	0.1	0.6	0.0	0.0	9.6	40.5	50.1	80.1	5.4	4.9
Bss1	22-38	1.3	301	7.9	32.4	7.3	0.2	0.6	0.0	0.0	4.8	40.5	45.3	89.4	4.5	4.5
Bss2	38-74	1.5	300	7.8	24.2	6.8	0.3	0.5	0.0	0.0	5.4	31.8	37.2	85.5	3.6	3.4
Bss3	74-100	1.0	320	7.9	21.8	5.9	0.3	0.4	0.0	0.0	4.8	28.4	33.2	85.5	3.7	4.1
BCg1	100-140	1.3	187	7.7	25.3	7.2	0.4	0.5	0.0	0.0	6.0	33.3	39.3	84.7	3.5	2.9
BCg2	140-150	1.2	226	7.8	24.5	7.7	0.5	0.5	0.0	0.0	6.0	33.2	39.2	84.7	3.2	1.7
RR-F-1 (Red River WMA, Fausse clay)																
A	0-3	3.4	158	5.3	23.7	9.9	0.2	0.8	0.0	0.2	15.8	34.8	50.4	68.7	2.4	-
BA	3-21	1.2	235	6.9	24.9	9.0	0.2	0.7	0.0	0.0	7.2	34.7	41.9	82.8	2.8	-
Bss1	21-38	1.1	212	7.7	32.4	9.2	0.4	0.7	0.0	0.0	5.7	42.7	48.4	88.2	3.5	2.4
Bss2	38-54	1.2	174	7.8	32.8	10.0	0.6	0.7	0.0	0.0	6.0	44.2	50.2	88.0	3.3	2.4
Bssg1	54-96	0.7	130	7.6	26.8	10.5	0.7	0.7	0.0	0.0	6.9	38.7	45.6	84.9	2.6	1.8
Bssg2	96-150	0.6	143	7.5	28.5	11.1	1.4	0.7	0.0	0.0	6.9	41.6	48.5	85.8	2.6	1.6

table con'd.

Horizon	Depth	OM	Available P	pH	Exchangeable Ca	Exchangeable Mg	Exchangeable Na	Exchangeable K	Exchangeable H	Exchangeable Al	Extractable Acidity	Effective CEC	Sum CEC	Base Saturation	Ca/Mg	CCE
	(cm)	(%)	(mg/kg)	(1:1)	(cmol(+)/kg)									(%)	(%)	(%)
GL-SO-3 (Grassy Lake WMA, Sharkey clay, occasionally flooded)																
A	0-5	3.8	191	7.2	26.4	7.3	0.2	0.6	0.0	0.0	6.0	34.5	40.5	85.2	3.6	-
AB	5-15	1.5	216	7.5	26.0	7.2	0.2	0.6	0.0	0.0	1.8	33.9	35.7	95.0	3.6	3.7
Bss1	15-29	1.3	309	7.8	33.5	6.2	0.2	0.5	0.0	0.0	0.6	40.4	41.0	98.5	5.4	-
Bw1	29-41	0.8	287	7.8	22.0	3.4	0.1	0.3	0.0	0.0	0.0	25.8	25.8	100.0	6.5	4.8
Bw2	41-50	1.1	311	7.9	30.5	5.4	0.2	0.4	0.0	0.0	2.4	36.6	39.0	93.8	5.6	4.7
Bss2	50-80	1.0	288	7.8	25.0	5.2	0.2	0.4	0.0	0.0	0.0	30.9	30.9	100.0	4.8	3.0
BCg1	80-92	1.0	274	7.8	21.6	6.0	0.3	0.4	0.0	0.0	0.0	28.3	28.3	100.0	3.6	2.7
BCg2	92-104	1.5	207	7.7	24.9	7.5	0.5	0.5	0.0	0.0	2.4	33.5	35.9	93.3	3.3	2.6
GL-F-2 (Grassy Lake WMA, Fausse clay)																
A	0-9	4.2	207	5.4	22.8	10.1	0.1	0.8	0.2	0.2	13.8	34.2	47.6	71.0	2.3	-
BA	9-18	1.5	257	6.7	24.6	9.9	0.2	0.8	0.0	0.0	6.6	35.4	42.0	84.3	2.5	-
Bss1	18-43	1.2	310	7.5	26.2	8.0	0.2	0.6	0.0	0.0	0.0	35.0	35.0	100.0	3.3	3.1
Bss2	43-74	1.1	304	7.8	32.3	7.8	0.2	0.6	0.0	0.0	1.2	40.9	42.1	97.1	4.1	4.0
Bss3	74-91	1.0	224	7.6	25.2	8.1	0.4	0.6	0.0	0.0	0.6	34.2	34.8	98.3	3.1	2.0
BCg1	91-116	1.2	168	7.5	28.2	9.4	0.6	0.6	0.0	0.0	1.2	38.8	40.0	97.0	3.0	1.7
BCg2	116-150	1.3	148	7.5	34.4	12.7	1.0	0.8	0.0	0.0	4.8	48.8	53.6	91.0	2.7	1.6

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Horizon	Depth	OM	Available P	pH	Ca	Mg	Na	K	H	Al	Extractable Acidity	Effective CEC	Sum CEC	Base Saturation	Ca/Mg	CCE
					------------Exchangeable-----------------											
	(cm)	(%)	(mg/kg)	(1:1)	--------------------------(cmol(+)/kg)--------------------------------									(%)	(%)	(%)
					GL-SF-4 (Grassy Lake WMA, Sharkey clay, frequently flooded)											
A	0-8	3.8	134	5.8	25.0	11.0	0.1	0.9	0.4	0.0	14.6	37.4	51.6	71.7	2.3	-
BA	8-25	1.6	162	6.1	25.3	11.0	0.1	0.9	0.0	0.0	10.9	37.4	48.3	77.4	2.3	-
Bss1	25-40	1.1	205	7.4	34.1	11.5	0.1	0.9	0.0	0.0	7.2	46.7	53.9	86.6	3.0	-
Bss2	40-52	1.0	232	7.7	31.9	9.6	0.2	0.6	0.0	0.0		42.3			3.3	-
Bss3	52-75	1.0	254	7.7	26.1	7.6	0.3	0.5	0.0	0.0	6.0	34.6	40.6	85.2	3.4	2.0
Bss4	75-88	1.0	167	7.7	30.9	10.5	0.7	0.6	0.0	0.0	8.6	42.7	50.7	84.2	2.9	1.8
BC	88-108	1.3	165	7.7	31.1	11.6	1.0	0.6	0.0	0.0	8.6	44.3	52.9	83.7	2.7	1.8
Cg	108-	1.0	174	7.6	31.4	12.4	1.8	0.7	0.0	0.0	8.9	46.2	55.1	83.8	2.5	1.5

Table 30. Dithionite-citrate extractable Fe, Mn, Al and their oxides, for profiles from pits within Sharkey clay and Fausse clay soil mapping units.

Horizon	Depth	Fe	Fe_2O_3	Mn	MnO_2	Al	Al_2O_3
	(cm)	(%)					
TR[1]-SO[2]-1[3]							
A	0-6	1.1	1.6	<0.1	<0.1	0.1	0.2
AB	6-15	1.4	2.0	<0.1	0.1	0.1	0.2
Bssg1	15-37	1.0	1.4	<0.1	0.1	0.1	0.1
Bssg2	37-63	0.9	1.3	<0.1	0.1	0.1	0.1
BC	63-90	1.2	1.8	0.1	0.1	0.1	0.1
TR-SF-1							
A	0-8	1.3	1.9	<0.1	<0.1	0.1	0.2
BA	8-19	1.2	1.7	<0.1	<0.1	0.1	0.2
Bssg1	19-40	1.2	1.7	<0.1	<0.1	0.1	0.2
Bssg2	40-63	1.0	1.5	<0.1	0.1	0.1	0.1
Bssg3	63-90	1.1	1.6	<0.1	0.1	0.1	0.2
BCg	90-125	1.0	1.4	<0.1	<0.1	0.1	0.1
TR-SF-5							
A	0-7	1.3	1.8	<0.1	<0.1	0.1	0.2
BA	7-21	1.4	1.9	0.1	0.1	0.1	0.2
Bss1	21-48	1.0	1.5	<0.1	0.1	0.1	0.2
Bss2	48-71	1.0	1.4	0.1	0.1	0.1	0.1
Bss3	71-100	0.6	0.8	<0.1	<0.1	<0.1	0.1
Bss4	100-114	0.9	1.3	<0.1	<0.1	0.1	0.2
TR-F-3							
Ag	0-10	0.7	1.0	<0.1	<0.1	<0.1	0.1
BAg	10-20	0.8	1.2	<0.1	0.1	<0.1	0.1
Bssg1	20-50	0.8	1.2	<0.1	0.1	<0.1	0.1
Bssg2	50-80	0.8	1.1	<0.1	<0.1	0.1	0.1
Bssg3	80-105	0.8	1.1	<0.1	<0.1	<0.1	0.1
BCg	105-120	0.6	0.9	<0.1	<0.1	<0.1	0.1
Cg	120-140	0.6	0.8	<0.1	<0.1	<0.1	<0.1

[1]TR=Three Rivers WMA, RR=Red River WMA, SB=Spring Bayou WMA, GL=Grassy Lake WMA

[2]SO=Sharkey clay, occasionally flooded, SF=Sharkey clay, frequently flooded, F= Fausse clay

[3]Plot identification number

table con'd.

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Horizon	Depth	Fe	Fe_2O_3	Mn	MnO_2	Al	Al_2O_3
	(cm)			-(%)-			
RR[1]-SF[2]-5[3]							
A	0-7	0.5	0.8	<0.1	<0.1	0.1	0.2
BA	7-21	0.6	0.8	0.0	<0.1	0.1	0.2
Bssg1	21-43	0.7	1.0	<0.1	<0.1	0.1	0.1
Bssg2	43-74	0.8	1.2	<0.1	0.1	0.1	0.1
Bssg3	74-121	0.7	1.0	<0.1	0.1	0.1	0.1
BCg	121-150	0.8	1.1	<0.1	<0.1	0.1	0.1
RR-F-4							
A	0-7	1.1	1.5	<0.1	<0.1	0.1	0.1
BA	7-22	1.3	1.8	0.1	0.1	0.1	0.1
Bss1	22-38	1.1	1.6	<0.1	<0.1	0.1	0.1
Bss2	38-74	1.3	1.9	<0.1	0.1	0.1	0.1
Bss3	74-100	0.5	0.7	<0.1	<0.1	0.1	0.1
BCg1	100-140	0.4	0.6	<0.1	<0.1	<0.1	0.1
BCg2	140-150	0.6	0.8	<0.1	<0.1	<0.1	0.1
RR-F-1							
A	0-3	1.0	1.5	<0.1	<0.1	0.1	0.2
BA	3-21	1.1	1.5	<0.1	0.1	0.1	0.1
Bss1	21-38	0.9	1.2	<0.1	<0.1	0.1	0.1
Bss2	38-54	0.5	0.7	<0.1	<0.1	<0.1	<0.1
Bssg1	54-96	1.3	1.9	<0.1	<0.1	0.1	0.2
Bssg2	96-150	0.8	1.2	<0.1	<0.1	<0.1	0.1

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Horizon	Depth	Fe	Fe_2O_3	Mn	MnO_2	Al	Al_2O_3
	(cm)	-------------------------------	-------	-------(%)-------	-------	-------	-------------------------------
SB[1]-F[2]-2[3]							
A	0-6	0.3	0.4	<0.1	<0.1	0.1	0.2
BA	6-18	0.4	0.6	0.0	<0.1	0.1	0.1
Bg	18-29	0.8	1.2	0.0	<0.1	<0.1	0.1
2Bg1	29-50	1.0	1.5	<0.1	<0.1	0.1	0.1
2Bg2	50-70	1.0	1.4	<0.1	<0.1	0.1	0.1
3C	70-100	0.6	0.8	0.0	0.0	<0.1	0.1
GL-SO-3							
A	0-5	1.1	1.6	<0.1	<0.1	0.1	0.1
AB	5-15	1.0	1.4	<0.1	0.1	0.1	0.1
Bss1	15-29	1.0	1.5	0.1	0.1	0.1	0.1
Bw1	29-41	0.7	1.0	<0.1	<0.1	<0.1	0.1
Bw2	41-50	0.9	1.3	<0.1	<0.1	0.1	0.1
Bss2	50-80	0.8	1.2	<0.1	<0.1	<0.1	0.1
BC1	80-92	0.9	1.2	<0.1	0.1	<0.1	0.1
BC2	92-104	0.8	1.1	<0.1	<0.1	<0.1	0.1
GL-SF-4							
A	0-8	1.3	1.9	<0.1	<0.1	0.1	0.2
BA	8-25	1.4	2.0	<0.1	0.1	0.1	0.2
Bss1	25-40	1.3	1.9	<0.1	0.1	0.1	0.2
Bss2	40-52	1.4	1.9	<0.1	0.1	0.1	0.2
Bss3	52-75	1.2	1.6	<0.1	0.1	0.1	0.2
Bss4	75-88	1.2	1.7	<0.1	<0.1	0.1	0.2
BC	88-108	1.3	1.9	<0.1	<0.1	0.1	0.2
Cg	108-	1.4	2.0	<0.1	0.1	0.1	0.2
GL-F-2							
A	0-9	1.0	1.5	0.0	<0.1	0.1	0.2
BA	9-18	1.3	1.8	<0.1	0.1	0.1	0.1
Bss1	18-43	1.2	1.6	0.1	0.1	0.1	0.1
Bss2	43-74	0.9	1.3	<0.1	0.1	<0.1	0.1
Bss3	74-91	0.7	0.9	<0.1	<0.1	0.1	0.1
BCg1	91-116	0.5	0.4	<0.1	<0.1	0.1	0.1
BCg2	116-150	1.0	1.4	<0.1	<0.1	0.1	0.2

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% in lower horizons. The Ca/Mg ratio of all three profiles ranged from 2.3 to 3.5 in the A and transitional horizons, but the values in the control section fell in the range 2.1 to 2.8.

The profile RR-SF-5 was sampled by a pit in a Sharkey clay mapping unit in Red River WMA. Texture was similar to the Three Rivers WMA Sharkey profiles, but the organic matter content declined from 2.2 % for the surface horizon to only 0.4 % in the BCg horizon. Bray 2 P levels, ranging from 65 to 142 mg/kg, were lower than those of the Sharkey clay mapping unit soils in Three Rivers WMA. The pH values of the A (5.0) and BA (4.6) horizons were also lower than that for the same horizons for Sharkey clay mapping unit profiles in Three Rivers WMA. RR-SF-5 also had the highest $BaCl_2$ extractable acidity from the Sharkey profiles, at 19.5 cmol(+)/kg in the BA horizon. The sum CEC in the Bssg1, Bssg3, and BCg horizons were 63.4 to 64.7 cmol(+)/kg. Base saturation percentage and Ca/Mg ratios of RR-SF-5 were similar to the Three Rivers WMA Sharkey clay mapping unit profiles.

The Fausse mapping unit profiles in Mississippi River alluvium were more variable in texture, pH, exchangeable bases, acidity, CEC, and Ca/Mg than were the Sharkey profiles. TR-F-4 was located near the Misssissippi River levee, and had less clay content in most of the upper sampled horizons. Three horizons, the Ag, Bg3, and Bssg1, had clay content from 31.1 to 36.6 %. The Bg1, Bg2, Bssg2, and Bssg3 had between 48 and 70.8 % clay. The organic matter distribution resembled that of the Sharkey profiles, ranging from 1.6 to 0.7 %. The pH of this profile was

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higher than the Sharkey profiles, with 5.9 for the surface horizon and 7.3 to 7.7 in the B horizons. The $BaCl_2$ extractable acidity was lower than that of the Sharkey soils, and ranged from 3.7 to 9.5 cmol(+)/kg. This profile had a calcium carbonate equivalent (CCE) maximum of 3.9 % in the Bg2 horizon, and CCE decreased to 1.7 % in the Bssg3 horizon. The CEC was quite variable, as was the clay content, and ranged from 27.3 to 51.2 cmol(+)/kg. The Ca/Mg ratio was 2.3 at the surface, but increased to a maximum of 3.4 in the Bssg1 horizon.

TR-F-3 was also located in a Fausse clay unit in Three River WMA, but was in an abandoned chute. Although the BAg horizon had only 51.9 % clay, all other horizons had about 63 % or more clay. Organic matter content in the surface horizon was only 1.2 %. Like the TR-F-4 profile, this soil had high P content, ranging from 194 to 335 mg/kg. The pH of the two profiles was also very similar, but extractable acidity values were 9.5 to 12.6 cmol(+)/kg. The sum CEC, base saturation, and Ca/Mg ratio of TR-F-4 were similar to the Sharkey profiles. CCE values of 1.5 to 1.9 % were measured in the lower horizons.

SB-F-2 was sampled in a backswamp area in Spring Bayou WMA, which was near two bodies of water. It was characterized by higher clay content (71.5 to 93.2 %), lower pH, and a higher surface organic matter content (4.9 and 3.2 %) in the A and BA horizons than the other profiles. The available P content was lower than that of the other two Fausse pedons, and ranged from 63 to 116 mg/kg. The pH of the upper horizons was 4.8 to 5.1, and increased to 7.1 lower in the profile. Very high amounts of $BaCl_2$ extractable acidity, 18.1 to 28.1 cmol(+)/kg, were present in

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the upper three horizons. Sum CEC ranged from 51.1 to 64.8 cmol(+)/kg. The base saturation in the upper horizons was only 55.7 to 64.6 %, due to the high extractable acidity. The Ca/Mg ratios of 1.3 to 1.9 for this site were the lowest of all the profiles.

Two profiles were sampled in Sharkey map units that were on Red River alluvium. These were both in Grassy Lake WMA. GL-SO-3 was located on the lower end of the natural levee of Bayou Natchitoches. All horizons of this profile had clay contents of less than 60 %. The Bw2 horizon had a high silt content, and the clay content was only 41.7 %. The pH was high throughout the profile, and was 7.8 or 7.9 for most of the B and BC horizons. Bray 2 P levels ranged from 191 mg/kg for the surface to 311 mg/kg for the Bw2 horizon. There was none or very little $BaCl_2$ extractable acidity throughout the profile, with the maximum of 6.0 cmol(+)/kg reached in the surface. Low amounts of Mg relative to high Ca content resulted in very high Ca/Mg ratios, which ranged from 3.3 for the BCg2 horizon to 6.5 for the Bw1 horizon. Many of the horizons of this profile had appreciable CCE content, which reached a maximum of 4.8 and 4.7 % in the Bw1 and Bw2 horizons. Sum CEC was lower than the Mississippi River alluvium Sharkey profiles, and ranged from 25.8 to 41.0 cmol(+)/kg.

GL-SF-4, another Sharkey mapping unit soil on Red River alluvium in the same WMA, was located in the backswamp downslope from GL-SO-3. This profile had higher clay contents than GL-SO-3, and only the Bss3 horizon had less than 60 % clay. The pH for the surface and BA horizons were only 5.8 and 6.1, and these

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horizons had $BaCl_2$ extractable acidity levels of 14.6 and 10.9 cmol(+)/kg. The rest of the profile had pH values from 7.4 to 7.7, and extractable acidity ranging from 6.0 to 8.9 cmol(+)/kg. Sum CEC was higher in this profile as compared to GL-SO-3, as all values were between 40.6 and 55.1 cmol(+)/kg. The Ca/Mg ratio was lower also, and reached a maximum of 3.4. The horizons with measured CCE content all had 2 % or less.

Three profiles were sampled from pits in Fausse map units in Red River alluvium: RR-F-4 and RR-F-1 in Red River WMA, and GL-F-2 in Grassy Lake WMA. All were in broad depressional backswamp positions. RR-F-4 had no sampled horizon with more than 58.5 % clay. The pH ranged from 7.5 at the surface to 7.9. Bray 2 available P was high and was about 300 mg/kg or more in 5 horizons. Every horizon had measurable CCE, and a maximum of 4.5 % was reached in the BA horizon. Despite a surface pH of 7.5, the extractable acidity for that horizon was 10.2 cmol(+)/kg. The BA horizon had a similar relationship between the two variables. Sum CEC in the control section ranged from 33.2 to 45.3 cmol(+)/kg. The Ca/Mg ratio peaked in the BA horizon at 5.4.

RR-F-1 only had one sampled horizon with less than 60 % clay. The surface horizon pH was only 5.3, and that horizon had 15.8 cmol(+)/kg of extractable acidity. This soil had mostly higher values of sum CEC , but had lower P content (130-235 mg/kg) and Ca/Mg ratios (peak at 3.5) than RR-F-4. The maximum measurement of CCE was also lower, at 2.4 %. Base saturation percentage was similar between these two soils (68.7 to 89.4 %), and was lower than that of GL-SO-3.

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Although the surface of GL-F-2 had 81 % clay, the Bss1 and the Bss3 had less than 60 % clay. The control section, however was very fine. The surface pH was only 5.4, and this horizon had 13.8 cmol(+)/kg of extractable acidity. Below the surface, pH ranged from 6.7 to 7.8. Extractable acidity was 6.6 cmol(+)/kg or less for these horizons. The Ca/Mg ratio (4.1) and CCE (4.0 %) reached maxima in the Bss2 horizon. Base saturation percentage remained above 91.0 % in the horizons below the BA horizon.

Clay Mineralogy of Selected Horizons

The total clay fraction of the Bss2 horizon from profile TR-SO-2 was dominated by smectite (68 % by peak area), and had lower amounts of illite (19 %) and kaolinite (13 %)(Table 31). All X-ray diffractograms except for Mg-ethylene glycolated and K saturated 300°C showed slight peaks at 14 Å, but the K saturated slide, after heating to 550°C, showed no 7 Å peaks. Chlorite is present in trace quantities, but was not quantifiable. Smectite was the dominant mineral in the Bss2 horizon from GL-SO-3, but in a lower quantity (45 %). Illite (20 %) and kaolinite (13 %) were also present, as was chlorite (23 %). Two horizons of profile RR-F-4 were analyzed by X-ray diffraction: Bss3 (a red horizon), and BCg (a grayer horizon). Both horizons had very similar composition with the GL-SO-3 Bss2 horizon. Smectite was the dominant clay mineral, followed by chlorite and illite, with lesser quantities of kaolinite.

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Table 31. Abundance of clay minerals in the total clay fraction of selected horizons of Sharkey clay and Fausse clay mapping unit soils, determined by semi-quantitative analysis of peak intensities.

			Clay Mineral			
Profile	Horizon	Depth	Smectite	Illite	Kaolinite	Chlorite
		(cm)	---(%)---			
TR-SO-1[1]	Bssg2	37-63	68	19	13	0
GL-SO-3	Bss2	50-80	45	20	13	23
RR-F-4	Bss3	74-100	44	23	8	25
RR-F-4	BCg1	100-140	48	17	15	20

[1]TR=Three Rivers Wildlife Management Area
GL=Grassy Lake Wildlife Management Area
RR=Red River Wildlife Management Area
SO=Sharkey clay, occasionally flooded soil mapping unit
F=Fausse clay soil mapping unit
Number in profile designation is plot identification

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Soil Properties of the Forest Types

Five forest types were found in the study areas (Chapter 3), and were named for their dominant species: Sugarberry (*Celtis laevigata*), Overcup Oak (*Quercus lyrata*), Water Hickory (*Carya aquatica*), Black Willow (*Salix nigra*) and Baldcypress (*Taxodium distichum*). The forest types did not differ significantly in soil surface textures, or soil organic matter content (Table 32). The Black Willow forest type had the highest mean surface pH (6.3), which was significantly higher than that for the Water Hickory (5.6) and Overcup Oak (5.2) forest types. Baldcypress type surface soils had the lowest mean pH (5.0), which was significantly lower than surface soil pH for the Black Willow and Sugarberry forest types. Forest types had significant difference for exchangeable Ca, Mg, and Na. Black Willow had the greatest mean exchangeable Ca content at 28.6 cmol(+)/kg. Baldcypress (22.2 cmol(+)/kg) and Overcup Oak (22.5 cmol(+)/kg) forest types had the lowest surface soil Ca content. Baldcypress type surfaces, however contained the highest exchangeable Mg content (12.0 cmol(+)/kg), which was significantly greater than that for the other four forest types. Black Willow type had the highest surface soil Na content (0.3 cmol(+)/kg), which was significantly greater than that for the Sugarberry forest type (0.1 cmol(+)/kg). Baldcypress forest type had a much greater mean content of exchangeable acidity (1.6 cmol(+)/kg) than that of the other four forest types, which ranged from 0.5 to 0.2 cmol(+)/kg. The base saturation percentage for the Baldcypress forest type surface horizons was significantly lower than that for the other four forest types, although it was 95.5 %. Black Willow and Sugarberry forest

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Table 32. Surface horizon texture and chemical properties of the forest types. Results of a one way ANOVA by forest type.

		Mean Value by Forest Type					
		Sugarberry	Overcup Oak	Water Hickory	Black Willow	Baldcypress	
Property	n	15	8	18	5	6	p-value
clay, %		66.4[1]	65.7	64.3	63.6	73.9	0.4116
sand, %		2.1	1.9	1.5	1.3	3.1	0.2057
silt, %		31.4	32.4	34.2	35.1	23.0	0.2319
organic matter, %		3.2	3.2	3.1	2.8	4.4	0.3044
pH, 1:1		5.8 ab[2]	5.2 bc	5.6 bc	6.4 a	5.0 c	0.0045
P, mg/kg		168.2	163.1	188.9	237.8	191.7	0.2854
Ca, cmol(+)/kg		26.5 ab	22.5 c	23.6 bc	28.6 a	22.2 c	0.0065
Mg, cmol(+)/kg		9.4 b	9.7 b	10.2 b	9.7 b	12.0 a	0.0434
Na, cmol(+)/kg		0.1 b	0.2 ab	0.2 ab	0.3 a	0.2 ab	0.0332
K, cmol(+)/kg		0.9	0.9	0.9	0.8	0.9	0.9013
Exchangeable Acidity, cmol(+)/kg		0.3 b	0.5 b	0.5 b	0.2 b	1.6 a	0.0149
Sum of Bases, cmol(+)/kg		37.0	33.4	34.9	39.4	35.4	0.1534
ECEC, cmol(+)/kg		37.3	33.4	35.6	39.6	36.9	0.1755
Base Saturation, %		99.1 a	98.7 a	98.7 a	99.5 a	95.5 b	0.0139
Ca/Mg		2.9 a	2.4 b	2.4 b	3.1 a	1.9 c	0.0001

[1]Mean values with no letters within the same row are not significantly different at α=0.05 level.

[2]Mean values with the same letter within the same row are not significantly different at α=0.05 level, by Duncan's Multiple Range Test.

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types had the highest surface horizon Ca/Mg ratios (3.1 and 2.9), which were significantly greater than that for Water Hickory (2.4) and Overcup Oak (2.4). Baldcypress had the lowest Ca/Mg ratio, 1.9.

Forest type control sections differed significantly for only four variables: organic matter content, pH, and exchangeable Mg and K (Table 32). Baldcypress forest type had the highest mean organic matter (1.8 %) amount, which was significantly higher than that of Black Willow (1.4 %) type. Overcup Oak forest type had the lowest mean organic matter content in the control section at 0.9 %. Black Willow type had the highest mean control section pH of 7.3, which was significantly different only from Baldcypress, which had the lowest mean pH of 6.2. Baldcypress had significantly more Mg (12.8 cmol(+)/kg) than the Sugarberry and Water hickory forest types, which had 9.5 and 8.7 cmol(+)/kg Mg in the control section. Baldcypress type also had the highest K content of 0.8 cmol(+)/kg, which was significantly greater than that for Sugarberry (0.6 cmol(+)/kg) and Water Hickory (0.6 cmol(+)/kg).

DISCUSSION

Soil Forming Factors

The climate of the study area has high levels of precipitation, which exceed evapotranspiration in the winter and spring. This creates a surplus of water for low relief soils with low permeability. Backswamp alluvial soils such as Sharkey and Fausse are wet during this period, and the wetness may be extended by flooding in the spring through early summer. The climate for the Mississippi River and Red

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Table 33. Control section (25-100cm) texture and chemical properties of the forest types. Results of a one way ANOVA by forest type.

		Mean Value by Forest Type					
		Sugarberry	Overcup Oak	Water Hickory	Black Willow	Baldcypress	
Property	n	14	5	17	3	5	p-value
clay, %		65.2[1]	72.1	64.1	68.9	76.6	0.2149
sand, %		1.4	0.7	0.6	0.5	1.1	0.4109
silt, %		33.4	27.2	35.2	30.6	22.3	0.1844
organic matter, %		1.0 bc[2]	0.9 c	1.0 bc	1.4 b	1.8 a	0.0001
pH, 1:1		6.5 ab	6.5 ab	7.3 a	6.9 ab	6.2 b	0.0074
P, mg/kg		215.9	178.4	223.6	232.0	185.2	0.5172
Ca, cmol(+)/kg		25.4	26.9	27.7	30.6	24.9	0.0979
Mg, cmol(+)/kg		9.5 b	10.9 ab	8.7 b	11.0 ab	12.8 a	0.0155
Na, cmol(+)/kg		0.4	0.7	0.5	0.4	0.4	0.3273
K, cmol(+)/kg		0.6 bc	0.8 ab	0.6 c	0.7 abc	0.8 a	0.0111
Exchangeable Acidity, cmol(+)/kg		0.1	0.1	0.1	0.0	0.4	0.1276
Sum of Bases, cmol(+)/kg		35.9	39.2	37.5	42.7	38.8	0.1576
ECEC, cmol(+)/kg		37.1	39.3	37.6	42.7	39.2	0.1896
Base Saturation, %		99.7	99.8	99.8	100.0	98.9	0.0962
Ca/Mg		2.8	2.5	3.5	2.8	2.0	0.0573

[1]Mean values with no letters within the same row are not significantly different at α=0.05 level.

[2]Mean values with the same letter within the same row are not significantly different at α=0.05 level, by Duncan's Multiple Range Test.

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River areas in central Louisiana is not different, yet climates of the original parent materials for the soils were and are different. The Red River alluvial soils are derived from the Permian aged red beds in the Red River valley of chiefly Oklahoma and Texas, whose evapotranspiration exceeds precipitation for much of the year. The Mississippi River alluvial soils originate from a much larger floodplain, much of which has more precipitation than the red bed area, affording a higher degree of weathering (Louissaint, 1993). Hence the Red River alluvium has horizons with carbonate accumulations and higher Ca/Mg ratios than the Mississippi River soils.

The parent materials of the Mississippi River and Red River derived soils share some characteristics, but also differ strikingly. Both soils have high base saturation, and a high clay content, of which a major component is smectite. The most obvious difference is the color of the soils. As mentioned previously, the red color of the Red River derived soils is owed to the hematite of the Permian red beds of Oklahoma and Texas. Hematite masks much of the redoximorphic feature development expected in soils deposited and formed in anaerobic and reducing conditions (Blodgett et al., 1993). The Mississippi River soils that formed in the backswamp environment display a gray matrix indicative of reduced conditions, and redoximorphic concentrations within the matrix indicating segregation and reoxidation of iron. Red River alluvial soils had less smectite, and more illite and kaolinite than Mississippi alluvial soils, and also had chlorite, which the latter alluvial system lacked. This mineralogy data, on a total clay basis, agrees well with fine clay fraction data of Louissaint (1993). Smectite in two Sharkey pedons investigated by

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Louissaint (1993) comprised 72 and 90 percent of the fine clay fraction, whereas two Moreland (Vertic Hapludoll, fine, mixed, thermic) clay soils derived from Red River alluvium had 41 and 51 percent smectite in the fine clay. The coarse clay of the Sharkeys had 43 and 48 percent smectite, but the Morelands had only 22 and 25 percent smectite in that fraction, with the largest constituent being illite. Louissaint also found the presence of chlorite in the Red River soils, and its absence in Mississippi River soils. The parent materials' differences are evident in some chemical characteristics of the present soils. The Red River soils have a higher pH throughout the profile than soils derived from the Mississippi River. The Sharkey and Fausse soils both have higher exchangeable Mg than their red-colored counterparts. Louissaint (1993), however, found Red River derived soils in Louisiana had roughly twice the Mg and K in the octahedral sheets than did the Mississippi River soils. The latter was attributed to more illite.

The geomorphic position and relief of backswamp soils are important factors in the formation of these soils. Floodwaters away from the rapidly flowing natural levee area (where coarse textured particles settle) slow down, and this reduction of velocity results in the deposition of finer materials, predominantly clays. Backwater flooding stays longer than flooding near the levee, and the fine sediments have more time to settle. The clays deposited in the backswamp areas of both the Mississippi River and Red River have high smectite content and shrink-swell potential. The low relief influences the soil moisture character of the soils. The Sharkey mapping unit soils are mostly in upper backswamp positions, whereas the Fausse is mapped in

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backswamp interiors and depressions that pond backwater flooding for longer periods than upper positions. This results in longer drying periods for soils situated higher in the backswamp and lower natural levee, and the clays shrink to a greater extent, creating vertic morphology such as cracks, slickensides, pressure faces, and strong angular blocky structure. Pettry and Switzer (1996) indicate that the Sharkey soil in Mississippi should be classified as a Vertisol, based on the cracking and vertic morphology. Soils in the interior backswamp positions dry out to a lesser extent, and have less expression of this character. Some soils in backswamp depressions (swamps) never or rarely dry out to the point of cracking, and remain Inceptisols (mostly epiaquepts). The decomposition of organic matter in these interior backswamp sites is slowed by longer periods of reducing conditions brought on by the longer hydroperiods, and organic matter accumulates faster than in the upper backswamp sites. The Fausse mapping unit soils of both Mississippi River and Red River origin had more textural variability than that of the Sharkey positions. This may be attributed to some soils in meander scroll areas with loamier texture being mapped Fausse clay due to high water levels.

Both these alluvial soils are less than 6,500 years old (Schumacher et al., 1988), which is very recent in geologic age. There has not been time to weather, and the wetness of the soils and low hydraulic conductivity of the clays has prevented leaching of bases and the destruction of clays and clay minerals. The movement of clays due to shrinking and swelling has also prevented or minimized translocation of clays and constituents. The soils had an annual deposition of clayey sediments until

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this century. Thus the profiles of backswamp soils are not much differentiated, and kept in a haploid state. The weathering of the soils can be assessed by the free Fe oxides chemical analysis (Table 30). No profile has pronounced accumulations or maxima or minima of Fe or Fe oxides. This indicates weathering is at an early stage.

Soil Forming Processes

An important addition process for the backswamp soils is the sedimentation of clay-sized particles from backwater flooding. Much of the area lies between artificial levees, so the addition of sediment from direct flooding has been greatly reduced within the last 100 years. Backwater flooding by overflow of bayous and minor drains still floods the backswamps, however. The sediment added includes organic matter, as is demonstrated by the irregular organic matter distributions of all the soils in this study. The decomposing organic matter produces exchangeable acidity in the horizons near the surface, particularly for the Sharkey soils which are shallowly ponded or not ponded and have water removed by evapotranspiration only (RR-SF-5, RR-SO-2, RR-SO-3). The soils flooded by higher, moving water flush some of the acidity out. Sharkey soils in Mississippi also had a pH minimum of 4.6 to 4.8 at 25 cm before increasing to pH 7 or more at 1 meter depth (Pettry and Switzer, 1996). The sediments also include high contents of bases and available phosphorus, so the soils maintain high base saturation and fertility.

Losses due to leaching are minimized because of low permeability of the clays, and long duration of flooded and saturated conditions. As mentioned previously, some sites flooded with moving water (TR-SF-1, TR-SF-5) may have

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exchangeable acidity or other constituents moved out near the surface by receding high floodwaters.

Comerma (1985) stated that hydromorphic Vertisols may have translocated clay within the profile. Some profiles in the bottomland hardwood study area have a slight increase in clay down the profile, but most pedons had irregular clay distribution, and there is little evidence of clay translocation. The Fe, Mn, and Al oxides also show very little pattern of translocation with depth. In the Red River alluvium, however, calcium carbonate has accumulated in the Bss horizons at levels up to 5 %. Exchangeable Na also showed a trend of increasing concentration with depth, from as low as 0.1 cmol(+)/kg for the surface to 1.8 cmol(+)/kg for the Cg horizon.

One of the most prominent transformations is the oxidation and reduction process. The prolonged flooding and saturation in the backswamp environment greatly retards oxygenation through the soil surface, and microbes quickly deplete the remaining oxygen in the pores. The microbes then utilize alternate electron acceptors, reducing each. The reduction and reoxidation of iron creates redoximorphic features. The Sharkey and Fausse soils show a high degree of redoximorphic features, and all met at least one hydric soil indicator, including depleted matrix, delta ochric, and the testing indicator delta vertic. Red-colored Sharkey and Fausse map unit soils had lower values and higher chromas of 2 to 4, and only qualified for the testing field indicator for red parent material. The redox concentrations and depletions were mostly of faint contrast. Hematite of the original

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parent material from the Permian red beds from Texas and Oklahoma is believed to mask redoximorphic features (Blodgett et al., 1993). Gray matrices and ped faces indicate that the ped interiors are saturated and reduced for long periods. The redoximorphic concentrations along both ped faces, ped interiors, and pore linings of Sharkey clay soils reflect oxidizing microsites within the ped. Some Fausse soils had oxidized rhizospheres or root coatings, which indicate conduction of oxygen into the saturated or flooded soil by hydrophytic plants. Comerma (1985) cautioned that some alluvial or lacustrine Vertisols have relict soil morphology formed under the intense reducing conditions at the time of deposition. Pettry and Switzer (1996) consider the low chromas of Mississippi Sharkey soils to be inherited from the initial sediments, just as the red colors of the red bed sediments are relict. Those Sharkey soils, however, did not have any field indicators of hydric soils, and soil colors became brighter with increasing depth. Pettry and Switzer's Sharkey study sites were on clay over loamy Pleistocene surfaces (Saucier, 1994) higher on the landscape from the sites in this study in Louisiana bottomland hardwood forests.

The soils derived from Mississippi River sediments in Sharkey clay mapping units were classified as very fine, thermic, smectitic, Aeric and Chromic Epiaquerts (Table 34). Currently, the Sharkey series is classified as a very fine, smectitic, nonacid, thermic Vertic Haplaquept, but this classification is controversial, as many believe the soil to be a Vertisol (Pettry and Switzer, 1996). The red-colored soils within the Sharkey clay mapping units resemble the Moreland and Buxin series (fine, mixed, thermic Vertic Hapludolls), but were largely Aeric Epiaquerts. Over

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Table 34. Taxonomic classification of 45 pedons within the Sharkey clay and Fausse clay mapping units of Wildlife Management Areas, Concordia and Avoyelles Parishes. Louisiana.

Taxonomic classification	Number of pedons
Sharkey	
Aeric Epiaquert, very fine, smectitic, thermic	9
Chromic Epiaquert, very fine, smectitic, thermic	6
Fausse	
Typic Epiaquept, very fine, smectitic, nonacid, thermic	4
Typic Epiaquept, fine, smectitic, nonacid, thermic	1
Aeric Epiaquept, very fine, smectitic, nonacid, thermic	1
Aeric Epiaquert, very fine, smectitic, thermic	1
Aeric Epiaquert, fine, smectitic, thermic	1
Chromic Epiaquert, very fine, smectitic, thermic	1
Red-colored Sharkey	
Aeric Epiaquert, very fine, smectitic, thermic	7
Aeric Epiaquept, fine, smectitic, nonacid, thermic	5
Chromic Epiaquert, fine, smectitic, thermic	1
Red-colored Fausse	
Aeric Epiaquert, very fine, smectitic, thermic	4
Aeric Epiaquert, fine, smectitic, thermic	2
Typic Epiaquept, very fine, smectitic, nonacid, thermic	1
Miscellaneous loamy soil in Sharkey map unit	
Vertic Epiaquept, fine-silty, smectitic, nonacid, thermic	1

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half of the pedons have very-fine textured control sections, and the remainder was fine. X-ray diffraction on selected horizons indicate that the mineralogy is smectitic. The most numerous classification of the Fausse map unit soils in Mississippi River alluvium was Typic Epiaquept, very fine, smectitic, nonacid, thermic. Five other families were represented. The official classification for Fausse is Typic Fluvaquent, very fine, smectitic, nonacid, thermic. The red-colored soils in the Fausse map units were Aeric Epiaquerts, very fine (57 percent) or fine (29 percent), thermic, smectitic. Similar soil series are the Perry (Vertic Haplaquept, very fine, smectitic, nonacid, thermic), which has gray clay over red clay, and Moreland and Buxin. The red-colored soils in the Fausse clay mapping units had a longer dry season and had a greater vertic morphology expression than their Mississippi River alluvium counterparts.

Evidence of biotic influences on the soils in the study area was restricted to factors related to organic matter. The Baldcypress forest type had significantly lower pH and higher exchangeable acidity of the surface horizon than other forest types. Although organic matter percent was not significantly different, Baldcypress type had the highest mean percentage, and the low pH is believed to be resulting from the production of organic acids. The Black Willow forest type, under similar hydroperiod, had the highest pH and lowest exchangeable acidity and organic matter content. The cause of the differential organic matter production is unclear, but may involve litter quality of the two species. The organic content of Baldcypress forest's control section is significantly higher than the other types, and the pH is the lowest.

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SUMMARY AND CONCLUSIONS

Summary and Conclusions

Most soils in this investigation displayed evidence of backswamp alluvial processes. The Sharkey mapping unit soils were situated on the upper end of the backswamps, whereas the Fausse mapping unit soils were located more in the backswamp interiors. The longer the areas are not flooded or saturated, the greater propensity they have to shrink and crack. The backswamp interior soils which have longer hydroperiods exhibit less vertic properties than soils in upper backswamp positions. Areas in backswamp interiors have reduced organic matter decomposition rates because of the prolonged hydroperiod, which results in higher organic matter accumulation than at positions nearer the natural levee. The extended flooding and saturation results in a longer and more intense Fe-reducing environment, which is manifested in soil matrix colors with lower chromas than in upper, less reduced positions. The Sharkey soils exhibit hydric soil morphology of depleted matrices, with redoximorphic concentrations and depletions. The soils from the river sediments are geologically very young, and the wet season prolonged flooding and saturation in the wet, as well as clay activity upon drying or wetting, keep the soil profile in a haploid or undifferentiated state. Soils within the Sharkey clay (occasionally and frequently flooded) and Fausse clay mapping units near the confluence of the Mississippi and Red Rivers in Avoyelles and Concordia Parishes are derived from sediments of one or both of those rivers. Sharkey soils developed from the Mississippi River have a higher clay content, lower silt fraction, lower pH,

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higher subsoil Mg content, higher K levels, lower surface base saturation, and lower Ca/Mg ratios than soils in similar landscape positions developed from Red River alluvium. In addition, the red-colored Sharkey clay mapping unit soils had calcium carbonate accumulations, whereas the soils developed from similar positions within Mississippi River alluvium did not. Clay fractions of the Mississippi River upper backswamp and lower natural levee soils (Sharkey positions) are differentiated from similar positions on the Red River alluvium by having a higher smectite content and the absence of chlorite.

The soils derived from Mississippi River sediments in Sharkey map units were predominantly classified as very fine, thermic, smectitic, Aeric and Chromic Epiaquerts. The red-colored soils within the Sharkey map units were largely Aeric Epiaquerts. Over half of the pedons have very fine-textured control sections, and the remainder was fine. X-ray diffraction on selected horizons from soils of both rivers indicate that the mineralogy was smectitic.

This study included a few plots in Sharkey clay and Fausse clay mapping units which were near natural levees, and were coarser textured than the backswamp soils more typical for the map units. These plots also had lower CEC than the soils in typical Sharkey and Fausse positions.

The greatest difference in soil properties between the forest types was organic matter accumulation, and its effects of the organic acids. Baldcypress forest type had the highest surface and control section organic content, and the lowest pH and exchangeable acidity.

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Recommendations for Further Research

Although all the Mississippi River Sharkey clay soils had one or more field indicators, testing needs to be continued on the indicators. The TF11 (Delta Vertic) field indicator needs work to fit more soils with demonstrated wetland hydrology. If the Depleted Matrix (F3) indicator is deleted for Mississippi River valley vertic soils, as planned, testing should assure that hydric Sharkeys will not fall out of that status, as TF11 is more selective.

Even more attention should be paid to the development of hydric soil indicators for soils derived from red parent materials. Presently the only indicator (TF2, Red Parent Material) is only a testing indicator, and omits some wetter red-colored Fausse clay mapping unit soils while including drier soils higher in the landscape.

Apparent gilgai microrelief in these Vertisols in the Sharkey clay mapping units needs to be quantified. The relationship between soil morphology and microrelief position needs to be further established, and the duration, depth, and intensity of hydric conditions of adjacent highs and lows should be investigated, and related to the morphology.

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CHAPTER 5

HYDROLOGIC REGIMES AND REDUCING CONDITIONS OF BOTTOMLAND HARDWOOD FOREST TYPES

INTRODUCTION

Wetlands must meet three criteria: hydrophytic vegetation, hydric soils, and wetland hydrology (Environmental Laboratory, 1987). Bottomland hardwood forests are seasonally flooded, ponded, or saturated, with various frequencies and duration. The wetland delineation of bottomland hardwoods is controversial. This controversy has been generated by differing delineations of bottomland hardwood wetlands by agencies and consultants. One reason is that hydric soil morphology and hydrophytic vegetation can be described easily in a field visit, but wetland hydrology and hydric soil conditions must be inferred using indicators. Wetland hydrology creates hydric soil conditions, and is the key for delineating and/or determining a wetland. The prevalence of hydrophytic vegetation has been used to assess hydrology and is an important part of wetland criteria. Investigating the relationship between vegetation composition and hydric soil conditions may provide important information for future wetland classifications and delineation/determination methods. Assessment of hydrological processes and functions of bottomland hardwood forest types may facilitate future wetland classifications.

Durations of inundation, saturation, and iron reducing conditions of some bottomland hardwood forests on lower natural levees and backswamps (Sharkey-

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Fausse soil association) of Central Louisiana were investigated to relate hydric soil conditions to plant community composition.

Dominant trees of the five forest types classified in the study area (Chapter 3) are: Sugarberry (*Celtis laevigata*), Overcup Oak (*Quercus lyrata*), Water Hickory (*Carya aquatica*), Black Willow (*Salix nigra*), and Baldcypress (*Taxodium distichum*).

A hydric soil is saturated, ponded, or flooded long enough during the growing season to develop anaerobic conditions in the upper part (30 cm for clay soils) (National Technical Committee for Hydric Soils, 1991). Anaerobic conditions imply that the iron in more than half the soil volume has been reduced (Soil Survey Staff, 1994). Wetland hydrology is defined as inundation occurring for 7 days in the growing season, or saturation near the surface for 14 or more consecutive days during the growing season (Soil Conservation Service, 1994). The 1987 Corps of Engineers Manual (Environmental Laboratory, 1987) defines wetland hydrology as inundation or saturation in the surface soil for 12.5 % of the growing season. Areas with inundation/saturation durations of between 5 and 12.5 % of the growing season may or may not have wetland hydrology.

The objective for this study was to relate bottomland hardwood forest species composition to hydric soil conditions to assess wetland hydrology functions. This was accomplished by defining the depth, timing, frequency, and duration of i) inundation, ii) soil saturation, iii) soil oxygen depleting conditions, iv) soil nitrate reducing conditions, and v) soil iron reducing conditions of the five forest types.

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METHODS

Soils in the study area were formed on clayey alluvium of the Mississippi and Red Rivers, and represent a flooding frequency gradient. The Sharkey series (current official NRCS taxonomic classification: Vertic Haplaquept, very fine, montmorillonitic, nonacid, thermic) is the main component of the Sharkey clay, occasionally flooded and Sharkey clay, frequently flooded soil mapping units. The mapping unit with the longest flooding duration in the area is Fausse clay, whose main component is the Fausse series (Typic Fluvaquent, very fine, montmorillonitic, nonacid, thermic). The NRCS is evaluating a reclassification of the Sharkey series to a Vertisol, (possibly Chromic Epiaquert, very-fine, smectitic, thermic) but this classification is not approved at this date (NRCS, 1997).

Water budgets for Sharkey clay were calculated for 0-25 cm, 0-50 cm, and 0-100 cm, assuming the water holding capacity of Sharkey to be 0.5 cm^3/cm^3, given available data (Romkens et al., 1986, Pettry and Switzer, 1996). Precipitation and temperature data from 1961 to 1979 from Old River Locks in Concordia Parish (Martin, 1988) was used, and the Thornthwaite method (Hargreaves, 1974) for calculating potential evapotranspiration was employed.

Vegetation and soils were described within 45 plots in five Louisiana Wildlife Management Areas: Three Rivers and Red River WMA's in Concordia Parish, and Grassy Lake, Spring Bayou and Pomme de Terre WMA's in Avoyelles Parish. Species importance values were used in a cluster analysis to classify five forest types. Prevalence Index (PI), a weighted average of wetland plant status, was computed for

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each plot. Wetland plant status categories are: obligate wetland = 1, facultative wetland = 2, facultative = 3, facultative upland = 4, and obligate upland = 5 (Federal Interagency Committee for Wetland Delineation, 1989). Flood Tolerance Index (FTI) (Theriot, 1993), a weighted hydrologic zone average based on observed southeastern bottomland forest species distribution in six wetland hydrologic zones, was also calculated for each plot.

Seventeen plots representing typical vegetation and soils were instrumented to monitor hydric soil conditions. PVC pipe piezometers were installed in triplicate at 25 cm, 50 cm, 100 cm, and sometimes at 200 cm depths to assess water-table depth and saturation. The piezometers were 1.5 in. (3.8 cm) diameter schedule 40 PVC pipe with 4 cm at the lower end slotted and covered with a geofabric screen. The piezometers were installed as described by Hudnall and Wilding (1992): the hole was augered to just below the desired piezometer depth, then 10 cm of sand was placed around the piezometer's slotted end. Then 10 cm of bentonite powder or chips were poured over the sand, followed by a fill of natural soil up to 8 cm from the top of the hole. A second layer of bentonite was added, followed by natural soil at the surface. The bentonite's purpose was prevent bypass flow, so the piezometric head at the desired depth could be measured. Saturation was defined as free water in the piezometers. Depth to the water in the piezometers was measured by blowing through a plastic tube and measuring the depth at which bubbling was first heard. Platinum wire redox electrodes were constructed using the mercury junction method (Faulkner et al., 1989) and tested using quinhydrone in pH 7 buffer solution (Szogi

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and Hudnall, 1990). The redox electrodes were installed in triplicate at 25 cm, 50 cm, and 100 cm depths and connected with a KCl-agar salt bridge with a syringeless filter and voltmeter (BK Precision Model 288, Maxtor Corp.) to measure soil redox potential, a reflection of reduction intensity. Temperature was measured by using installed thermocouples at 25, 50, and 100 cm depths and using a meter (Omega). The hydric conditions plots were monitored at biweekly or triweekly intervals during the 1994 and 1995 growing seasons (Natural Resources Conservation Service thermic temperature regime, February-October). Sites within the Wildlife Management Areas were monitored less frequently during the NRCS-defined nongrowing season, which coincided with deer hunting season.

Redox Potential Thresholds

Redox potential is a measure of the availability of electrons in the soil or solution. Redox potential (Eh) is related to the concentrations of reductants and oxidants in a redox equation. Redox potentials for oxidized soils range from 400 to 700 mV, whereas highly reduced soils may have an Eh as low as -250 mV. The field measurements of redox potential were corrected for using a saturated calomel reference electrode by adding 244 mV. Turner and Patrick (1968) related declining redox potential to disappearence of oxygen and nitrate, and appearence and increase of ferrous iron in a Sharkey soil inundated in the laboratory. Thresholds from that publication were used in this study on bottomland hardwoods largely on Sharkey. The redox potential threshold for depleting free oxygen conditions was less than or equal to 330 mV. Nitrate reducing and depleting conditions was less than or equal

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to 220 mV. Iron reduction occurred at a redox potential threshold of 150 mV. Nitrate depletion may overlap oxygen depletion. Oxygen and nitrate must be depleted before iron reduces. The thresholds for oxygen, nitrate, and iron were used for determining different levels of anaerobic soil conditions. A one way unbalanced ANOVA (SAS Institute, Inc., 1990) was used to compare the mean durations of inundation, saturation, and reduction of the forest types. Duncan's Multiple Range Test was used to detect differences between forest types for the significant (at $\alpha=0.05$) ANOVAs.

RESULTS

Inundation and Saturation

In 1994, most soils in the study area were saturated or flooded from early spring to May or June (Figures 10 and 11). During this period the study area received high levels of precipitation (about 60 cm) (Figure 12) and the river levels reached flood proportions (Figure 13). After the river levels dropped in June, soils were much drier the rest of the year, except in August during heavy precipitation. In November and December 1994, precipitation levels increased to about 40 cm, and in March and April 1995, precipitation amounted to 48 cm. The Mississippi River rose to flood levels in June, 1995. Temperature data recorded (Figures 14) indicates all or most of the year is above biological zero (5°C). The calculated water budgets (Figures 15 and 16), which assumed no flooding, indicate recharge starts in September, and a surplus begins in December to February, depending on soil depth.

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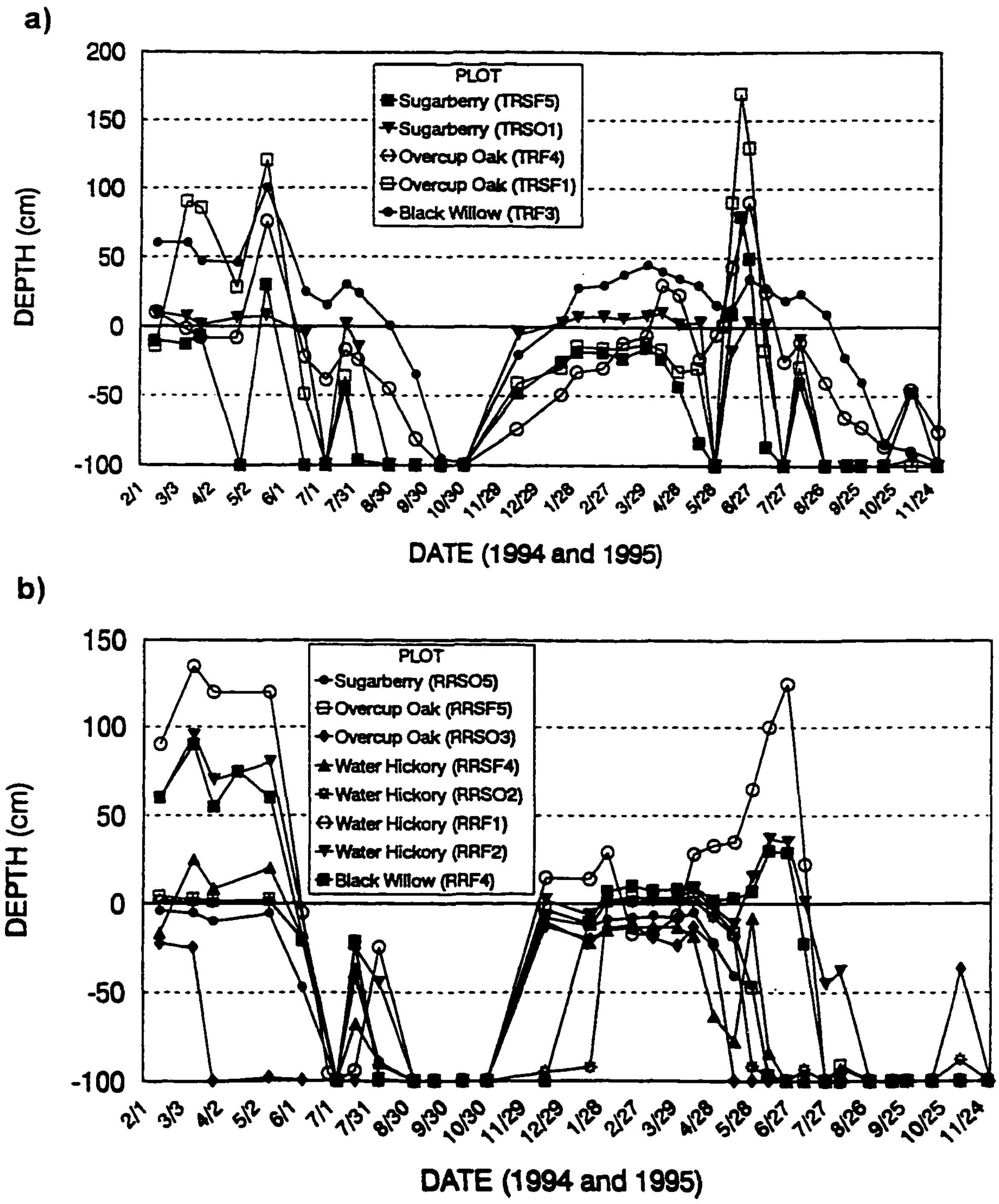

Figure 10. Height of inundation or depth to shallowest occurring water table during the 1994 and 1995 growing seasons for plots in a) Three Rivers Wildlife Management Area, and b) Red River Wildlife Management Area.

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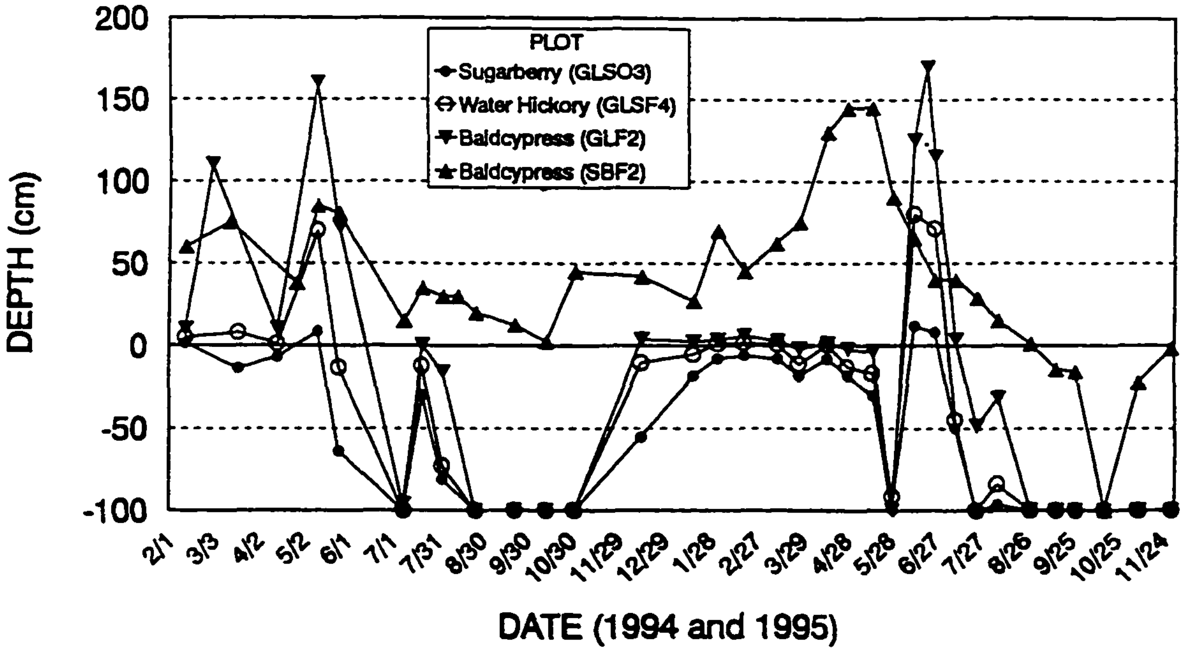

Figure 11. Height of inundation or depth to shallowest occurring water table during the 1994 and 1995 growing seasons for plots in a) Grassy Lake (GL) and Spring Bayou (SB) Wildlife Management Areas.

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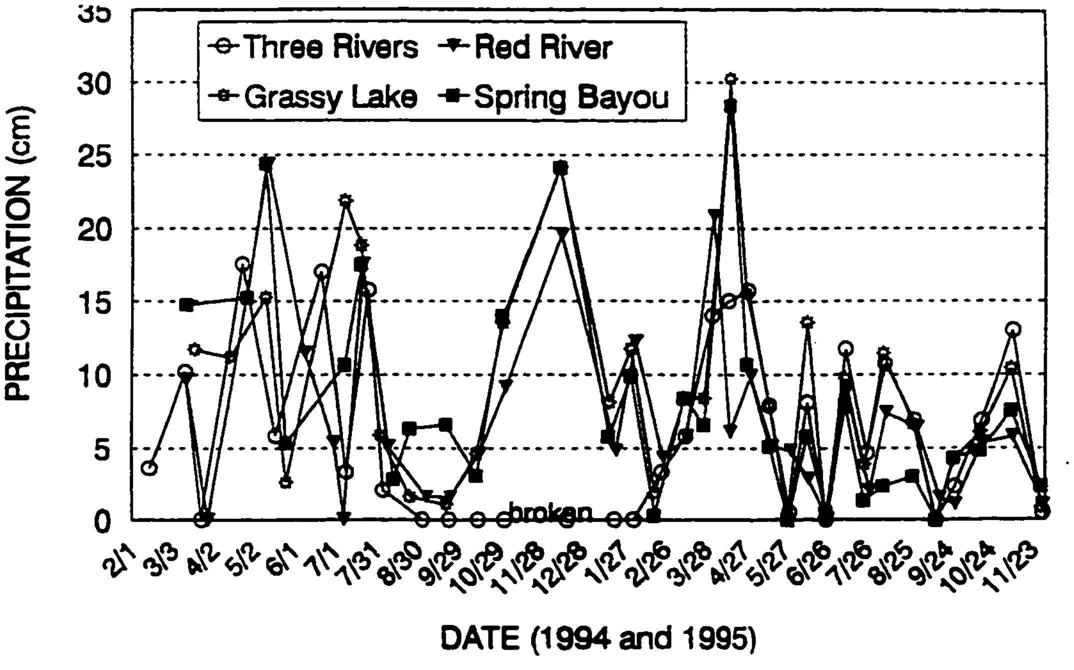

Figure 12. Precipitation measured at four central Louisiana Wildlife Management Areas during the 1994 and 1995 growing seasons.

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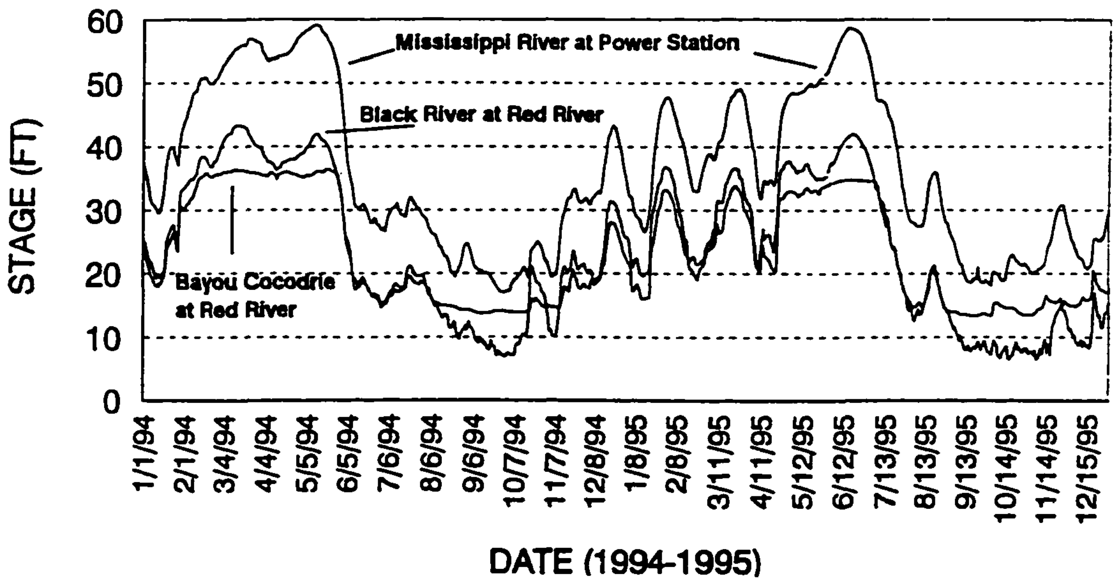

Figure 13. River stage data (from the US Army Corps of Engineers Vicksburg and New Orleans Districts) in or near Three Rivers and Red River Wildlife Management Areas during the 1994 and 1995 growing seasons.

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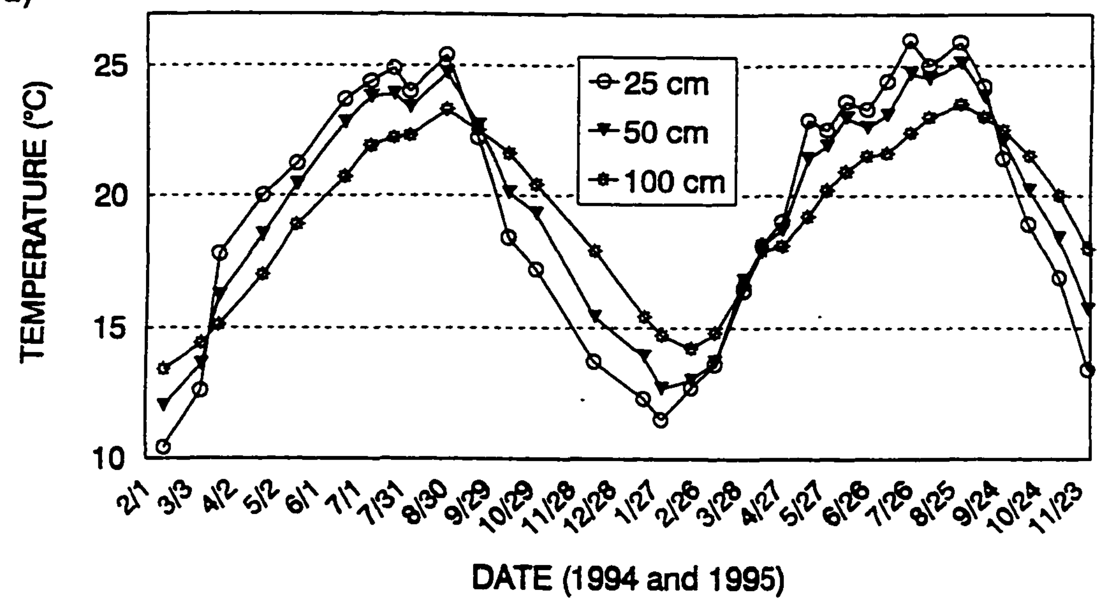
a)



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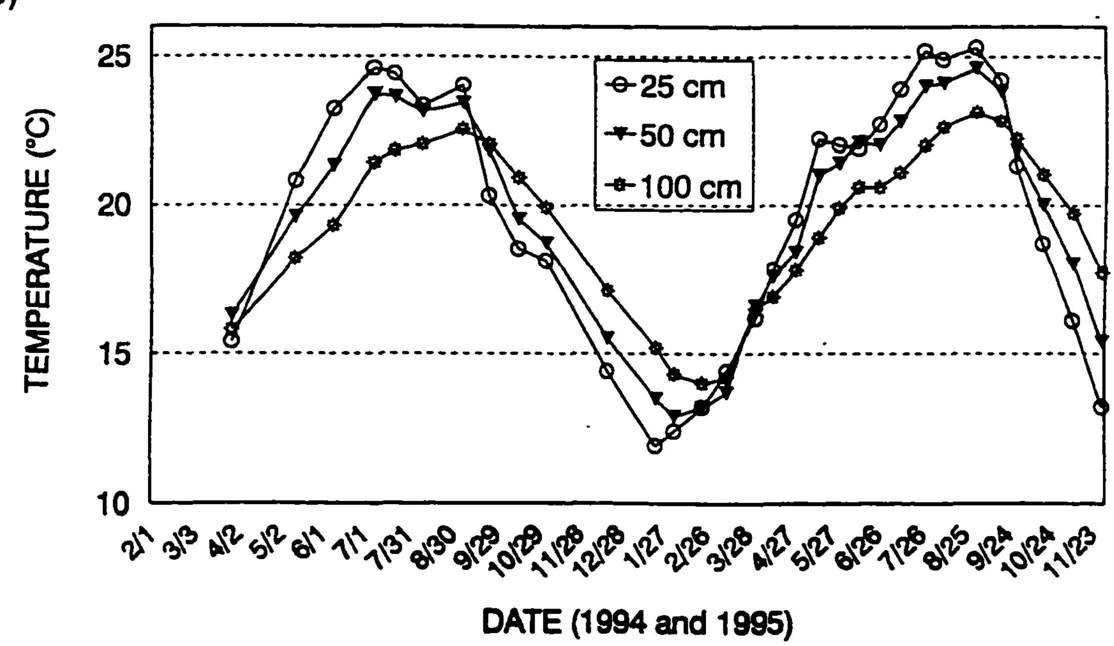

Figure 14. Mean plot soil temperature measured in a) Three Rivers Wildlife Management Area and b) Red River Wildlife Management Area during the 1994 and 1995 growing seasons.

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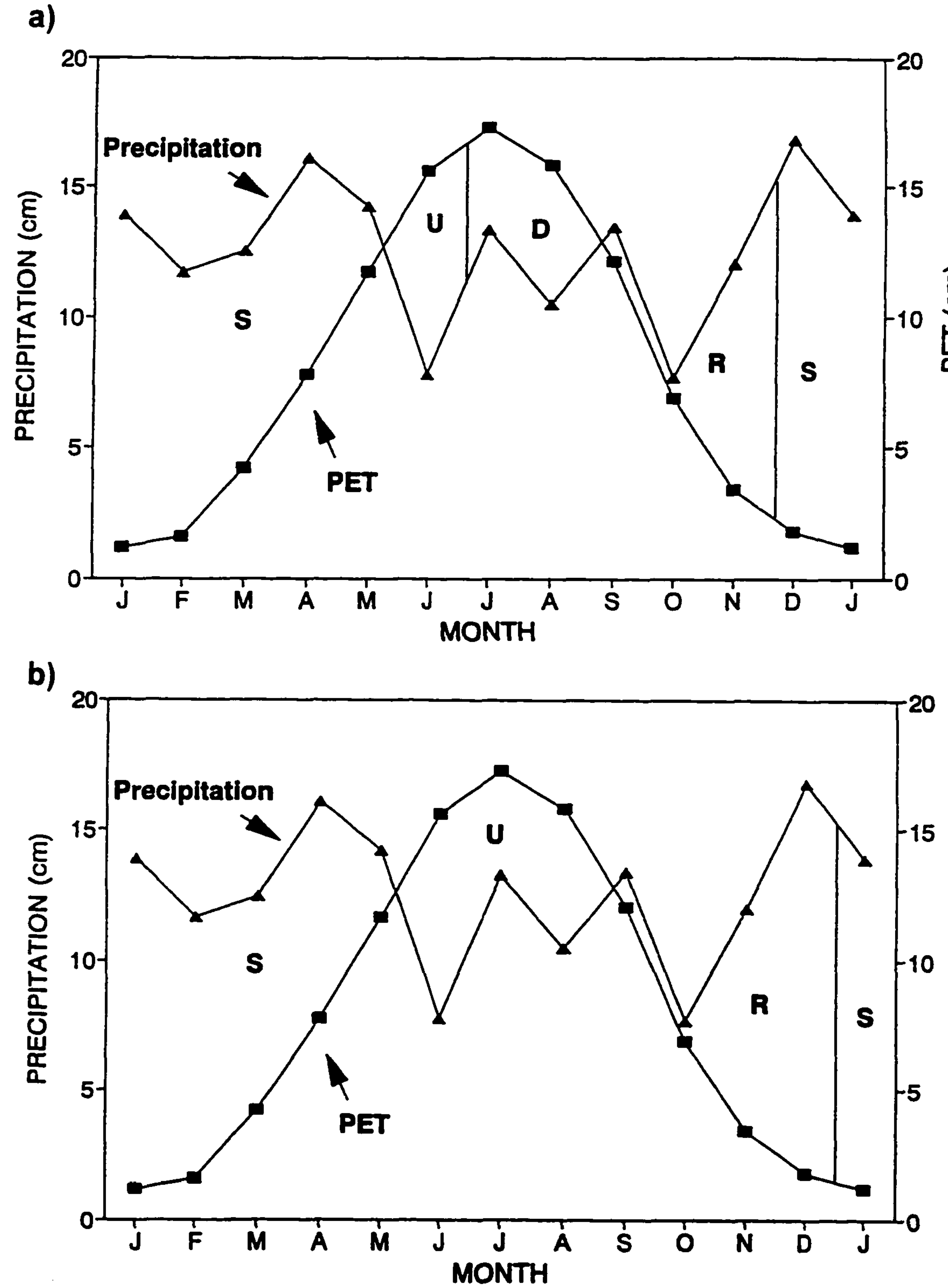

Figure 15. Soil water budget calculated for Sharkey clay at Old River Locks, Louisiana for a) 0-25 cm depth, and b) 0-50 cm depth. PET=Thornthwaite potential evapotranspiration, S=surplus, U=utilization, D=deficit, and R=recharge.

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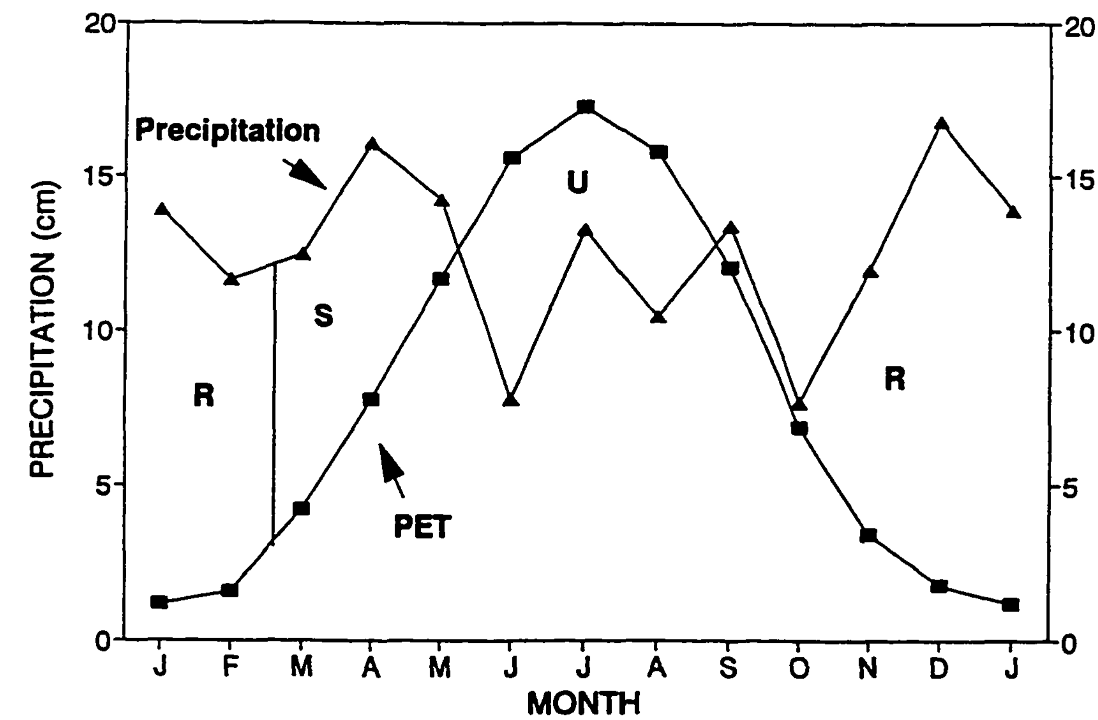

Figure 16. Soil water budget calculated for Sharkey clay at Old River Locks, Louisiana for 0-100 cm depth. PET=Thornthwaite potential evapotranspiration, S=surplus, U=utilization, and R=recharge.

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The surplus lasts into late May. Soil water is utilized until September at all depths except in the top 25 cm, where a deficit begins in July.

All monitoring plots had hydrophytic vegetation (Table 35), as PI was < 3.0. The Sugarberry forest type had the least hydrophytic prevalence (most facultative wetland species), followed by the Overcup Oak and Water Hickory forest types. The Baldcypress and Black Willow forest types had the maximum hydrophytic prevalence of obligate wetland species. FTI means for the forest types also show a differentiation of vegetation distribution with respect to the hydrologic regime (Table 36). The Black Willow forest type had the lowest mean overall FTI (2.98), indicating the plants of that type are the most tolerant to flooding. The Baldcypress forest type also had a low FTI (3.20), and the Sugarberry type had the highest mean FTI of 4.24, which reflects a shorter duration of flooding.

The Baldcypress forest type was inundated the longest portion of the growing season (mean of 69 % cumulative duration) (Table 37). The Black Willow forest type was inundated 62 % of the growing season, and had a similar flooding regime. Sugarberry and Overcup Oak forest types had the shortest inundation durations, with mean cumulative duration in the growing season ranging from 18 to 19 %. The Water Hickory forest type was intermediate betwwen the two extremes in inundation hydroperiod, and was inundated a mean of 31 % of the growing season. The Baldcypress plots had the highest mean height of flooding of 141.2 cm. The Sugarberry forest type had the lowest mean flood height, at 18.8 cm. Overcup Oak

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Table 35. Mean Prevalence Index (PI) calculated for the canopy, sapling, subsapling/shrub, and total strata for the forest types.

Forest Type	Prevalence Index[1] Canopy	Sapling	Subsapling/ Shrub	Overall
Sugarberry	1.58 a	1.52 a	1.87 a	1.66 a
Overcup Oak	1.21 b	1.25 ab	1.21 b	1.24 b
Water Hickory	1.07 bc	1.21 ab	1.41 b	1.21 b
Baldcypress	1.02 c	1.00 b	1.00 b	1.01 b
Black Willow	1.00 c	1.00 b	_	1.00 b
p-value (ANOVA)	0.0001	0.0412	0.0005	0.0001

[1]PI is an average of hydrophytic plant status, weighted by abundance. Hydrophytic plant status is: obligate wetland =1, facultative wetland =2, facultative=3, facultative upland=4, upland=5.

[2]Means with same letters within the same stratum (column) are not significantly different at α=0.05 level, using Duncan's Multiple Range Test.

Table 36. Mean Flood Tolerance Index (FTI) calculated for the canopy, sapling, subsapling/shrub, and total strata for the forest types.

Forest Type	Flood Tolerance Index[1] Canopy	Sapling	Subsapling/ Shrub	Overall
Sugarberry	4.30 a[2]	4.05 a	4.44 a	4.24 a
Overcup Oak	3.75 b	3.85 ab	3.88 b	3.78 b
Water Hickory	3.55 c	3.68 b	3.72 b	3.69 b
Baldcypress	3.10 d	3.56 b	3.20 c	3.20 c
Black Willow	2.88 e	3.08 c	_	2.98 d
p-value (ANOVA)	0.0001	0.0001	0.0001	0.0001

[1]FTI corresponds to hydrologic zones: 2.5 = permanently flooded/saturated, 3.5 = semipermanently or regularly flooded/saturated, 4.5 = seasonally flooded/saturated, 5.5 = temporarily flooded/saturated, 6.5 = intermittently flooded/saturated.

[2] Means with same letters within the same stratum (column) are not significantly different at α=0.05 level, using Duncan's Multiple Range Test.

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Table 37. Inundation and soil saturation regimes of plots of bottomland hardwood forest types of central Louisiana Wildlife Management Areas (WMAs) for the 1994 and 1995 growing seasons, and results of a one way ANOVA by forest type.

Forest Type and Plot	Mean max. flood height (cm)	Mean percent of growing season, 1994-1995: Inundated	Soil saturated at: 25 cm	50 cm	100 cm
Sugarberry					
TR[1]-SF[2]-5[3]	55.0	9.4	37.6	43.2	42.4
TR-SO-1	10.0	53.6	64.1	64.1	55.8
RR-SO-5	0.0	0.0	36.1	50.0	11.2
GL-SO-3	10.2	13.9	41.6	48.6	65.2
Overcup Oak					
TR-F-4	82.5	21.6	61.3	80.1	92.3
TR-SF-1	145.0	21.0	41.4	58.4	41.6
RR-SF-5	3.8	30.6	47.2	50.0	57.0
RR-SO-3	0.0	0.0	27.8	0.0	4.2
Water Hickory					
RR-SF-4	12.5	12.5	40.3	36.1	59.7
RR-SO-2	2.0	30.6	40.3	44.4	59.7
RR-F-1	130.0	40.4	56.4	56.4	78.4
RR-F-2	66.0	40.4	56.4	65.8	65.8
GL-SF-4	75.0	33.3	52.8	52.8	65.5
Black Willow					
TR-F-3	72.5	80.1	82.9	89.5	100.0
RR-F-4	60.0	44.4	58.4	58.4	62.5
Baldcypress					
GL-F-2	167.5	47.2	55.6	61.1	66.1
SB-F-2	115.0	91.6	97.2	97.2	97.2
ANOVA RESULTS (one way ANOVA by forest type)[4]					
Sugarberry	18.8	19.2 a	44.8	51.5	53.6
Overcup Oak	57.8	18.3 a	44.4	47.1	48.8
Water Hickory	57.1	31.4 ab	49.2	51.1	65.8
Black Willow	66.2	62.2 bc	70.6	74.4	81.2
Baldcypress	141.2	69.4 c	76.4	79.2	81.6
F test	2.12	4.15	2.79	1.26	1.52
p-value	0.141	0.024	0.076	0.340	0.259

[1]WMAs: TR=Three Rivers, RR=Red River, GL=Grassy Lake, SB=Spring Bayou.
[2]Soil mapping unit: SO=Sharkey clay, occasionally flooded, SF=Sharkey clay, frequently flooded, F=Fausse clay.
[3]Plot identification number.
[4]Numbers with same letters within column are not different, using Duncan's Test at α=0.05.

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and Water Hickory forest types had wide variation in maximum flood heights, ranging from 0.0 to 145 cm.

Soil saturation data (Table 37) for the major part of the root zone (25 cm) show a trend (although not significant at α=0.05) of Black Willow (saturated a mean 70.6 % of the growing season) and Baldcypress (saturated 76.4 %) forest types having a longer soil saturation durations than the Sugarberry, Overcup Oak, and Water Hickory forest types, which ranged from means of 44.4 to 49.2 %. Soil saturation durations at 50 cm and 100 cm depths also were not significantly different between forest types, although a similar trend existed. The Baldcypress and Black Willow forest types had soil saturation at those depths from 74.4 - 81.6 % of the growing season, but the other three types had soil saturation durations ranging from 47.1 to 65.8 % of the growing season.

Reduction

The trend of oxygen depleted conditions (Eh $\leq$ 330 mV) at the 25 cm depth for the forest types is very similar to the soil saturation duration at that depth (Table 38). At 25 cm depth, Black Willow and Baldcypress mean soil saturation duration ranges from 75.8 % to 83 %, but the Sugarberry, Overcup Oak, and Water Hickory forest types have mean soil saturation durations ranging from 52.3 to 52.7 % of the growing season. The apparent trends for oxygen depleted conditions at 25, 50 and 100 cm are not significant at the α=0.05 level. At 100 cm however, the p-value for the ANOVA was 0.052, and the Sugarberry forest type had the shortest duration of oxygen depleted conditions at 48.6 % of the growing season. The other four forest

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Table 38. Reduction regimes for soils of bottomland hardwood types within central Louisiana Wildlife Management Areas (WMAs) for the 1994 and 1995 growing seasons.

	Mean percent of sampling times in 1994-1995								
	Oxygen Depleted			Nitrate Depleted			Iron Reduced		
Forest Type	25 cm	50 cm	100 cm	25 cm	50 cm	100 cm	25 cm	50 cm	100 cm
Sugarberry									
TR[1]-SF[2]-5[3]	36.1	45.8	50.0	18.0	47.2	7.0	5.6	9.7	0.0
TR-SO-1	66.7	72.2	70.8	30.6	47.2	45.8	0.0	7.0	8.4
RR-SO-5	51.4	26.6	2.8	26.8	2.8	2.8	16.6	0.0	0.0
GL-SO-3	55.0	57.8	70.7	43.2	34.8	60.6	33.1	2.8	16.6
Overcup Oak									
TR-F-4	74.6	86.1	86.1	59.6	50.0	26.4	23.6	7.4	22.2
TR-SF-1	55.6	40.3	59.7	36.1	25.0	23.6	13.6	9.1	5.0
RR-SF-5	50.0	61.2	57.0	45.0	47.8	61.1	12.8	5.0	22.2
RR-SO-3	29.4	45.0	66.7	7.8	18.9	5.6	0.0	5.0	0.0
Water Hickory									
RR-SF-4	52.2	52.2	79.0	42.2	42.2	52.8	11.9	29.4	21.6
RR-SO-2	39.4	62.8	83.3	23.4	42.8	55.6	5.0	10.6	27.8
RR-F-1	50.0	68.8	72.2	45.8	61.1	72.2	40.3	52.8	68.0
RR-F-2	63.9	63.9	73.6	63.9	41.4	51.4	63.9	33.3	19.4
GL-SF-4	57.8	72.4	72.4	50.6	60.6	56.1	35.8	21.6	19.4
Black Willow									
TR-F-3	88.1	100.0	100.0	75.2	83.6	95.4	41.2	79.0	72.8
RR-F-4	63.4	63.4	72.4	60.6	58.8	58.4	58.4	32.8	35.0
Baldcypress									
GL-F-2	66.1	73.9	100.0	47.8	53.4	75.0	16.1	21.1	75.0
SB-F-2	100.0	100.0	100.0	95.8	79.2	100.0	83.4	76.4	95.8
ANOVA RESULTS (one way by forest type)[4]									
Sugarberry	52.3	50.6	48.6	29.6	33.0 a	29.0 a	13.8	4.9 a	6.2 a
Overcup Oak	52.4	58.2	72.6	37.1	35.4 a	29.2 a	12.5	6.6 a	12.4 a
Water Hickory	52.7	63.9	76.1	45.2	51.6 ab	57.6 ab	31.4	29.5 ab	31.2 ab
Black Willow	75.8	81.7	86.2	67.9	71.2 b	76.9 b	49.8	55.9 b	53.9 b
Baldcypress	83.0	87.0	100.0	71.8	66.3 b	87.5 b	49.8	48.8 b	85.4 c
F test	2.50	2.09	3.21	2.84	3.29	4.51	2.00	5.01	9.96
p-value	0.099	0.145	0.052	0.072	0.049	0.019	0.159	0.013	0.001

[1]WMAs: TR=Three Rivers, RR=Red River, GL=Grassy Lake, SB=Spring Bayou.
[2]Soil mapping unit: SO=Sharkey clay, occasionally flooded, SF=Sharkey clay, frequently flooded, F=Fausse clay.
[3]Plot identification number.
[4]Numbers with same letters within column are not different, using Duncan's Test at α=0.05.

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types all had mean oxygen depleting conditions at 100 cm of 72.6 % or more of the growing season.

The duration of redox potentials low enough to deplete nitrate (Eh $\leq$ 220 mV) was significant (at α=0.05 level) at 50 cm and 100 cm, but not at 25 cm. At 50 cm and 100 cm depths, the Black Willow, and Baldcypress types have about double the nitrate depletion period (71.2 % to 87.5 % of the growing season) of the Sugarberry and Overcup Oak forest types, which ranged from 29.2 % to 35.4 % of the growing season. The Water Hickory forest type had intermediate nitrate depleting durations at 50 and 100 cm depth.

The Sugarberry and Overcup Oak forest types had significantly shorter mean durations of iron reducing conditions (Eh $\leq$ 120 mV) at 50 cm and 100 cm than the Black Willow and Baldcypress forest types. At 50 cm, these drier types had mean cumulative growing season durations of iron reduction of only 4.9 to 6.6 %. Black Willow and Baldcypress had mean durations at 50 cm of 48.8 to 55.9 %. Water Hickory again had an intermediate duration. At 100 cm depth, Baldcypress forest type had the longest iron reducing duration of 85.4 % of the growing season, and Black Willow followed with a mean of 53.9 % cumulative duration of inundation. The Sugarberry and Overcup Oak forest types had significantly shorter mean iron reducing condition durations of 6.2 to 12.4 % at 100 cm.

Correlation of Hydric Soil Condition Variables

Table 39 reports the correlations of mean growing season durations of hydric soil condition variables with each other. Inundation duration had a high correlation

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Table 39. Correlations of durations of hydric conditions with each other, and their associated p-values.

	Inund	Sat25	Sat50	Sat100	Ox25	Ox50	Ox100	Nit25	Nit50	Nit100	Fe25	Fe50	Fe100
Inund	1.0000	0.9442	0.7885	0.7534	0.8308	0.8562	0.6667	0.7945	0.8442	0.8452	0.6352	0.8137	0.8183
	0.0	0.0001	0.0002	0.0005	0.0001	0.0001	0.0035	0.0001	0.0001	0.0001	0.0061	0.0001	0.0001
Sat25		1.0000	0.8850	0.8116	0.9362	0.8923	0.6109	0.8838	0.8247	0.7560	0.7028	0.8036	0.7817
		0.0	0.0001	0.0001	0.0001	0.0001	0.0092	0.0001	0.0001	0.0004	0.0017	0.0001	0.0002
Sat50			1.0000	0.8111	0.9155	0.7439	0.4232	0.8459	0.6624	0.6082	0.6291	0.6127	0.6296
			0.0	0.0001	0.0001	0.0006	0.0906	0.0001	0.0038	0.0096	0.0068	0.0089	0.0068
Sat100				1.0000	0.7630	0.8957	0.7528	0.8289	0.8705	0.8032	0.5944	0.6840	0.7309
				0.0	0.0004	0.0001	0.0005	0.0001	0.0001	0.0001	0.0119	0.0025	0.0009
Ox25					1.0000	0.7993	0.5362	0.9086	0.6636	0.6674	0.6795	0.6839	0.6832
					0.0	0.0001	0.0265	0.0001	0.0037	0.0034	0.0027	0.0025	0.0025
Ox50						1.0000	0.8235	0.7827	0.8945	0.7873	0.5375	0.7036	0.7658
						0.0	0.0001	0.0002	0.0001	0.0002	0.0261	0.0016	0.0003
Ox100							1.0000	0.5661	0.7564	0.7288	0.3494	0.5742	0.6862
							0.0	0.0179	0.0004	0.0009	0.1693	0.0159	0.0024
Nit25								1.0000	0.7385	0.7625	0.8661	0.7722	0.7376
								0.0	0.0007	0.0004	0.0001	0.0003	0.0007
Nit50									1.0000	0.8209	0.5597	0.7919	0.7779
									0.0	0.0001	0.0195	0.0002	0.0002
Nit100										1.0000	0.6065	0.7634	0.8659
										0.0	0.0098	0.0004	0.0001
Fe25											1.0000	0.7255	0.6064
											0.0	0.0010	0.0099
Fe50												1.0000	0.8334
												0.0	0.0001
Fe100													1.0000
													0.0

(0.9442, p-value = 0.0001 with the duration of saturation at 25 cm. Saturation at 25 cm was also highly correlated (0.9362, p-value = 0.0001) with the duration of oxygen depleted conditions at the same depth. The duration of nitrate depleted conditions at 25 cm was most correlated (0.9086, p-value=0.0001) with oxygen depleting conditions at that depth. Inundation duration was more highly correlated with the reducing conditions of iron at 50 cm (0.9137, p-value=0.0001) and 100 cm (0.8183, p-value =0.0001) than at 25 cm (0.6352, p-value=0.0061).

Species Flood Tolerance and Hydric Conditions

Flood Tolerance Index (FTI) weighted averages calculated for the monitoring plots were correlated highest with duration of nitrate depleted conditions at 50 cm (-0.8173, p-value<0.001), inundation hydroperiod (-0.7984, p-value<0.001), and flood frequency map unit (-0.7760, p-value<0.001)(Table 40). A higher FTI value indicates less tolerance to flooding, hence the negative correlation. Oxygen depleting conditions duration at 25 cm (-0.7585, p-value<0.001), saturation period at 25 cm (-0.7461, p-value =0.001), and iron reducing condition durations at 50 cm (-0.7343, p-value=0.001) and 100 cm (-0.7338, p-value=0.001) were also highly negatively correlated with FTI.

Hydroperiods and Reducing Conditions of Selected Plots

There were four patterns of inundation and water table movement observed for the 17 hydric soil conditions monitoring plots: backwater flooding only, ponding only, ponding and backwater flooding, and no ponding or backwater flooding. The first condition was inundation from backwater flooding only, with no ponding. These

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Table 40. Correlations of Flood Tolerance Index (FTI) with hydric soil conditions variables for bottomland hardwood forest type plots in central Louisiana. Pearson product-moment correlation coeffecients and associated significance.

Hydric Soil Variable	Correlation with FTI*	p-value
Flood Frequency Map Unit	-0.7760	<0.001
Inundation duration	-0.7984	<0.001
Maximum flood height	-0.3901	0.122
Saturation duration		
at 25 cm	-0.7461	0.001
at 50 cm	-0.5868	0.013
at 100 cm	-0.5531	0.021
Oxygen depleting conditions		
at 25 cm	-0.7585	<0.001
at 50 cm	-0.7003	0.002
at 100 cm	-0.5340	0.027
Nitrate depleting conditions		
at 25 cm	-0.6303	0.007
at 50 cm	-0.8173	<0.001
at 100 cm	-0.6445	0.005
Iron reducing conditions		
at 25 cm	-0.4453	0.073
at 50 cm	-0.7343	0.001
at 100 cm	-0.7338	0.001

*FTI is scaled from 2.5 for the most flood tolerant bottomland forest species to 6.5 for the least flood tolerant bottomland forest species.

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plots occurred on convex, microhigh topographic relief, and had predominantly downward moving water tables, where the water in the 25 cm piezometers was at shallower levels than water in the 50 cm piezometers, which had a higher head than water in the 100 cm piezometers. TR-SF-5 (Sugarberry forest type), TR-SF-1 (Overcup Oak forest type), GL-SO-3 (Sugarberry forest type), and RR-SF-4 (Water Hickory forest type) plots were characterized by this pattern.

Three plots were not flooded by backwaters, but were ponded only: TR-SO-1 (Sugarberry), RR-SF-5 (Overcup Oak), and RR-SO-2 (Water Hickory). These plots occurred on concave, microtopographic low relief. Soils in these plots had static water tables at least part of the time during the growing season.

Some plots had ponding and backwater flooding. They were situated in the lowest topographic positions, and were mostly in Fausse soil mapping units. These plots had the highest flood levels, longest duration of inundation, and static water tables. Plots displaying this hydrologic pattern were: TR-F-3 and RR-F-4 (Black Willow), TR-F-4 (Overcup Oak), SB-F-2 and GL-F-2 (Baldcypress), GL-SF-4, RR-F-1, and RR-F-2 (Water Hickory).

Results from the piezometers and soil redox electrodes of four plots, representing each of the four hydrologic pattern are discussed. Also the driest plot and the wettest plots of this research will be discussed.

The backwater flooding only condition was represented by TR-SF-5, a Sugarberry forest type plot, which was located on a minor slough ridge or old bayou levee with a convex slope shape, within the Sharkey clay, frequently flooded

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mapping unit. It was flooded briefly by backwater Mississippi River water in both 1994 and 1995 (Figure 17). The 25 cm piezometers had water for several months in the early spring both years. Only in 1995 did water stay in the 50 cm piezometers for more than brief periods. The 100 cm depth piezometers never had water levels equal to those of the 25 or 50 cm piezometers, so the soil at 100 cm was probably not fully saturated, or water in the piezometers at that depth indicated water movement through the profile. The 200 cm depth piezometers were overtopped in the flooding. Bypass flow or water moving through the profile could account for the rest of the water in the 200 cm piezometers. The redox potential at 50 cm was below 200 mV for several months both years, and dropped below 100 mV briefly both years. Redox at 25 cm did not exhibit such low levels except for brief periods. Redox at 100 cm never dropped below 200 mV.

The second hydrology pattern, ponding only, was exemplified by an Overcup Oak forest type plot, RR-SF-5, which occurred in a micro-low position within Sharkey clay, frequently flooded map unit on Mississippi River alluvium within Red River WMA. This site was ponded for long periods during the winter and spring of both 1994 and 1995 (Figure 18). The 25, 50, and 100 cm piezometers had about equal levels of water in them during that time, indicating a stagnant water table. Redox potentials during those wet periods remained below 200 mV for all three depths for an extended duration. Redox at 25 cm even remained below 150 mV for several months.

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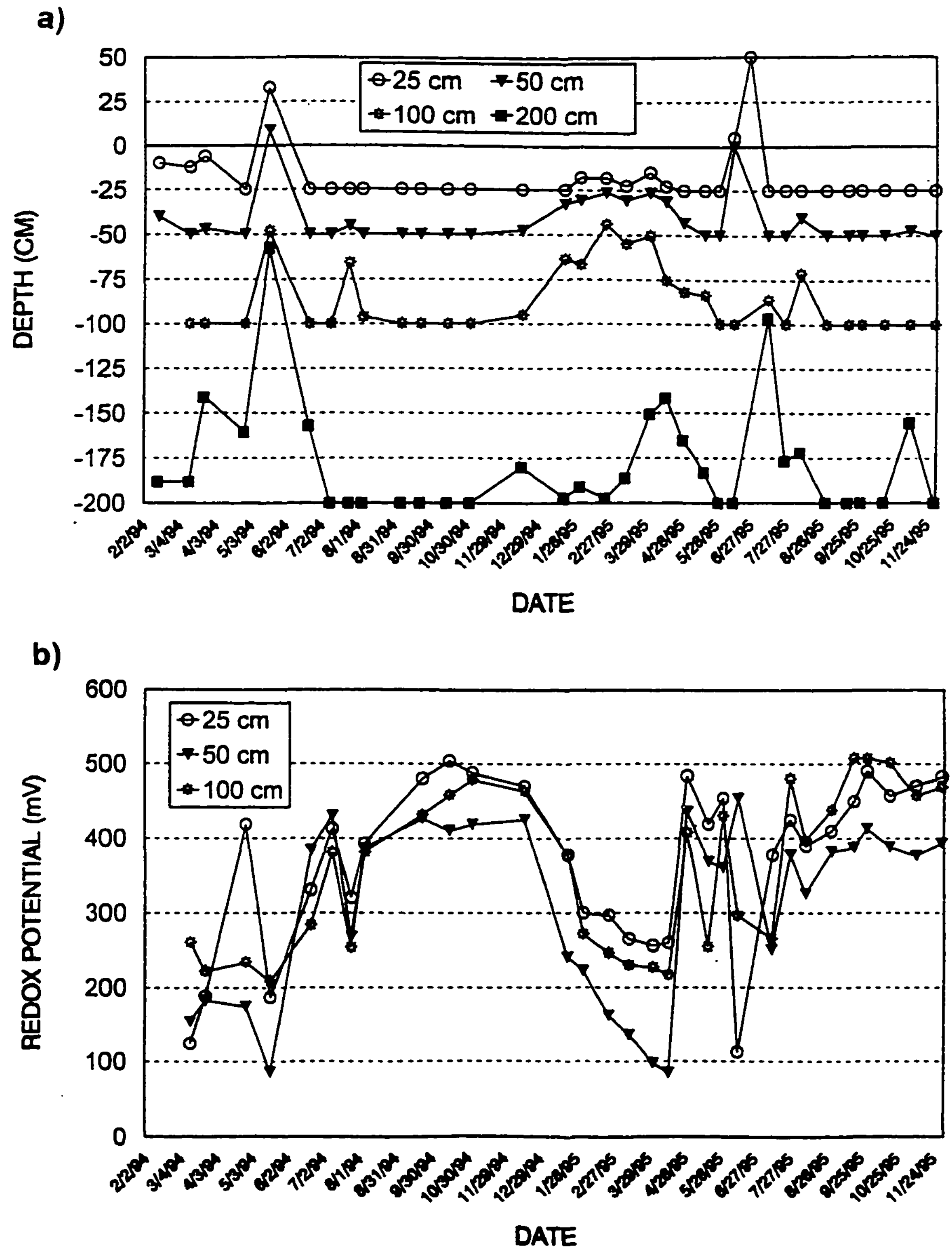

Figure 17. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Sugarberry forest type plot TR-SF-5, Sharkey clay, frequently flooded mapping unit on Three Rivers Wildlife Management Area.

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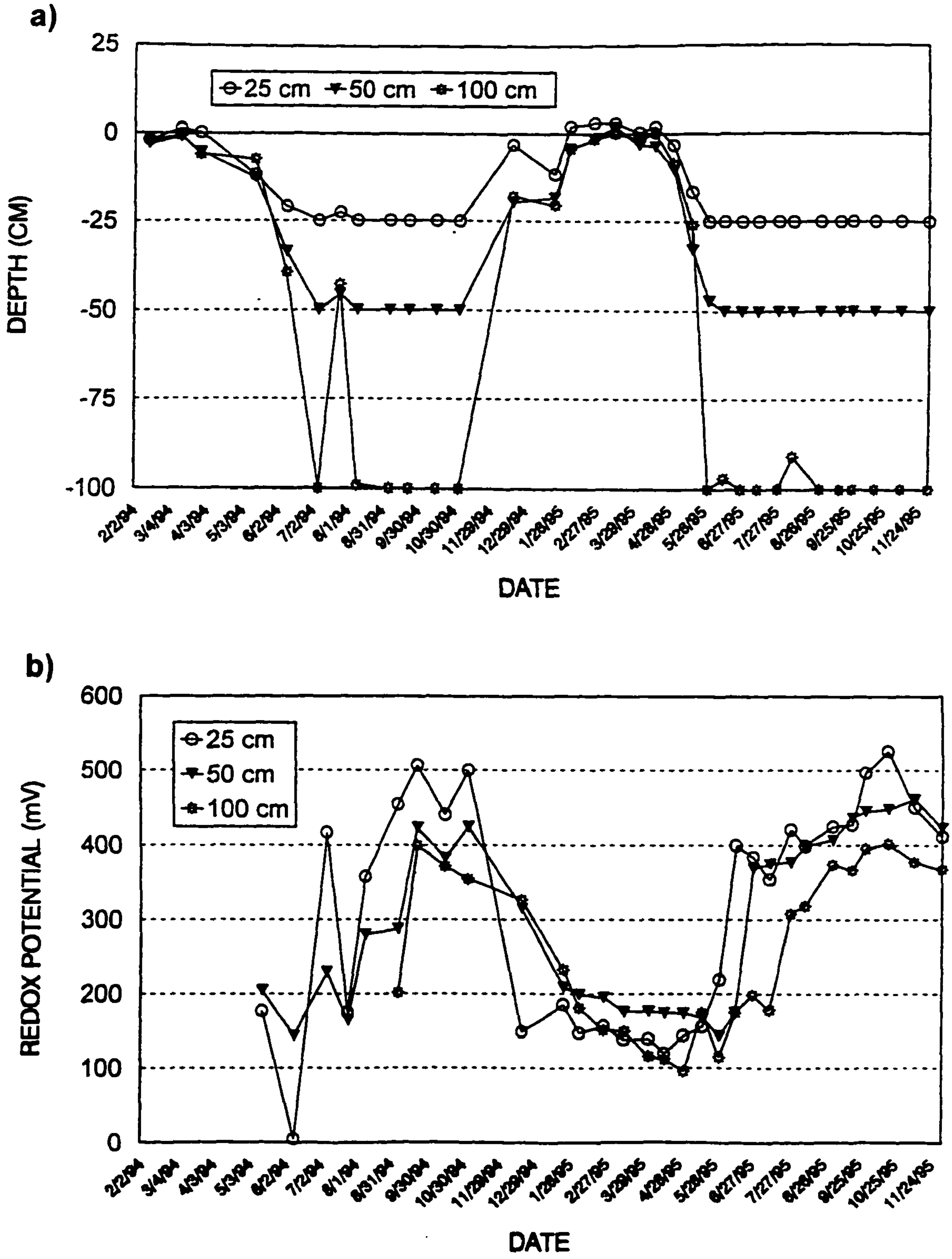

Figure 18. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Overcup Oak forest type plot RR-SF-5, Sharkey clay, frequently flooded mapping unit on Red River Wildlife Management Area.

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The third type of hydrology, ponding and backwater flooding, was present in TR-F-3, a Black Willow forest type plot located in a large ponded area of the Fausse clay mapping unit. It was ponded from February through August both 1994 and 1995 (Figure 19). During this period of ponding in 1995, the 25, 50, and 100 cm piezometers had the same level of water measured, indicating saturation down to 100 cm. Piezometers at 50 cm and 100 cm depths were not installed until August and October 1994, when the ponding was over. In October of both years, the 25 cm and 50 cm depth piezometers became dry. The 100 cm piezometers became dry or nearly so soon after. The redox potential at 25 cm was below 200 mV for extended periods during the spring and summer of 1994 and 1995, including periods less than 150 mV. During March and April of both years, however, the redox climbed above 200 mV. This seems unusual, since the site was ponded for such a long duration. There are several possible explanations: i) a great amount of rainfall moved oxygen down to 25 cm, or ii) black willow and other hydrophyte roots leaked oxygen into the root zone. The presence of many oxidized rhizospheres to a depth of 1 m support the latter situation. The 50 and 100 cm depth redox electrodes stayed very reduced at 100 mV or less for much of the growing season, until rising to oxidized level as the water table dropped in late September and October.

Only two plots were characterized by the third hydrology type, which had no inundation during the study time. RR-SO-5 is situated in an occasionally flooded Sharkey clay map unit. There is 25 cm of Red River derived soil over Mississippi River alluvium. Although the soil is saturated at 25 cm for an extended period in the

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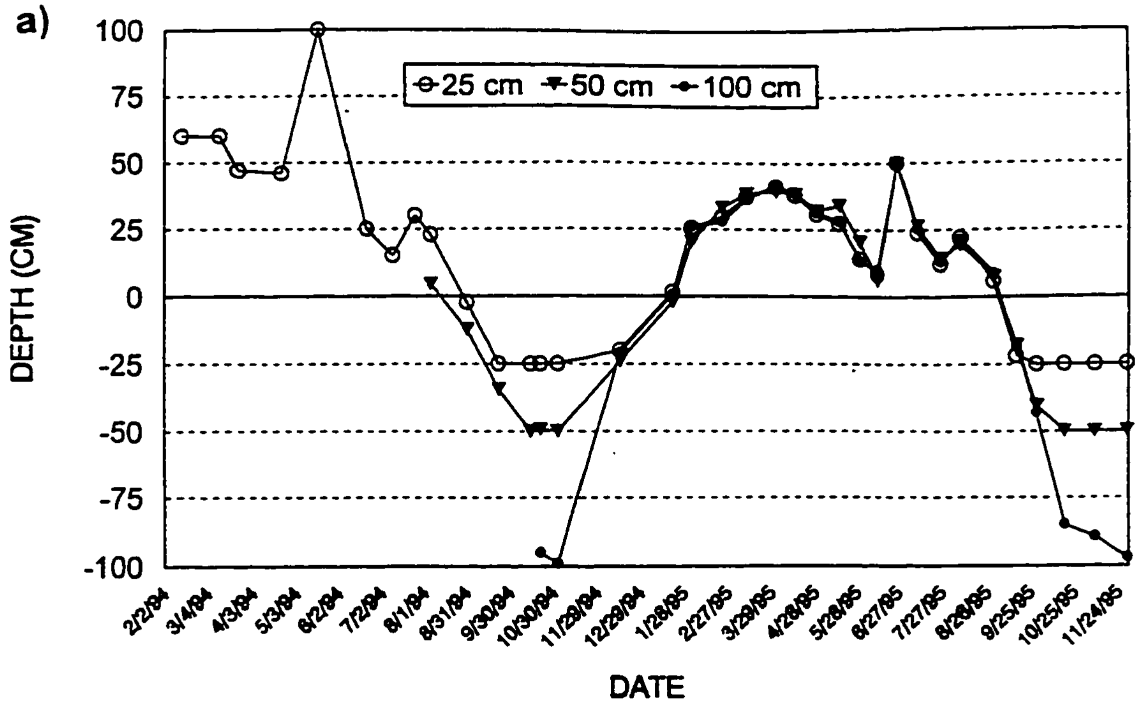

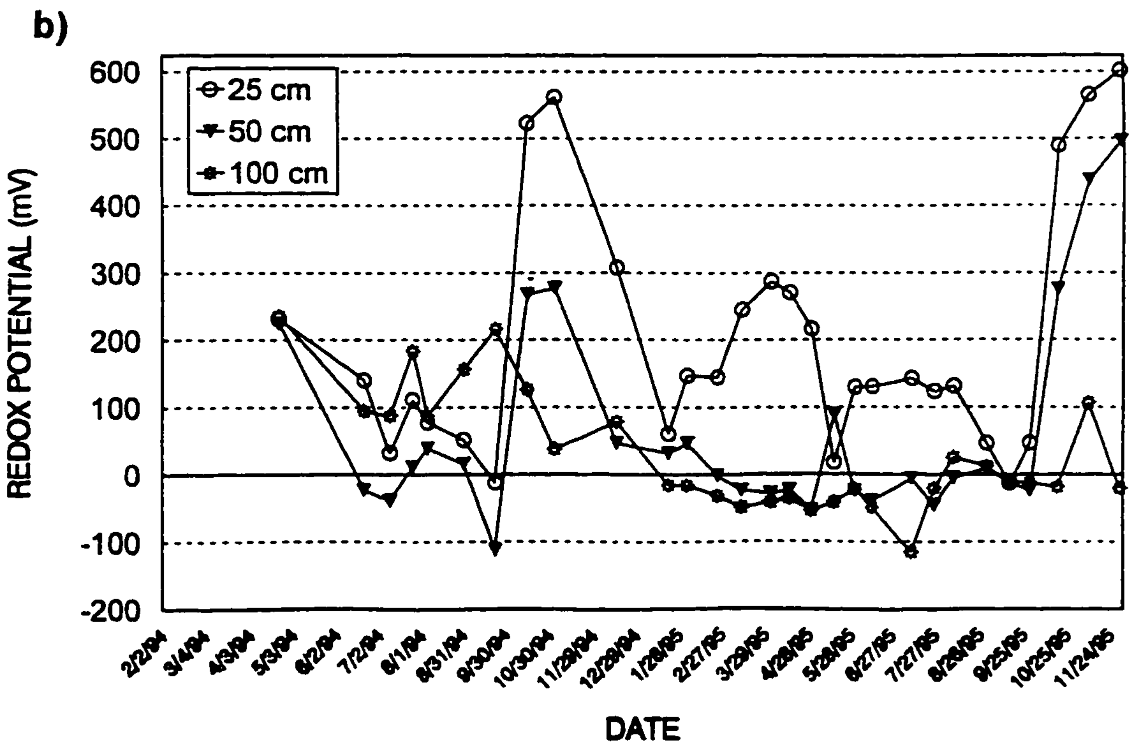

Figure 19. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Black Willow forest type plot TR-F-3, Fausse clay mapping unit on Three Rivers Wildlife Management Area.

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spring, the soil is dry at 25 and 50 cm for long periods in the summer and fall (Figure 20). In 1995, but not 1994, the 25 and 50 cm piezometer's water levels often coincided. The 100 cm and 200 cm piezometers largely remained dry, indicating episaturation above these depths. During the spring of 1995, redox potential at 25 cm fell to 100 or less for several months. In 1994, however redox at 25 cm only dropped to 200 mV. Redox at 50 and 100 cm seldom fell much below 300 mV.

The driest plot was an Overcup Oak forest type site, RR-SO-3, which was situated on a micro-high position within the Sharkey clay, occasionally flooded map unit in Red River WMA. Only the 25 cm piezometers had any water for other than very brief periods (Figure 21). The only extended period with a water table within 25 cm was during the winter and early spring of 1995. During this period, redox potential at 25 cm dropped from oxidized levels to 200-250 mV. Redox at 50 cm declined to just below 200 mV. Redox potential measured at 100 cm fell only to levels just below 300 mV during the wet period.

SB-F-2, classified in the Baldcypress forest type, is in a swamp in a Fausse clay map unit in Spring Bayou WMA. The site was flooded most of the time in 1994 and 1995, except for periods in the fall (Figure 22). The 50 and 100 cm piezometers dried out only in 1995 during this time. The piezometer at 200 cm, although having water in it continually, never achieved a piezometric head with the shallower pipes except when high floodwaters overtopped it. This inequality suggests episaturation, where a layer between 100 and 200 cm was not saturated. The

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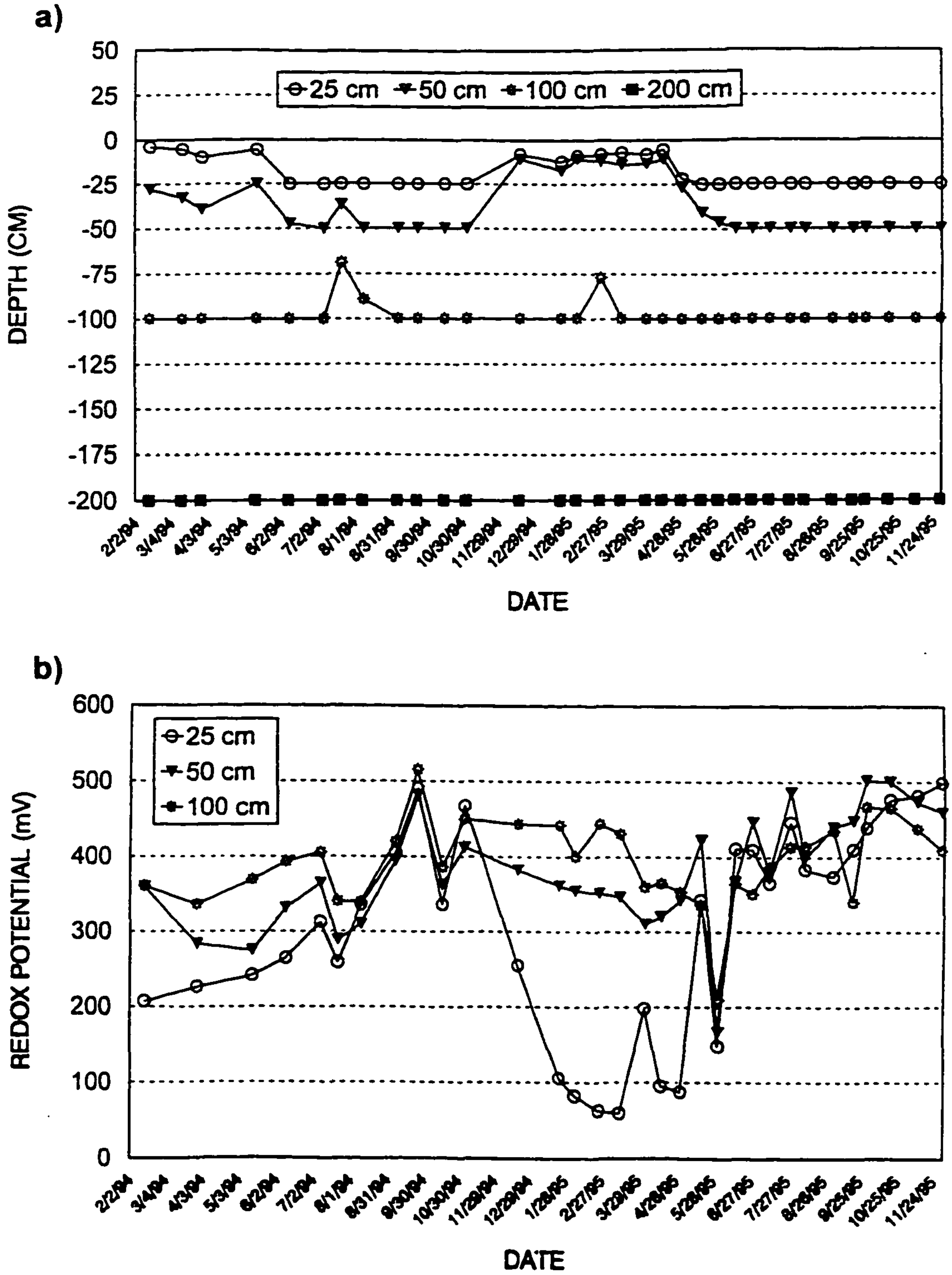

Figure 20. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Sugarberry forest type plot RR-SO-5, Sharkey clay, occasionally flooded mapping unit on Red River Wildlife Management Area.

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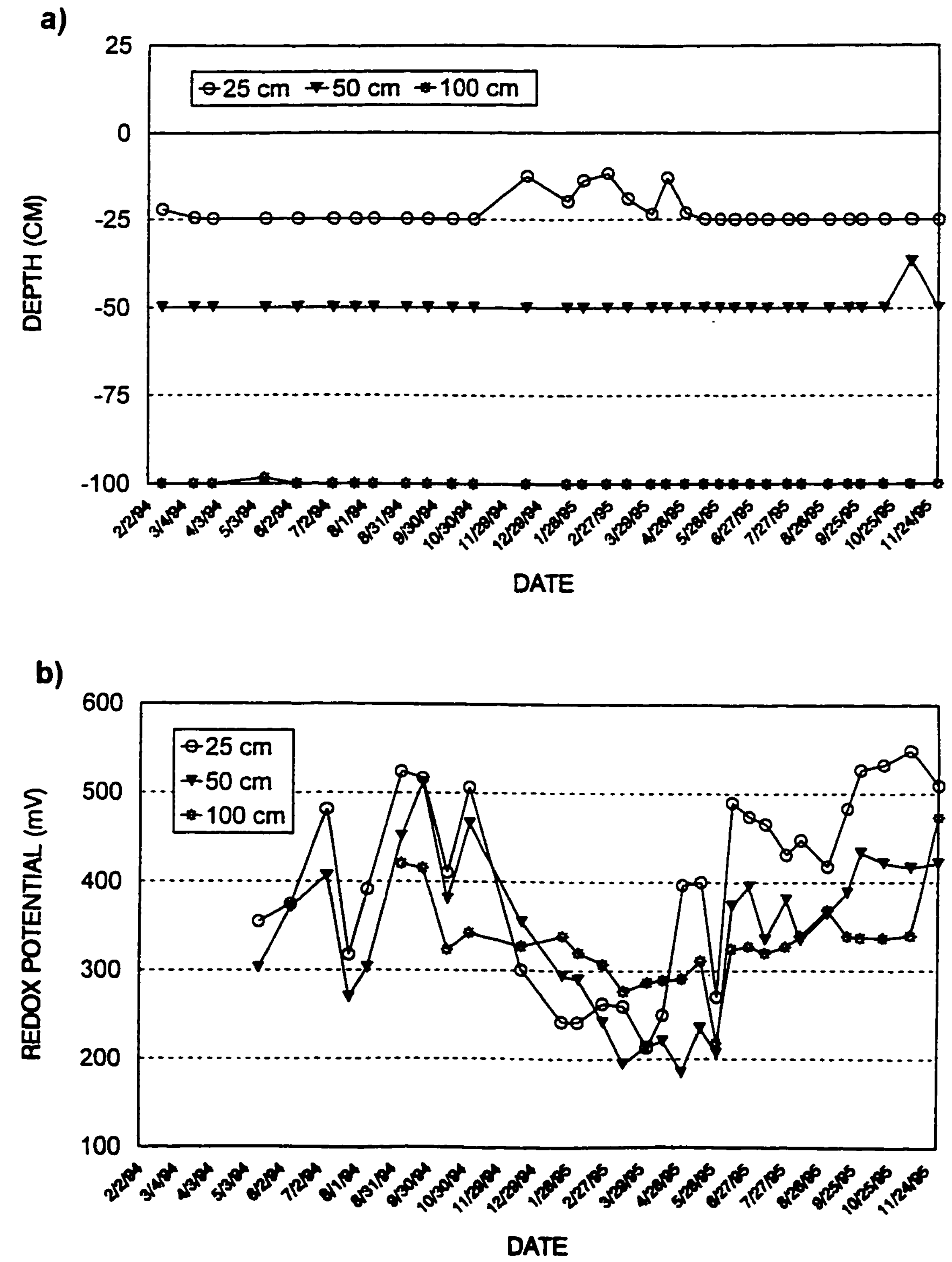

Figure 21. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Overcup Oak forest type plot RR-SO-3, Sharkey clay, occasionally flooded mapping unit on Red River Wildlife Management Area.

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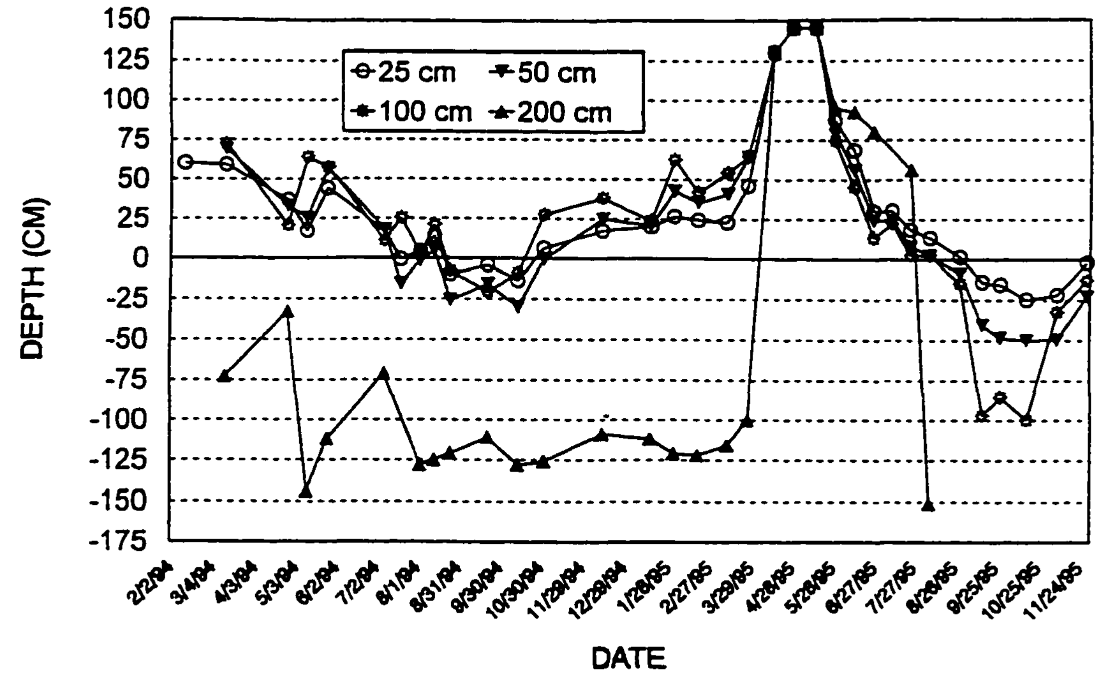
a)



b)

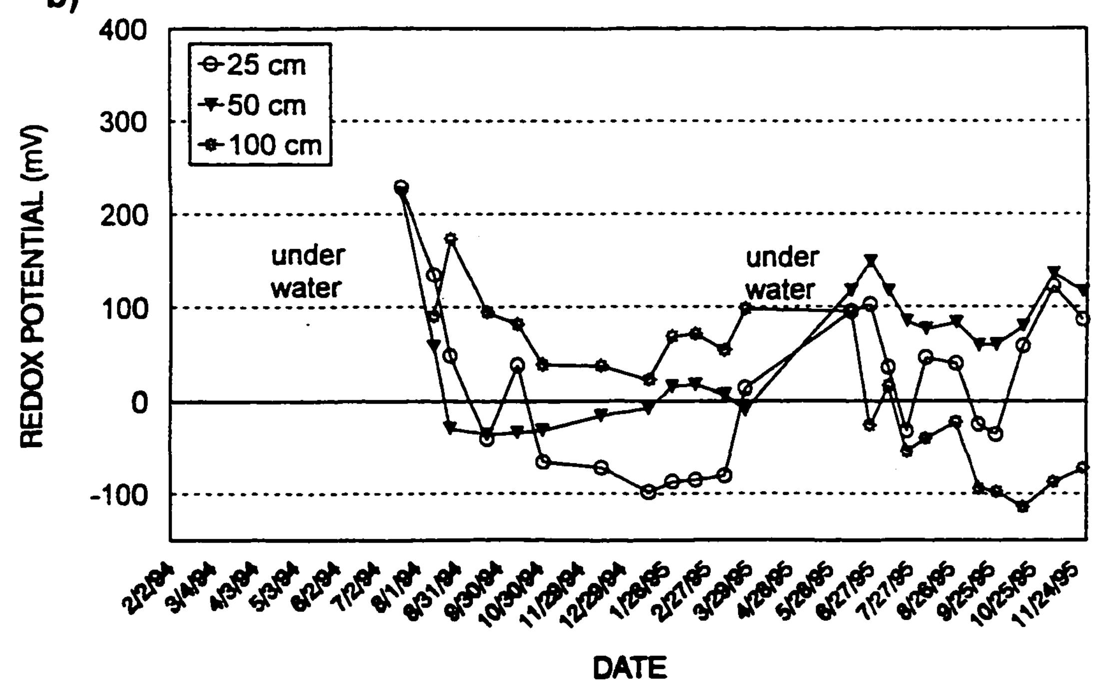


Figure 22. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Baldcypress forest type plot SB-F-2, Fausse clay map unit on Spring Bayou Wildlife Management Area.

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measured redox potential rose above 100 mV only for brief periods during the measurement period for all three depths.

DISCUSSION

Researchers at the Lake Lanier Bottomland Hardwood Wetland Conference (Larson et al. 1981, Huffman and Forsythe 1981) classified six hydrologic zones for southeastern U.S. bottomland hardwoods. The 1987 Corps of Engineers Wetland Delineation Manual later modified these zones (COE 1987). The forested zones with their expected growing season inundation or saturation durations and frequencies include Zone II: Semipermanently to nearly permanently inundated or saturated (75 to 100 % of the growing season); Zone III: Regularly inundated or saturated (25 to 75 %, and greater than 51 years out of 100 years frequency); Zone IV: Seasonally inundated or saturated (12.5 to 25 %, and 51 years of 100 years); and Zone V: Irregularly inundated or saturated (5 to 12.5 % and 11 to 50 years of 100 years. Touchet et al. (1990) concluded there is a direct correlation between hydrology, soil series mapping units, and bottomland hardwood plant communities. Zone II species such as baldcypress, water tupelo, and black willow are commonly found on Maurepas, Barbary, and Fausse soils in the Mississippi River floodplain. Zone III soils include the clayey Sharkey and Alligator, and support water hickory and overcup oak. Zone IV hydrology typically has sugarberry, sweetgum, green ash and others on loamier soils (Commerce, Dundee, Tensas and Tunica).

Most of the plots in the study area in Central Louisiana bottomland forests exhibit Zone II (Baldcypress, Black Willow) and III (Overcup Oak, Water Hickory)

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hydrology. A few Sugarberry and Overcup Oak sites would fall in Zone IV. based on lack of inundation and short duration, low frequency saturation.

Sugarberry is rated as weakly tolerant to waterlogging, and green ash (*Fraxinus pennsylvanica*), a major component of the Sugarberry forest type, is rated as moderately tolerant (Hook. 1984). Both species have the hydrophytic classification of facultative wetland plants (Reed, 1988). Overcup oak and water hickory are rated as highly waterlogging tolerant, whereas black willow and baldcypress are recognized as most tolerant to waterlogging. The last four species mentioned are all classified as obligate wetland species (Reed, 1988). Theriot (1993) calculated the following Flood Tolerance Index values for the species: Sugarberry 4.84, green ash 4.44, overcup oak 3.73, water hickory 3.54, black willow 2.83, and baldcypress 2.97. The number corresponds to the average National Wetland Technical Council (Larson et al. 1981) floodplain hydrology zone of 2.5 (II) through 6.5 (VI), where 2.5 is the wettest and 6.5 is the driest.

Bedinger (1979), related southern Arkansas bottomland hardwoods to duration and frequency of flooding and found stands dominated by overcup oak and water hickory were flooded annually, for durations of 29-40 % of the year. Sites with dominant vegetation of sugarberry and Nuttall oak with significant overcup oak presence were flooded 10 to 21 % of the time (annual basis). Phipps (1979) used data from Bedinger (1971) from southern Arkansas in a bottomland hardwood forest growth and succession model. Bedinger supplied Phipps with estimated optimal water table depths for late May to early July for a number of species. Baldcypress's

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water table was 15 cm, and flooded 30-50 % of the time. Water locust and water elm had optimal water tables at 30 cm, and flooding durations of 30-40 %. Water hickory and overcup oak had a wide range of flooding duration (less than 10 to 40 % of the time), but overcup oak had a less frequent lower range, and a deeper water table of 60 cm, as compared to water hickory's depth of 30 cm. Sugarberry also had an estimated optimal water table depth of 60 cm, and was flooded 5-35 % of the time. Green ash and Nuttall oak both had water table depths of 90 cm, and inundation up to 30 % of the time. Persimmon and honeylocust had water table depths of 1.5 m and flood durations of 0-30 % and 0-15 %. Phipps concluded that species composition of the overstory can remain basically unchanged for several decades even after hydrological alteration. This indicates a problem with measuring just one strata of vegetation for wetland delineation. Although canopy or overstory vegetation is a good long-term indicator of hydrology, the sapling and shrub level vegetation should reflect more recent hydrology.

In the bottomland forests of the Apalachicola River floodplain in Florida, Leitman (1983) estimated durations of inundation and saturation by using six parameters. She found that a water tupelo - baldcypress forest type had a median inundation of 90 % of the time, with a median saturation of 100 %. A water hickory - green ash - overcup oak - diamond leaf oak forest type had a median inundation and saturation durations of 20 %. The sweetgum - sugarberry - water oak type had less than 10 % inundation and saturation.

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Huffman (1980) investigated the effect of timing and flood frequency (within a season) on the distribution of bottomland hardwood saplings in southern Arkansas. The species in his investigation were all on the facultative end of the wetland continuum, however. Ironwood basal area had a significant high positive correlation with repeated short duration flooding at variable times in the growing season. Sweetgum had a similar correlation with early spring flooding (first 30 days), followed by short term flooding in the mid-spring. Cherrybark oak basal area has a high positive correlation with short duration flooding in the early spring. Water oak was negatively correlated with recurring flooding, and cherrybark oak and blackgum basal areas were both negatively correlated with short term flooding occurring after mid-spring.

While the Baldcypress and Black Willow forest types in central Louisiana were ponded or flooded the majority or most of the growing season, there was variation in the timing of inundation in the less wet bottomland hardwood forest types. While two of the Red River alluvium (Fausse clay mapping unit) Water Hickory forest type sites had long periods of inundation all through the early and late spring into July, two sites on Sharkey clay mapping units were inundated in the late spring by high backwater flooding. One of those sites had earlier ponding, and the other was flooded only one of the two measurement years. The Overcup Oak forest type had a wide range of inundation regimes, ranging from no inundation to long term spring ponding, to shorter term, very high backwater flooding in late spring.

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The Sugarberry forest type had a similar range, except the short-term late season flooding was much lower.

The type, height, velocity, and timing of inundation are all important regulators of bottomland forest community structure (Lugo et al. 1990). The backswamp positions of the Sharkey-Fausse soil association have several hydrogeomorphic classifications. The positions near the lower natural levees are classic riverine, receiving flowing short-term flooding. Kangas (1990) calls this a strip landscape form class, with energy distributed in unidirectional lines. Lower positions in the backswamp have even less slope, and low areas may pond water after flooding. These areas have properties of both background (sheet energy designation with no orientation) and the centers landscape forms. The latter pattern has depressional focused areas within a background network. The longer inundated or flooded Fausse sites are similar to the centers within a background, but more extreme. During high flood events, these sites may also exhibit the linear, directional flows of the strip riverine geomorphic forms. All three landscape positions within the Sharkey-Fausse association may have combinations of hydronamic flows: unidirectional flow, vertical fluctuation, and bidirectional flow (terminology from Brinson 1993). The ponded Sharkey and Fausse soils have dominantly vertical fluctuations, the lower natural levee Sharkeys have mostly unidirectional flow, and the intermediate Sharkey backswamp positions are combination mostly of those two. Typically, low-power, high-frequency floods such as backwater flooding influence seed germination and seedling survival, and medium-power, intermediate frequency

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inundation affects more long term plant distribution. High power, low frequency events form great areas of geomorphic features (Brinson 1990).

Such estimations of inundation and saturation as those of Bedinger (1979), Leitman (1983), Theriot (1993) and Huffman (1980) involve river stage data and hydrologic modeling. The models fail to take into account ponding and soil saturation from precipitation alone. The data from central Louisiana bottomland forests (many leveed) indicate that saturation from backwater flooding in May or June every year is a recharge of soils at the drying end of the saturation season. Soils in the central Louisiana bottomland hardwoods recharge in the fall due to precipitation, and have a surplus beginning in December or January. From January into May, the soil water budget is in surplus, and soils are saturated. Microlow positions pond water, and have longer and more static, oxygen deficient, reducing, shallower water tables than the convex microhigh positions, which have more moving water fronts through the profile, carrying oxygen and favoring less intense reduction.

Several researchers have directly related water table and reducing conditions in bottomland hardwood forests. In a study of Lower Mississippi Valley wetland-nonwetland transition zones, Faulkner et al. (1991) and Faulkner and Patrick (1992) measured water tables in wells, oxygen content, and redox potential. Based on those properties at 30 cm, they classified four Sharkey or very similar clayey backswamp soils (including Red River parent material soils) as wetland. Three Sharkey-like soils were classified as transitional wetland. All Fausse or the corresponding Red River Yorktown were classified wetland. Transitional wetlands were saturated, anaerobic

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(< 5% O_2) and oxygen reducing (< 300 mV) less than 30 % of the drier growing seasons of 1984 and 1985. During the wetter year 1983, the transitional wetlands were inundated, saturated, anaerobic and reduced longer.

The hydrology results from central Louisiana bottomland hardwood forests are very different from those of Pettry and Switzer (1996) in Washington County, Mississippi. They investigated several Sharkey clay soils in bottomland hardwood forests which were not inundated or ponded. Pettry and Switzer used wells at 25 cm, 50 cm, 100 cm, and 300 cm to measure water table, and also applied α-α'dipyridyl to indicate the presence of reduced iron. During a five year period, the three true Sharkey soils (one soil mapped as Sharkey was loamy) monitored never had measured water tables in the 25 cm or 50 cm wells, and rarely at 100 cm depth. None of the soils ever showed a positive reaction to the α-α'dipyridyl dye. These soils cracked wider than the central Louisiana Sharkey clays. The soil at 2 meters depth was also loamier than the central Louisiana counterparts. In central Louisiana, potential evapotranspiration is greater than precipitation for only 3 or 4 months, but in Stoneville, Mississippi (Pettry and Switzer 1996) evaporation exceeds precipitation for 7 months, almost the entire growing season. Vegetation at these Mississippi sites also reflects drier conditions than the central Louisiana bottomland hardwood forest sites. Mean PI for all layers at sites 1 and 3 was 2.3, and that of sites 2 and 4 was 2.9 (Pettry and Switzer, 1996).

There is considerable variation in water table depth, saturation, and reduction dynamics for soils within the forest types. This is perhaps due to i) altered

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hydrology by beaver activity or man (pumping and levees), ii) parent material (Mississippi River vs Red River alluvium), or iii) microsite topography (gilgai microhighs and microlows). Overall, vegetation composition appears to be segregated by iron reducing conditions and duration of inundation. The more obvious wetland forest types of Baldcypress and Black Willow have longer durations of oxygen depletion, iron reduction, saturation, and inundation than Sugarberry, Overcup Oak, and Water Hickory forest types. Portions of the Sugarberry and Overcup Oak forest types exhibit the least hydric soil conditions.

CONCLUSIONS

Iron reducing conditions and inundation duration best segregated the forest types. Hydrophytic vegetation, saturation duration, and oxygen depleting conditions were not as effective discriminators of forest types. In the study areas, all vegetation was hydrophytic and most soils were saturated for a significant portion of the growing season. Inundation duration and frequency, saturation duration, water table movement, and reducing intensity and duration were key to assessing the degree of wetland expression. The Sugarberry forest type has the least proportion of sites exhibiting all hydric soil conditions. The Overcup Oak and Water Hickory forest type sites predominantly meet wetland criteria. Baldcypress and Black Willow forest type sites exhibit the best expression of the wetland functions and meet all criteria of wetlands. Some of the Sugarberry forest type and the Overcup Oak type do not appear to meet the reduction requirement of the hydric soil definition, or meet it

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marginally. Also some sites in those forest types may marginally meet the consecutive growing season duration of the wetland hyrology definition.

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CHAPTER 6

SUMMARY AND CONCLUSIONS

Wetlands must meet three criteria: hydrophytic vegetation, hydric soils, and wetland hydrology. Wetland delineation and evaluation of bottomland hardwood forest, a shrinking resource in the southern United States, has been controversial because the wetland hydrology factor of the wetland definition is difficult and costly to measure, and estimates of hydroperiods vary widely.

Quantifying vegetation, soils and hydrology and investigating their relationships aids in our understanding of wetland processes and their application to wetland delineation and evaluation. Vegetation composition, soil morphology, soil physical and chemical characteristics, and soil hydrology and reducing conditions were measured on bottomland forests in backswamp and lower natural levee positions of the Mississippi and Red River floodplains. The study area consisted of Sharkey clay (frequently flooded), Sharkey clay (occasionally flooded), and Fausse clay soil mapping units within five Louisiana Wildlife Management Areas in Concordia and Avoyelles Parishes.

The objective of this research was to evaluate differences in wetland character between forest types occurring in backswamps and lower natural levees of the Missisippi and Red Rivers by: i) classifying forest communities and quantifying their hydrophytic prevalence, ii) describing soil morphology and measuring chemical and physical properties, and iii) measuring soil inundation, saturation, and reduction depth

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and duration, and reduction intensity. A second objective was to compare the morphology, chemistry, physical characteristics, and mineralogy of backswamp environment soils of the Mississippi and Red River alluvium.

Five forest types were classified in the study areas, and named for their dominant species: Sugarberry (*Celtis laevigata*), Overcup Oak (*Quercus lyrata*), Water Hickory (*Carya aquatica*), Black Willow (*Salix nigra*), and Baldcypress (*Taxodium distichum*). Sugarberry forest type is predominantly situated on occasionally flooded Sharkey clay sites with the lowest occurrence of wetland hydrology indicators. The Overcup Oak forest type was less frequent, and was concentrated on frequently flooded Mississippi River alluvium. The Water Hickory forest type was abundant on Red River alluvial sites with frequent flooding. The Black Willow and Baldcypress forest types were limited to the frequently flooded Fausse clay sites with the longest inundation duration. Soils of the Baldcypress forest type have a higher organic matter content and a lower pH than the soils of the Black Willow forest type.

Canonical correspondence and correlation analyses of species distribution and environmental characteristics datasets indicate that sugarberry and green ash (*Fraxinus pennsylvanica*) are more prevalent on the driest sites, and water elm (*Planera aquatica*), black willow, and baldcypress are concentrated on the wettest sites. Black willow importance is favored by a higher pH and less organic matter than baldcypress and water elm species. Overcup oak has a preference for

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Mississippi River alluvium, but water hickory and swamp privet (*Forestiera acuminata*) are distributed more on Red River alluvium, which has a higher pH.

The soils in the study areas are principally mapped into three units along a flooding gradient: Sharkey clay, occasionally flooded; Sharkey clay, frequently flooded; and Fausse clay, which is flooded longest. The occasionally flooded Sharkey clay soils were situated on the upper site positions of the backswamp environment and on the lower site positions of the natural levee. The Fausse clay soils occupy depressions in the backswamp interior, and the frequently flooded Sharkey clays were in intermediate site positions between the Sharkey clay, occasionally flooded and the Fausse clay. The Sharkey clay soils, which have a longer drying period, had a greater expression of the vertic morphology, with the presence of cracks, slickensides and pressure faces. The Fausse sites had higher organic matter accumulation due to lower decomposition rates under prolonged hydroperiods.

Sharkey and Fausse soil mapping units within the Mississippi River alluvium exhibited hydric soil morphology, with low chroma (2 or less) matrix and common or many distinct or prominent redoximorphic concentrations. The Sharkey and Fausse mapping unit sites on Red River alluvium did not meet the indicators of hydric soil morphology; red color from hematite pigment masked them. Many of those red-colored soils meet a testing indicator that allows a matrix chroma of 3 (with common redoximorphic depletions and/or concentrations). Backswamp soils derived from the Mississippi River had a higher clay content, lower silt fraction,

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lower pH, higher subsoil Mg and K levels, lower surface base saturation, and lower Ca/Mg ratios than those derived from Red River sediments. The Red River soils also had accumulations of calcium carbonate in the Bss and Bssk horizons. Horizons from both environments had clay fractions dominated by smectite, with lower amounts of illite and kaolinite. The Mississippi River alluvial soil had a higher smectite content than soils formed in Red River alluvium. Horizons in the red-colored soils also had chlorite present.

The Sugarberry and Overcup Oak forest types had shorter mean cumulative durations of inundation than the Black Willow and Baldcypress types. The durations of soil saturation at 25 cm, 50 cm , and 100 cm depths were not significantly different between the five forest types. Sugarberry forests had the highest proportion of sites with downward moving water tables during the wet season. The Water Hickory, Black Willow, and Baldcypress forest types exhibited stagnant water tables. Durations of oxygen depleting conditions were not significantly different at any depth for the forest types. Black Willow and Baldcypress forest types had longer mean nitrate and iron reducing condition durations at 50 and 100 cm than those of the Sugarberry and Overcup Oak forest types.

All vegetation surveyed in this study in the clayey backswamps and lower natural levees of the Mississippi River and Red Rivers was hydrophytic, with Prevalence Index less than 3. The Sugarberry forest type had the highest Prevalence Index, and therefore the least hydrophytic vegetation among the five forest types. Because of the dynamic nature of the herb layer, not all plots at that stratum could be

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measured within the same phenological time frame. Therefore, herb layer data are not reported. The herbaceous layer is more sensitive to short term shifts in hydrology, such as the seasonal wet-dry cycle. Future work should investigate the shift in species composition and abundance that occurs during these seasonal changes. Poison ivy (facultative=3) is one plant whose cover may dramatically increase during the growing season, and may increase the prevalence index for the Sugarberry, Overcup Oak, and Water Hickory forest types. If herbaceous and shrub layers were measured on paired, adjacent microhigh and microlow positions, the relationship between vegetation to microrelief could be elucidated.

The soil color morphology indicated most soils formed in Mississippi River alluvium in the study area met hydric indicators. Most plots met Depleted Matrix (F3) indicator criteria, but acceptance and use of a new testing indicator, Delta Vertic (TF11) would not allow F3 to be used in the Mississippi River Valley. This would prevent some soils which exhibited hydrophytic vegetation and wetland hydrology from being classified hydric, and thus wetland. It is possible that in areas with wetland hydrology and hydrophytic vegetation near the confluence of the Red River and Mississippi River, the alluvium may be mixed, and soil horizons with a hue of 10YR may have values of 4 and chromas of 2.

The Red Parent Material hydric soil indicator (TF2) was present within red-colored Sharkey clay mapping unit soils, but was not met on two wetter red-colored Fausse clay mapping unit soils in backswamp depressions. The requirement of a value of 4 or more prevented these soils from meeting TF2. If values of 3 were

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allowed (as the field indicators were published in 1996), these soils would meet the indicator. Pits should be excavated on adjacent microhigh and microlow areas to determine the relationships of soil morphology and color to microrelief.

Subsurface hydrology measurements in Vertisols and other soils with swelling clays are more difficult than in other soils. Special attention must be placed on sealing the area directly above the soil water entry into the piezometer, as well as the area near the soil surface, so as to minimize bypass flow. Multiple depths of piezometers are essential to interpreting the depth, thickness and movement of the water table. Investigation of the hydrology of adjacent, paired microhighs and microlows would be a logical next step in wetland research of these areas.

Most of the backswamp and lower natural levee soils in the study area mapped as Sharkey and Fausse clays meet wetland criteria. Forests dominated by sugarberry exhibit, in comparison with the other forest types: i) higher prevalence of facultative wet species; ii) higher proportion of soils meeting only one hydric soil indicator (F3); iii) lower proportion of sites with wetland hydrology indicator present; iv) higher proportion of downwardly moving and shorter duration water tables; and v) shallower and shorter duration inundation. Results from this and similar studies should improve wetland classifications and assessment analyses such as Hydrogeomorphic Assessment (HGM). Results from this study should only be applied to flooded mapping units of Sharkey clay and Fausse clay on lower natural levees and backswamps of the Mississippi River and Red River. The relationships between microrelief and vegetation, soil morphology, and hydrology factors,

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however, need to be further investigated in bottomland hardwood forests on Sharkey clay and similar smectitic clay soils.

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APPENDIX A

SOIL PROFILE DESCRIPTIONS

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Table 41. Soil profile description for TR-SF-5 (Sugarberry forest type).

Soil identification: TR-SF-5
Location: Three Rivers Wildlife Management Area, Concordia Parish, Louisiana.
Map unit: Sharkey clay, Frequently flooded
Setting: Backswamp of Mississippi River. On minor slough ridge/ old bayou levee.
Taxonomic Classification(1996): Aeric Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): F.3. Depleted Matrix

Horizon	Depth,cm	Description
A	0-7	10YR 4/2 clay, 20 % medium 7.5YR 3/4 redox Fe masses, in ped matrix. Moderate, medium subangular blocky structure.
BA	7-21	10YR 4/2 clay, 35 % fine and medium 5YR 4/6 redox Fe masses, in ped matrix. Moderate, medium subangular blocky structure.
Bss1	21-48	10YR 4/2 clay, 20 % medium 7.5YR 4/6 redox Fe masses in ped interior. 15 % fine and medium 10YR 4/1 redox depletions along pores. Strong, medium angular blocky structure. Common, fine slickensides and pressure faces.
Bss2	48-71	10YR 4/1 clay, 20 % medium 7.5YR 3/4 redox Fe masses, inped and exped. Strong, medium angular blocky structure. Many medium slickensides and pressure faces.
Bss3	71-100	10YR 4/2 clay, 20 % medium and coarse 7.5YR 3/4 redox Fe masses, in ped interiors. 10 % fine and medium redox concentrations as pore linings. Strong, coarse angular blocky structure, with many, coarse slickensides and pressure faces.
Bss4	100-114+	10YR 4/1 clay, 30 % medium and coarse 7.5YR 4/4 redox masses, in ped interiors. Strong, coarse angular blocky structure, and many medium and coarse slickensides and pressure faces.

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Table 42. Soil profile description for TR-SF-1 (Overcup Oak forest type).

Soil identification: TR-SF-1
Location: Three Rivers Wildlife Management Area, Concordia Parish, Louisiana.
Map unit: Sharkey clay, Frequently flooded
Setting: Backswamp of Mississippi River and Red River. On slight old bayou levee.
Taxonomic Classification (1996): Aeric Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): F.3. Depleted Matrix
F.4. Depleted Below Dark Surface
F.6. Redox Dark Surface

Horizon	Depth (cm)	Description
A	0-8	10YR 3/2 clay. Moderate, fine subangular blocky structure. Cracks evident.
BA	8-19	10YR 3/2 clay, 20 % medium 7.5YR 3/3 redox Fe masses, in ped interiors. 10 % 10YR 4/2 redox depletions in ped matrix. Moderate, medium subangular blocky structure. Cracks common.
Bssg1	19-40	10YR 4/2 clay, 25 % medium 7.5YR 3/4 inped redox Fe masses. 15 % fine and medium 10YR 4/1 redox depletions in matrix. Strong, medium angular blocky structure. Medium slickensides and pressure faces common.
Bssg2	40-63	10YR 4/1 clay, 10 % fine and medium 7.5YR 3/4 redox Fe masses, inped. Strong, medium and coarse angular blocky structure. Many common slickensides and pressure faces.
Bssg3	63-90	10YR 5/1 clay, 20 % fine and medium 7.5YR 4/4 redox Fe masses, in ped interiors. Strong, coarse angular blocky structure, and many coarse slickensides.
BCg	90-125+	10YR 5/1 clay, 10 % 7.5YR 4/4 redox masses in matrix interior. Strong, coarse angular blocky structure, with few medium slickensides.

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Table 43. Soil profile description for TR-SO-1 (Overcup Oak forest type).

Soil identification: TR-SO-1
Location: Three Rivers Wildlife Management Area, Concordia Parish, Louisiana.
Map unit: Sharkey clay, Occasionally flooded
Setting: Lower natural levee/upper backswamp of Mississippi River. Ponding occurs frequently, possibly caused by beaver activity (Wildlife Manager).
Taxonomic Classification (1996): Chromic Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): F.3. Depleted Matrix

Horizon	Depth (cm)	Description
A	0-6	10YR 4/2 clay, 25 % medium 7.5YR 4/3 redox Fe masses, in ped interior. 10 % medium 10YR 4/1 redox depletions in matrix. Moderate, fine and medium subangular blocky structure.
BA	6-15	clay, no dominant matrix color. 50 % medium 7.5YR 4/3 matrix, and 50 % medium 10YR 4/1 redox depletions in matrix. Moderate, medium subangular blocky structure.
Bssg1	15-37	10YR 4/1 clay, 30 % medium 7.5YR 4/4 inped redox Fe masses. Strong, medium angular blocky structure. Many, medium pressure faces.
Bssg2	37-63	10YR 4/1 clay, 35 % coarse 7.5YR 4/4 redox Fe masses, in ped interior. Strong, coarse angular blocky structure. Many coarse slickensides and pressure faces.
Bssg3	63-90+	10YR 4/1 clay, 35 % medium and coarse 7.5YR 4/6 redox Fe masses, in ped interiors. 20 % medium 10YR 4/2 redox depletions in matrix. Strong, coarse angular blocky structure. Many coarse pressure faces.

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Table 44. Soil profile description for plot TR-F-3 (Black Willow forest type).

Soil identification: TR-F-3
Location: Three Rivers Wildlife Management Area, Concordia Parish, Louisiana.
Map unit: Fausse clay
Setting: Backswamp interior of Mississippi River, concave position.
Taxonomic Classification(1996): Chromic Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): F.3. Depleted Matrix
F.11. Depleted Ochric

Horizon	Depth, cm	Description
Ag	0-10	2.5Y4/1 clay with common (5%), fine and medium 7.5YR5/8 redox concentrations in matrix. Common (10%) 7.5YR 5/8 lining roots and pores. Common (15%), medium N5/0 redox depletions around oxidized rhizosphere. Many roots.
BAg	10-20	2.5Y4/1 clay with many (25%) medium and coarse 5YR4/6 and 10YR4/6 redox concentrations on the ped exterior. Common (15%) 7.5YR5/8 root and pore linings. Many roots.
Bssg1	20-50	2.5Y5/1 clay with common (15%), medium and coarse 5YR4/6 and 10YR4/6 redox concentrations on ped faces. Common (15%) 7.5YR5/8 root and pore linings. Common (5%), medium N5/0 redox depletions around large roots. Common roots. Weak expression of slickensides.
Bssg2	50-80	2.5Y5/2 clay with common (5%), medium 7.5YR5/8 redox Fe masses on ped faces. Common (10%) 7.5YR5/8 root and pore linings. Common (5%), medium 2.5Y5/1 redox depletions around medium roots. Common roots. Weak expression of slickensides.
Bssg3	80-105	2.5Y5/2 clay with common (5%), medium 7.5YR5/8 redox Fe masses on ped faces. Common (5%), fine 7.5YR5/8 pore linings. Common (10%) medium N5/0 redox depletions around medium roots. Few, fine and common, medium roots. Weak expression of slickensides.
BCg	105-120	N5/0 clay with common (5%) medium 7.5YR4/6 redox masses in ped interior. Common (2%) 7.5YR4/6 pore linings around roots. Few roots.
Cg	120-140	N5/0 clay with few 7.5YR4/6 redox concentrations in ped interior.

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Table 45. Soil profile description for plot TR-F-4 (Overcup Oak forest type).

Soil identification: TR-F-4
Location: Three Rivers Wildlife Management Area, Concordia Parish, Louisiana.
Map unit: Fausse clay
Setting: Backswamp of Mississippi River, but 1000 feet from the river's artificial levee.
Taxonomic Classification(1996): Chromic Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): F.3. Depleted Matrix
F.11. Depleted Ochric

Horizon	Depth, cm	Description
A	0-12	10YR4/1 clay, Common (15%) fine and medium 7.5YR4/6 redox Fe masses, in ped interior. Pore linings, 7.5YR4/6. Few (1%), fine 10YR5/1 redox depletions in matrix.
Bg1	12-25	10YR4/2 clay, common (5% each) fine and medium 5YR4/6 and 7.5YR4/6 redox Fe masses, in ped interiors. Common (15%) medium 10YR5/1 redox depletions in ped exteriors. 5YR 4/6 pore linings.
Bg2	25-32	10YR 4/2 clay, common (10 %), fine 7.5YR 4/6 inped redox Fe masses. 7.5YR 4/6 pore linings. Common (15%), fine 10YR5/1 redox depletions in matrix interior.
Bg3	32-45	10YR 4/2 silty clay loam, common (7%) fine and medium 7.5YR 4/6 redox Fe masses in ped interiors. Root and pore linings of 7.5YR4/6. Common (20%), fine and medium 10YR5/1 redox depletions in matrix interior.
Bssg1	45-70	10YR 4/1 clay, common (2%) medium 7.5YR 4/4 and few (1%), fine 7.5YR4/6 redox Fe masses, in ped interiors. 7.5YR4/6 pore linings around roots. Common (10%), fine and medium 10YR5/1 redox depletions in matrix interior. Common (15%), medium 10YR4/2 redox depletions in interior and exterior of peds. Slickensides present.
Bssg2	70-90	10YR 5/1 clay, with common (10%), medium and coarse 7.5YR 4/6 redox masses in ped interior. Pore linings of 7.5YR4/6 and 5YR4/6 around roots. Slickensides present.

Table con'd.

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Bssg3	90-110	10YR5/1 clay with many (25%) medium and coarse 7.5YR4/6 and 5YR4/6 redox concentrations in matrix interior. Pore linings of 5YR4/6 in root pores. Common (2% each), fine and medium redox depletions of 10YR4/1 and 10YR4/2.

Table 46. Soil profile description for RR-SO-2 (Water Hickory forest type).

Soil identification: RR-SO-2
Location: Red River Wildlife Management Area, Concordia Parish, Louisiana.
Map unit: Sharkey clay, Occasionally flooded
Setting: Backswamp of Mississippi River. In low area within unit which appears to be old bayou or slough.
Profile described from auger hole.
Taxonomic Classification (1996): Chromic Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): F.3. Depleted Matrix
F.11. Depleted Ochric

Horizon	Depth (cm)	Description
A	0-10	10YR 4/2 clay, common 7.5YR 4/6 redox Fe masses, and common 10YR 4/1 redox depletions, both in matrix.
Bg1	10-40	10YR 5/1 clay, many 7.5YR 4/6 redox Fe masses, on ped interiors.
Bg2	40-75	10YR 5/1 clay, common 7.5YR 4/6 inped redox Fe masses.
Bssg1	75-112	10YR 5/1 clay, common 7.5YR 4/6 redox Fe masses, inped. Strong, coarse angular blocky structure. Many coarse slickensides and pressure faces.
Bssg2	112-132	10YR 5/1 clay, common 7.5YR 4/6 redox Fe masses in ped interiors. Many coarse slickensides and pressure faces. Strong angular blocky structure.

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Table 47. Soil profile description for RR-SO-3 (Overcup Oak forest type).

Soil identification: RR-SO-3
Location: Red River Wildlife Management Area, Concordia Parish, Louisiana.
Map unit: Sharkey clay, Occasionally flooded
Setting: Backswamp of Mississippi River. On microhigh position within unit. Ten feet from area which ponds. 200 feet from shallow ditch which runs into a very deep ditch 1100 feet from site.
Profile described from auger hole.
Taxonomic Classification (1996): Chromic Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): F.3. Depleted Matrix
F.11. Depleted Ochric

Horizon	Depth (cm)	Description
A	0-10	10YR 4/2 and 10YR 4/3 clay, common medium 10YR 4/6 redox Fe masses, and common, medium 10YR 4/1 redox depletions, both in matrix.
Bg1	10-22	10YR 5/1 clay, common, medium 10YR 5/8 redox Fe masses, in ped interiors. Common medium 10YR 4/2 redox depletions in matrix.
Bg2	22-50	10YR 5/1 clay, common , medium 10YR 5/8 inped redox Fe masses.
Bg3	50-72	10YR 5/1 clay, common , medium 10YR 5/8 inped redox Fe masses.
Bssg1	72-92	10YR 5/1 clay, common, medium 10YR 5/8 inped redox Fe masses. Many medium slickensides and pressure faces.
Bssg2	92-125	10YR 5/1 clay, common, medium 10YR 5/8 inped redox Fe masses. Many coarse slickensides and pressure faces. Pockets of calcium carbonate crystals.
Bssg3	125-150+	10YR 5/1 clay, common, medium 10YR 4/4 inped redox Fe masses. Common medium slickensides and pressure faces.

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Table 48. Soil profile description for RR-SO-5 (Sugarberry forest type).

Soil identification: RR-SO-5
Location: Red River Wildlife Management Area, Concordia Parish, Louisiana.
Map unit: Sharkey clay, Occasionally flooded
Setting: Backswamp of Mississippi River, with thin overwash of Red River sediment.
Profile described from auger hole.
Taxonomic Classification(1996): Aeric Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): F.3. Depleted Matrix
TF.2. Red Parent Material

Horizon	Depth (cm)	Description
A	0-8	5YR 4/2 clay, common, medium 5YR 4/6 redox Fe masses, and common, medium 5YR 4/1 redox depletions, both in matrix.
Bw1	8-25	5YR 4/2 and 5YR 4/1 clay, with common, medium 5YR 4/6 redox Fe masses, in ped interiors.
2Bw2	25-42	10YR 4/1 clay with many, coarse 7.5YR 4/6 redox concentrations in matrix.
2Bw3	42-75	10YR 5/1 clay with many, coarse 7.5YR 4/6 redox concentrations in matrix.
2Bssg1	75-88	10YR 5/1 clay, many, coarse 7.5YR 4/6 redox Fe masses in ped interiors. Common medium coarse slickensides and pressure faces.
2Bssg2	88-138	10YR 5/1 clay, common,, coarse 7.5YR 4/6 redox Fe masses in ped interiors. Many, coarse slickensides and pressure faces.

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Table 49. Soil profile description for plot RR-SF-5 (Overcup Oak forest type).

Soil identification: RR-SF-5
Location: Red River Wildlife Management Area, Concordia Parish, Louisiana.
Map unit: Sharkey clay, Frequently flooded
Setting: Backswamp of Mississippi River, concave position.
Taxonomic Classification(1996): Chromic Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): F.3. Depleted Matrix
F.11. Depleted Ochric

Horizon	Depth, cm	Description
A	0-7	10YR 4/2 clay, 5 % fine and medium 7.5YR 5/6 redox Fe masses, on ped interior and exterior. Pore linings, 7.5YR 5/6 (3%), and 10YR 5/2 (2%). Strong, medium subangular blocky structure. Cracks evident.
BA	7-21	10YR 4/1 clay, 20 % medium 7.5YR 4/6 redox Fe masses, on ped interiors and exteriors. 10YR 5/2 redox depletions on ped exteriors. 5 % 7.5YR 4/6 pore linings. Moderate, medium angular blocky structure. Cracks present.
Bssg1	21-43	10YR 5/1 clay, 15 % medium 7.5YR 5/8 inped and exped redox Fe masses. 1 % 7.5YR 4/6 pore linings. Strong, medium angular blocky structure. Slickensides and pressure faces present.
Bssg2	43-74	10YR 5/1 clay, 15 % medium and coarse 7.5YR 4/6 redox Fe masses, inped and exped. Strong, coarse angular blocky structure. Slickensides and pressure faces.
Bssg3	74-121	10YR 5/1 clay, 12 % fine and medium 7.5YR 4/4 redox Fe masses, in ped interiors and on ped exteriors. Moderate, coarse angular blocky structure
BCg	121-150+	10YR 5/1 clay, 17 % 7.5YR 4/4 redox masses, both inped and exped. Weak, medium subangular blocky structure.

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Table 50. Profile description for plot RR-F-1 (Water Hickory forest type).

Soil identification: RR-F-1
Location: Red River Wildlife Management Area, Concordia Parish, Louisiana.
Map unit: Fausse clay
Setting: Backswamp of the Red River.
Taxonomic Classification(1996): Aeric Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): TF.2. Red Parent Material

Horizon	Depth, cm	Description
A	0-3	7.5YR3/2 clay with many (25%), fine 7.5YR4/3 and common (10%), fine 7.5YR4/6 redox concentrations as Fe masses. Common (5%), fine 10YR5/1 redox depletions on ped faces. Weak subangular blocky structure.
BA	3-21	7.5YR4/3 clay with common (2%), fine 7.5YR4/4 redox concentrations in ped interior. Common (20%), fine and medium 7.5YR4/2 redox depletions on ped exteriors. Weak angular blocky structure.
Bss1	21-38	7.5YR4/3 clay with common (10%), fine 7.5YR4/4 redox Fe masses in interior matrix. Common (10%), fine and medium 7.5YR4/2 redox depletions on ped exteriors. 7.5YR4/1 pore linings. Strong angular blocky structure. Slickensides.
Bss2	38-54	7.5YR4/3 clay, common (10%), coarse 5YR4/4 redox concentrations in ped interiors. Common (12%), medium 7.5YR4/2 and common (5%), medium 7.5YR5/1 redox depletions on ped exteriors. 7.5YR4/1 pore linings. Strong angular blocky structure.
Bssg1	54-96	7.5YR4/2 clay, common (20%), medium 5YR4/4 redox concentrations in ped interior. Many (35%), coarse 7.5YR4/1 redox depletions on ped exteriors. 7.5YR4/1 pore linings. Strong angular blocky structure.
Bssg2	96-150	7.5YR4/2 clay, with common (8%), medium 5YR5/8 ped interior redox concentrations and common (8%), meium 7.5YR4/4 exterior ped redox concentrations. Many (35%), coarse 7.5YR4/1 redox depletions on ped exteriors. 7.5YR4/1 pore linings. Strong angular blocky structure.

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Table 51. Profile description for plot RR-F-4 (Black Willow forest type).

Soil identification: RR-F-4
Location: Red River Wildlife Management Area, Concordia Parish, Louisiana.
Map unit: Fausse clay
Setting: Backswamp of the Red River.
Taxonomic Classification(1996): Aeric Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): TF.2. Red Parent Material

Horizon	Depth, cm	Description
A	0-7	5YR3/2 clay, with common (10%), medium 5YR3/3 mottles in ped interior. Common (2%), fine 5YR5/8 redox concentrations on ped exterior. 5YR4/1 pore linings around roots in matrix. <1% fine Fe/Mn concentrations (red around black). Moderate subangular blocky structure.
BA	7-22	5YR4/3 clay, common (5%) medium 5YR4/4 redox concentrations in ped interiors. Common (10%), medium 5YR4/1 and common (5%), medium 5YR5/1 redox depletions, both on ped exteriors. Moderate subangular blocky. Few weak slickensides and pressure faces.
Bss1	22-38	5YR4/3 clay, with many (30%), coarse 5YR4/2 redox depletions on ped exteriors. Common pore linings in matrix, around roots, and in ped interior of 5YR4/1. Strong angular blocky structure, with strong slickensides and pressure faces.
Bss2	38-74	5YR4/3 clay, common (10%), medium 5YR4/4 and common (5%), medium 5YR4/6 redox concentrations in ped interiors. Common (20%), coarse 5YR4/2 and common (10%), medium 5YR5/1 redox depletions on ped faces. Common 5YR4/1 and 5YR5/1 pore linings around roots. Strong angular blocky structure. Strong slickensides and prewssure faces.
Bss3	74-100	5YR4/3 clay, with common (15%), coarse and medium 2.5YR3/6 redox concentrations on ped exteriors. Common (10%), coarse 5YR4/1 and common (5%), medium 5YR5/1 redox depletions on ped faces. 5YR5/1 pore linings on ped interiors, exteriors, and around roots. Strong angular blocky structure and slickensides and pressure faces.

Table con'd.

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Cg1	100-140	7.5YR4/1 clay with common (15%), coarse and medium 2.5YR3/6 redox concentrations on ped exteriors and common (2%), fine 5YR4/6 redox concentrations in ped interiors. Common (5%), medium 7.5YR5/1 redox depletions in ped interiors and on ped exteriors. Few 5YR5/8 pore linings around roots in matrix. Strong angular blocky structure.
Cg2	140-150	7.5YR5/1 clay with common (10%) fine 2.5YR3/6 redox Fe masses in ped interiors. Common (5%), medium 10YR5/1 redox depletions in ped interiors and exteriors. Few (2%) 2.5YR3/6 pore linings.

Table 52. Profile description for plot RR-F-2 (Water Hickory forest type).

Soil identification: RR-F-2
Location: Red River Wildlife Management Area, Concordia Parish, Louisiana.
Map unit: Fausse clay
Setting: Backswamp of the Red River.
Taxonomic Classification(1996): Aeric Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): none

Horizon	Depth, cm	Description
A	0-12.5	5YR3/3 clay.
BA	12.5-25	5YR3/4 clay with common, medium, faint 5YR4/4 redox concentrations. Pressure faces.
Bss1	25-45	5YR3/4 clay with common, medium, faint 5YR4/4 redox concentrations. Few, fine, and distinct 7.5YR4/2 redox depletions. Pressure faces.
Bss2	45-57.5	5YR4/4 clay, with many, medium, distinct 5YR4/6 redox concentrations. Common, medium, prominent 10YR4/1 redox depletions. Pressure faces.
BCg	57.5-80	10YR4/1 clay, with many, coarse, distinct 7.5YR4/6 redox concentrations. Pressure faces.
Cg	80-	10YR4/1 clay, with common, medium, distinct 7.5YR4/6 redox concentrations.

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Table 53. Profile description for plot RR-SF-4 (Water Hickory forest type).

Soil identification: RR-SF-4
Location: Red River Wildlife Management Area, Concordia Parish, Louisiana.
Map unit: Sharkey clay, Frequently Flooded
Setting: Backswamp of the Red River.
Taxonomic Classification(1996): Aeric Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): TF2. Red Parent Material

Horizon	Depth, cm	Description
A	0-7.5	5YR3/3 clay.
BA	7.5-20	5YR4/3 clay.
Bw	20-40	5YR4/3 clay with many, faint 5YR4/4 redox concentrations.
Bss1	40-62.5	5YR4/4 clay, with common, prominent N5/ redox depletions. Pressure faces.
BCg1	62.5-85	2.5Y4/1 clay, with many, coarse, prominent 5YR4/6 redox concentrations. Common, faint 2.5Y5/1 redox depletions.
BCg2	85-	2.5Y4/1 clay, with many, prominent 5YR4/6 redox concentrations.

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Table 54. Soil profile description for plot SB-F-2 (Baldcypress forest type).

Soil identification: SB-F-2
Location: Spring Bayou Wildlife Management Area, Avoyelles Parish, Louisiana.
Map unit: Fausse clay
Setting: Backswamp of Red River.
Taxonomic Classification(1996): Chromic Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): F.3. Depleted Matrix
F.11. Depleted Ochric
TF.11. Delta Vertic

Horizon	Depth, cm	Description
O	5-0	Muck. Many medium and coarse roots.
A	0-6	mucky clay, 2.5Y4/1. Many medium and coarse roots. Fluid consistence.
BA	6-18	2.54/1 clay with common (7%), medium 7.5YR5/8 redox concentrations. 7.5YR4/6 root and pore linings. Common (20%), medium N5/0 redox depletions in ped interior. Firm consistence. Many fine and medium roots.
Bg	18-29	2.5Y4/1 clay with common (20%), medium and coarse 7.5YR4/6 redox Fe masses. 7.5YR4/6 root and pore linings. Common (5%) N5/0 redox depletions. Firm consistence. Common, medium roots.
2Bg1	29-50	2.5Y5/1 clay with common (20%), medium 7.5YR4/6 redox concentrations. 7.5YR4/6 pore lings in ped interiors. Common (10%), medium N5/0 redox depletions in ped interiors. Firm consistence. Few, medium roots.
2Bg2	50-70	10YR5/2 clay with many (30%), medium and coarse 5YR 5/6 redox concentrations in ped interiors. Many (30%), medium and coarse 2.5Y5/1 redox depletions in matrix. Pore linings in ped interiors of N5/0 and 7.5YR 4/6. Firm consistence. Few, medium roots.
3C	70-100	2.5Y5/1 clay with common (3%), medium 7.5YR 4/6 and common (5%), medium 10YR4/4 redox concentrations in ped interiors. Few, medium roots.

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Table 55. Soil profile description for plot GL-SO-3 (Sugarberry forest type).

Soil identification: GL-SO-3
Location: Grassy Lake Wildlife Management Area, Avoyelles Parish, Louisiana.
Map unit: Sharkey clay, Occasionally flooded
Setting: Lower position on natural levee of Bayou Natchitoches, a distributary of the Red River.
Taxonomic Classification(1996): Aeric Epiaquert, fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): TF.2. Red Parent Material

Horizon	Depth, cm	Description
A	0-5	7.5YR3/2 clay, with few (1-2%), fine 7.5YR4/1 redox depletions. Moderate, medium, subangular blocky structure.
AB	5-15	7.5YR4/2 clay, with many (25%), medium 5YR4/3 redox concentrations in matrix. Moderate, medium subangular blocky structure.
Bss1	15-29	5YR4/2 clay, common (10%), medium 5YR4/3 redox concentrations in matrix. Moderate, medium angular blocky structure. Common, fine pressure faces.
Bw1	29-41	5YR4/3 silty clay, with common (10%), coarse 5YR3/3 coatings on ped surface. Strong, medium angular blocky structure.
Bw2	41-50	5YR4/3 silty clay loam, with many (25%), coarse 5YR4/4 redox Fe masses in matrix. 5YR4/2 depletions as coatings on ped surfaces. Moderate, medium subangular blocky structure.
Bss2	50-80	5YR4/3 clay, with many (30%), medium 5YR4/1 redox depletions in matrix, and common (10%), coarse redox depletions of 5YR4/1 along pores. Strong, coarse angular blocky structure.
BCg1	80-92	5YR4/2 clay, with many (25%), medium 5YR4/1 redox depletions in matrix, and common (10%), coarse 5YR4/1 depletions along pores. Strong, coarse angular blocky structure.
BCg2	92-104+	5YR4/1 clay, common (20%), coarse 5YR4/4 and common (10%) 5YR4/3 redox concentrations as Fe masses. Moderate, medium angular blocky structure.

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Table 56. Soil profile description for plot GL-SF-4 (Water Hickory forest type).

Soil identification: GL-SF-4
Location: Grassy Lake Wildlife Management Area, Avoyelles Parish, Louisiana.
Map unit: Sharkey clay, Frequently flooded
Setting: Backswamp of Bayou Natchitoches, a distributary of the Red River.
Taxonomic Classification(1996): Aeric Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): TF.2. Red Parent Material

Horizon	Depth, cm	Description
A	0-5	5YR4/3 clay, with common (20%), medium 5YR4/6 redox concentrations in ped interiors. Common (20%), medium 5YR4/2 redox depletions on ped faces. Open cracks.
BA	5-18	5YR4/3 clay, with common (5%), medium 5YR4/4 redox Fe masses in ped interior. Common (15%), medium 5YR4/2 redox depletions on ped exterior. Open cracks.
Bss1	18-30	5YR4/2 clay, common (10%), medium 5YR4/3 redox concentrations. 2.5Y4/1 pore linings around roots. Slickensides.
Bss2	30-45	5YR3/3 clay, few (2%), medium 5YR4/4 redox Fe masses in ped interiors. Few (2%), common 5YR4/2 redox depletions on ped exteriors. Slickensides.
Bss3	45-65	5YR4/3 clay, with few (2%), medium 5YR4/6 redox concentrations in ped interiors. Common (5%), medium 7.5YR4/2 redox depletions on ped faces. Slickensides.
Bssg	65-105	2.5Y5/1 clay, many (40%) medium and coarse 7.5YR4/6 and common (5%), fine and medium 7.5YR5/8 redox concentrations. Few (<1%) 5YR5/8 pore linings in ped interiors. Slickensides.
BCg1	105-130	2.5Y4/1 clay, many (40%), medium 7.5YR4/6 redox Fe masses. Common (5%), medium 2.5Y5/1 redox depletions on ped exteriors. Few slickensides.
BCg2	130-150	2.5Y5/1 clay, with common (7%), medium 7.5YR4/6 redox concentrations. Few (<1%) 7.5YR5/8 pore linings. Few slickensides. Calcite crystals.

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Table 57. Soil profile description for plot GL-F-2 (Baldcypress forest type).

Soil identification: GL-F-2
Location: Grassy Lake Wildlife Management Area, Avoyelles Parish, Louisiana.
Map unit: Fausse clay
Setting: Backswamp interior of Bayou Natchitoches, a distributary of the Red River.
Taxonomic Classification(1996): Aeric Epiaquert, very fine, smectitic, thermic.
Field Indicators of Hydric Soils (1996): TF.2. Red Parent Material

Horizon	Depth, cm	Description
A	0-9	7.5YR3/2 clay with common (5%), fine 7.5YR4/6 redox concentrations in matrix. Common (5%), fine 7.5YR4/1 redox depletions in matrix. Weak, subangular blocky structure.
BA	9-18	5YR3/3 clay, common (10%), medium and fine 2.5YR4/8 redox concentrations in ped interiors. 5YR5/8 pore linings around roots. Many (25%), coarse 7.5YR4/1 redox depletions on ped faces. Moderate subangular blocky structure.
Bss1	18-43	5YR3/3 clay with common (2%), fine 5YR4/6 redox Fe masses in ped interiors. Common (5%), medium 7.5YR4/2 redox depletions in ped interiors. Common (8%), medium 5YR5/1 redox depletions on ped exteriors. 7.5YR5/1 pore linings on ped exteriors and roots. Strong angular blocky structure, pressure faces.
Bss2	43-74	5YR3/3 clay, with common (20%), coarse 5YR4/2 redox depletions on ped faces, and common (5%), medium 5YR4/1 redox depletions. Strong angular blocky structure.
Bss3	74-91	5YR4/3 clay, common (2%), fine 5YR4/6 redox Fe masses in ped interior. Many (25%), coarse 5YR4/2 redox depletions on ped exteriors. Common (10%), medium 5YR5/1 redox depletions. Strong, angular blocky structure.
BCg1	91-116	2.5Y5/1 clay, with common (5%), fine and medium 5YR5/8 redox concentrations in ped interior. 2.5YR4/8 pore linings in matrix around roots. Strong angular blocky structure. Abrupt upper boundary.
BCg2	116-150	2.5Y5/1 clay with common (8%), medium 5YR5/8 redox concentrations in ped interiors. 2.5YR4/8 pore linings in matrix around roots. Strong angular blocky structure

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APPENDIX B

PIEZOMETER AND SOIL REDOX DATA

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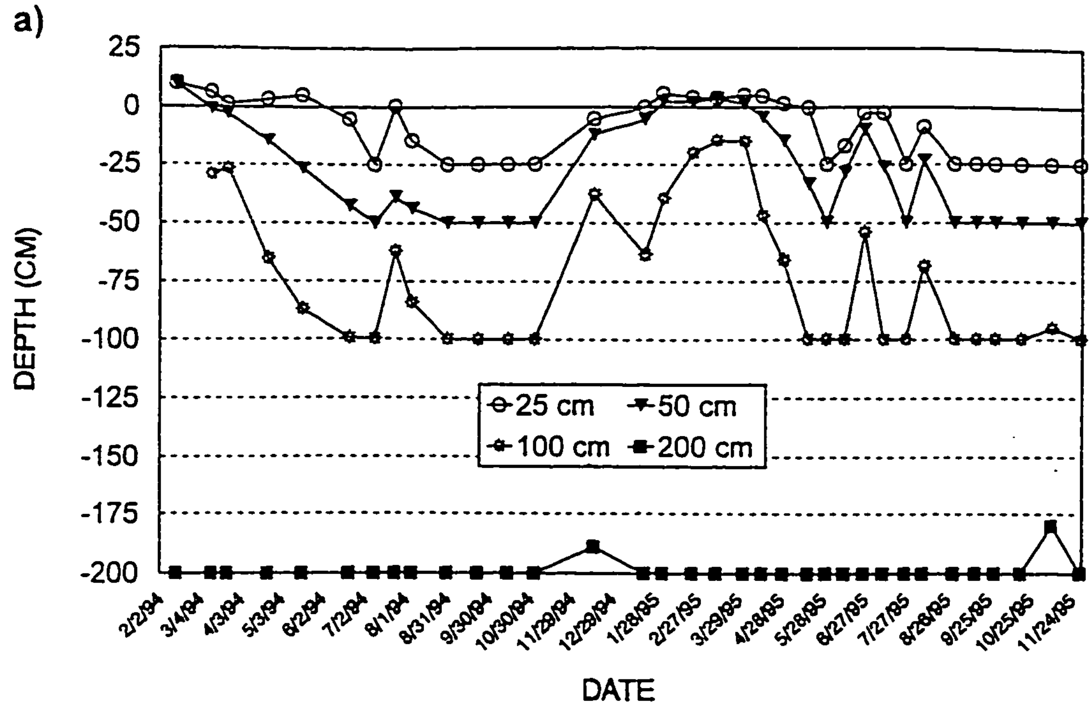
a)



b)

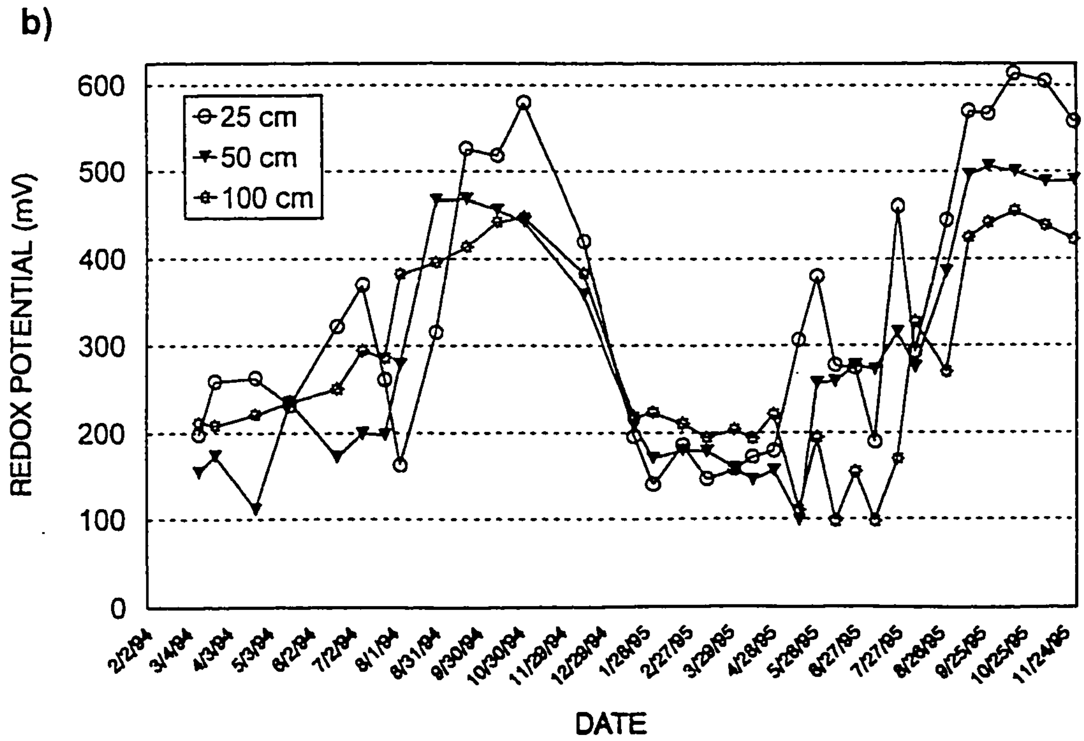


Figure 23. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Sugarberry forest type plot TR-SO-1, Sharkey clay, occasionally flooded map unit on Three Rivers Wildlife Management Area.

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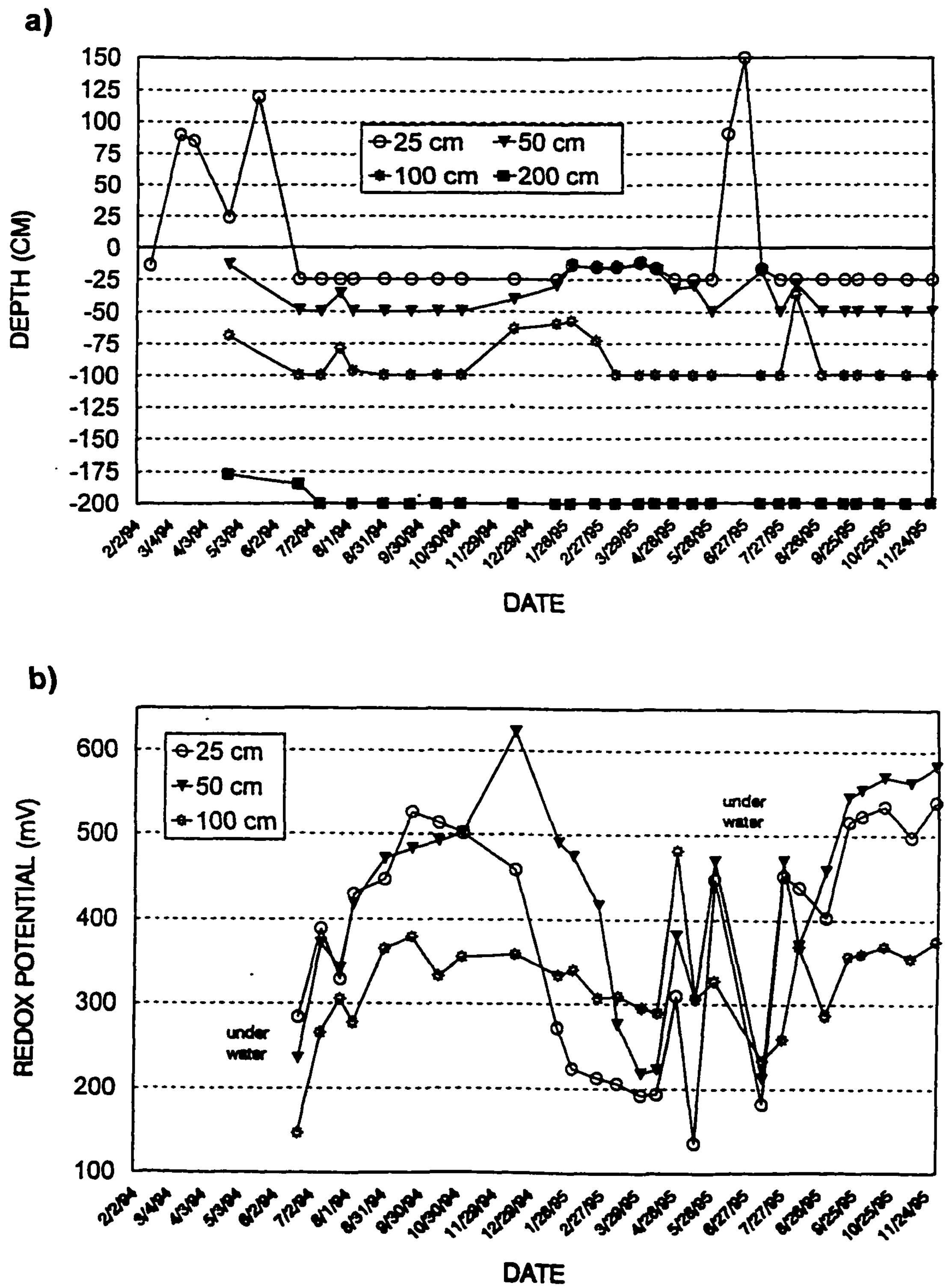

Figure 24. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Overcup Oak forest type plot TR-SF-1, Sharkey clay, frequently flooded mapping unit on Three Rivers Wildlife Management Area.

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a)

b)

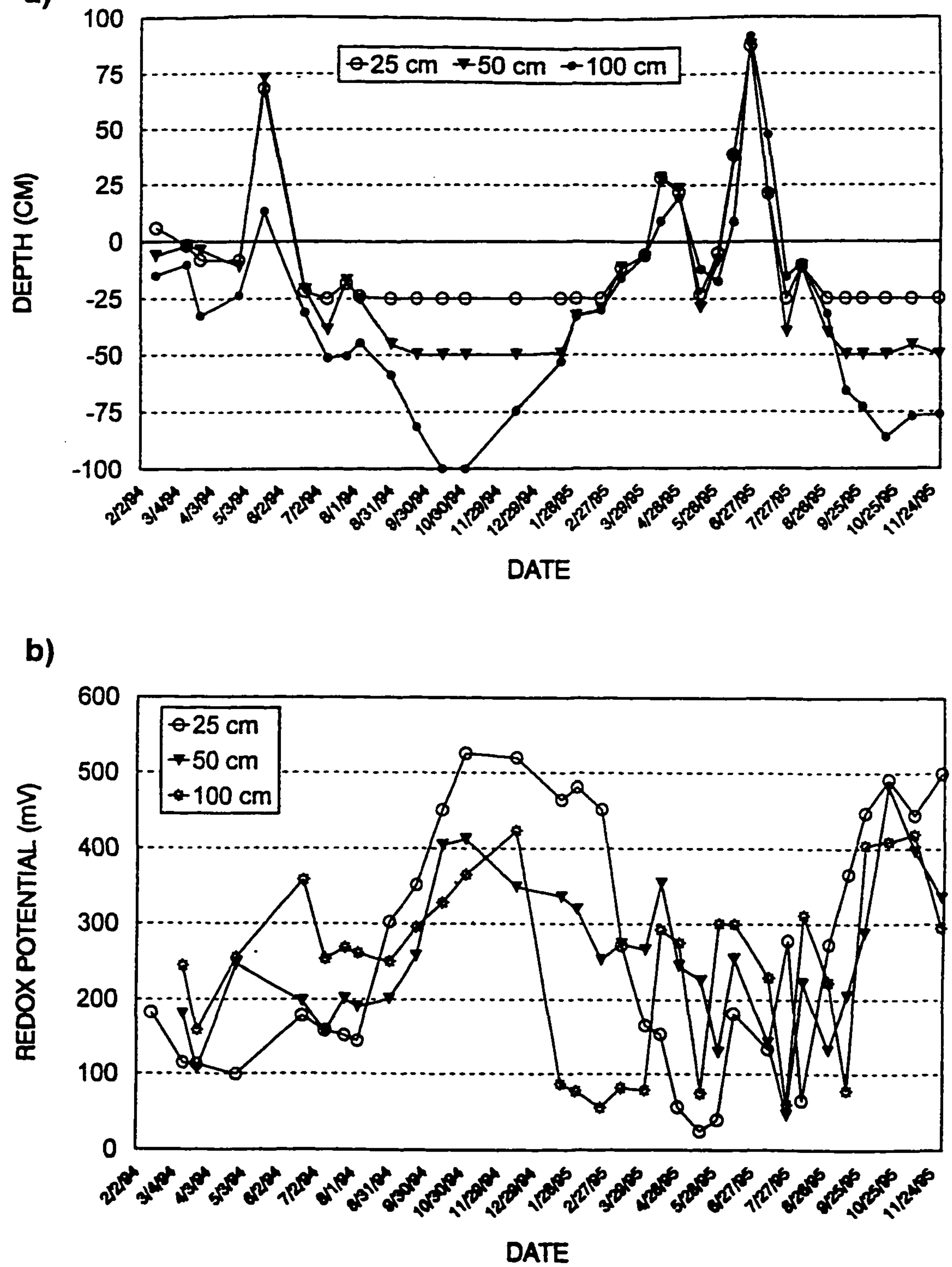

Figure 25. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Overcup Oak forest type plot TR-F-4, Fausse clay mapping unit on Three Rivers Wildlife Management Area.

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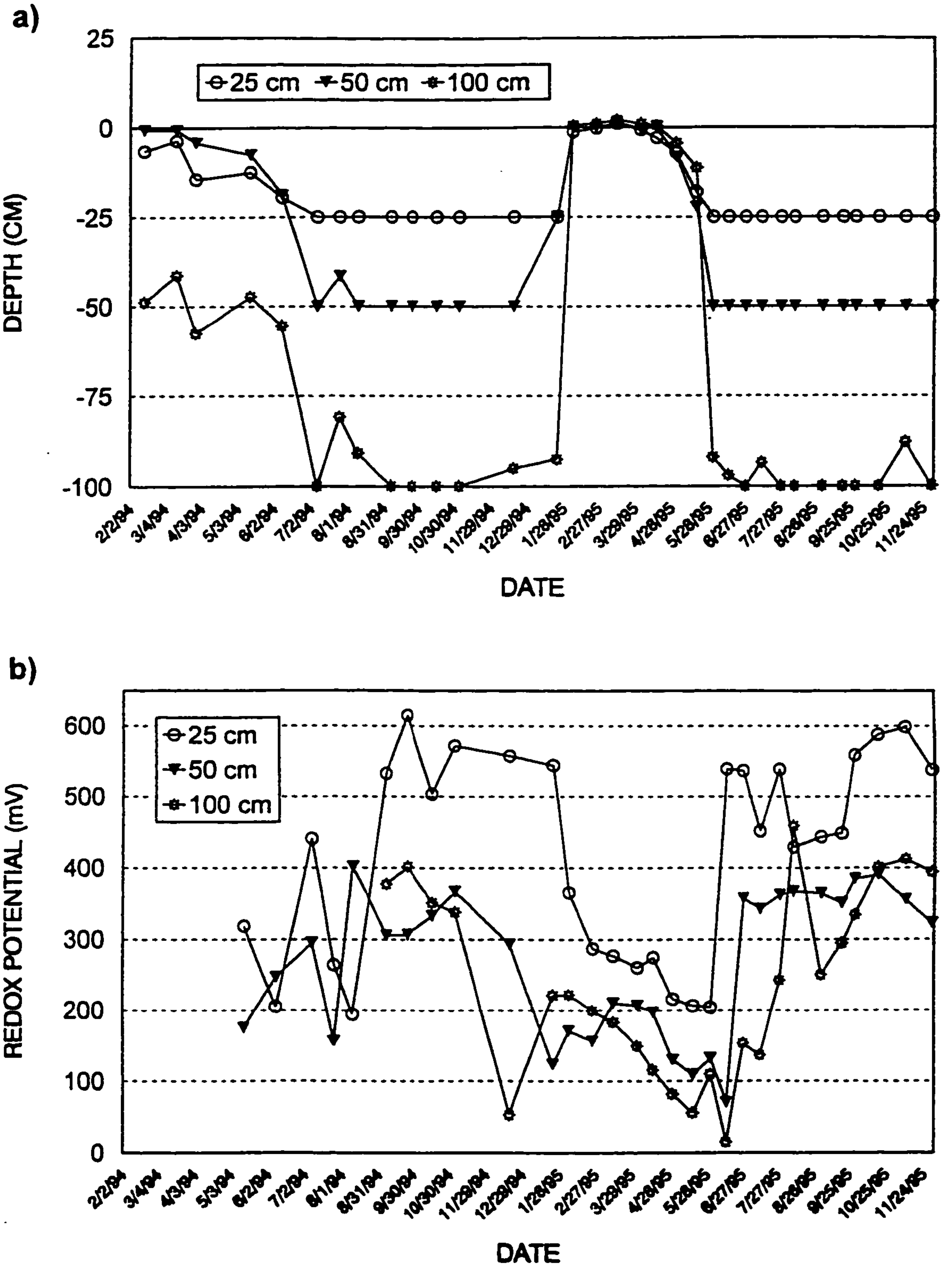

Figure 26. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Water Hickory forest type plot RR-SO-2, Sharkey clay, occasionally flooded mapping unit on Red River Wildlife Management Area.

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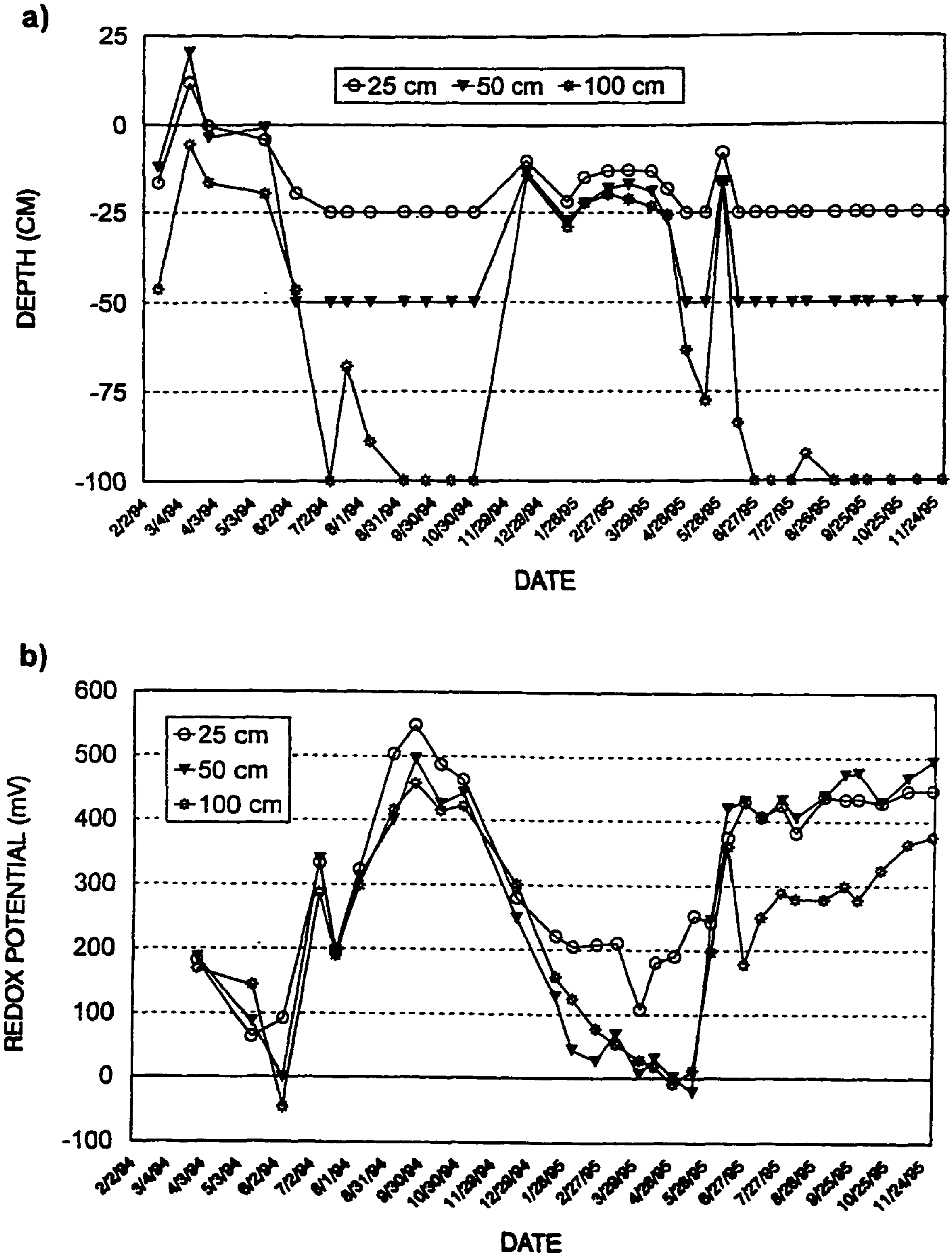

Figure 27. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Water Hickory forest type plot RR-SF-4, Sharkey clay, frequently flooded mapping unit on Red River Wildlife Management Area.

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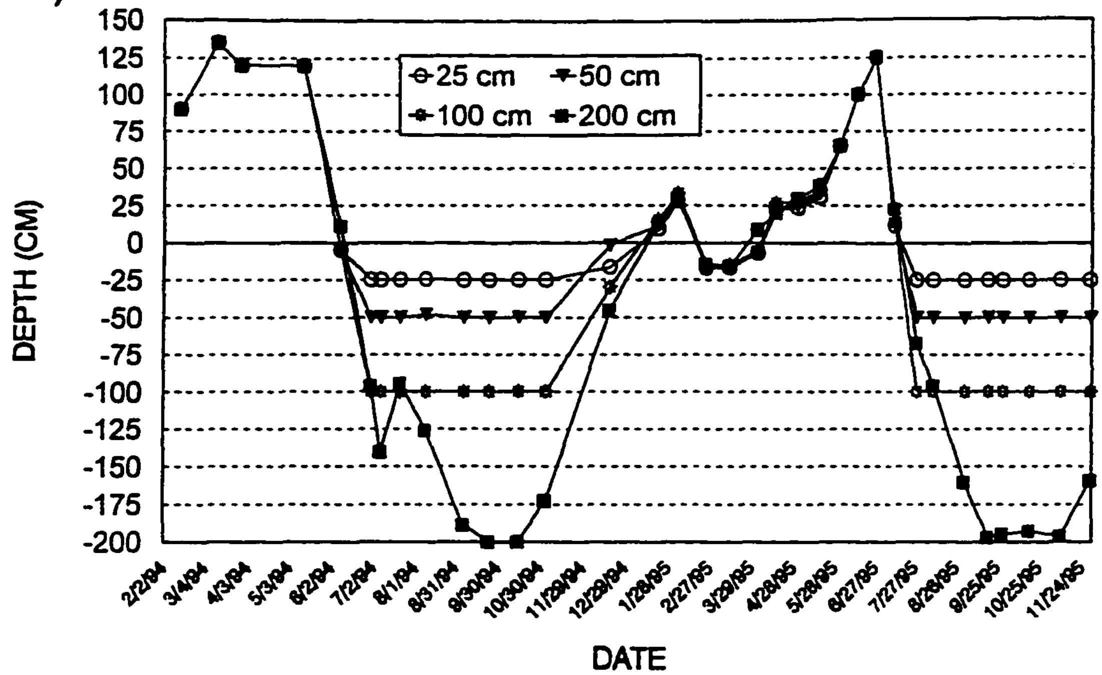
a)



b)

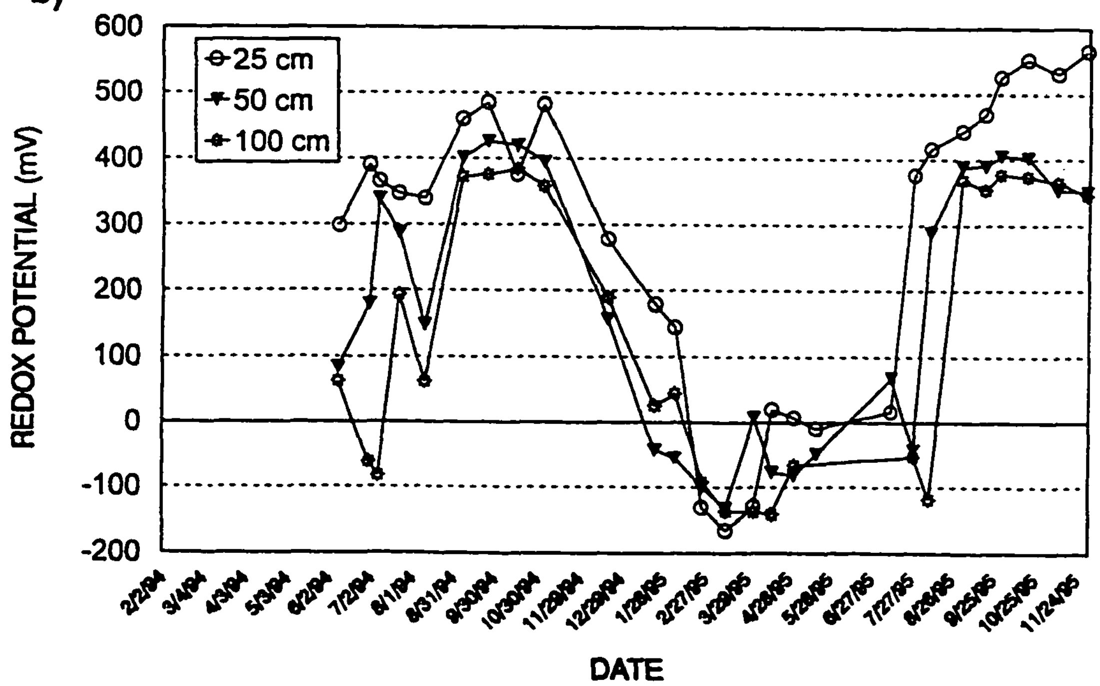


Figure 28. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Water Hickory forest type plot RR-F-1, Fausse clay mapping unit on Red River Wildlife Management Area.

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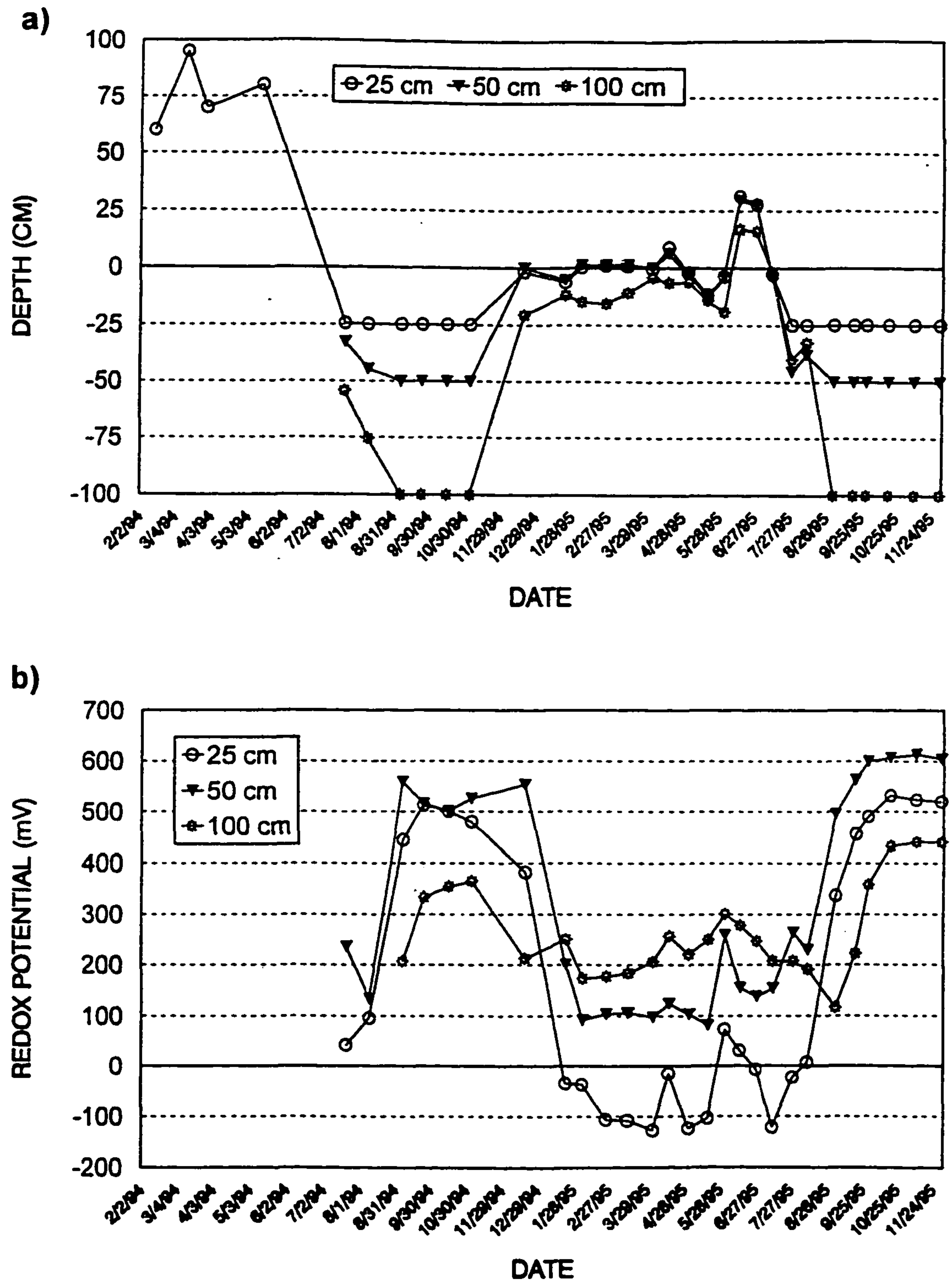

Figure 29. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Water Hickory forest type plot RR-F-2, Fausse clay mapping unit on Red River Wildlife Management Area.

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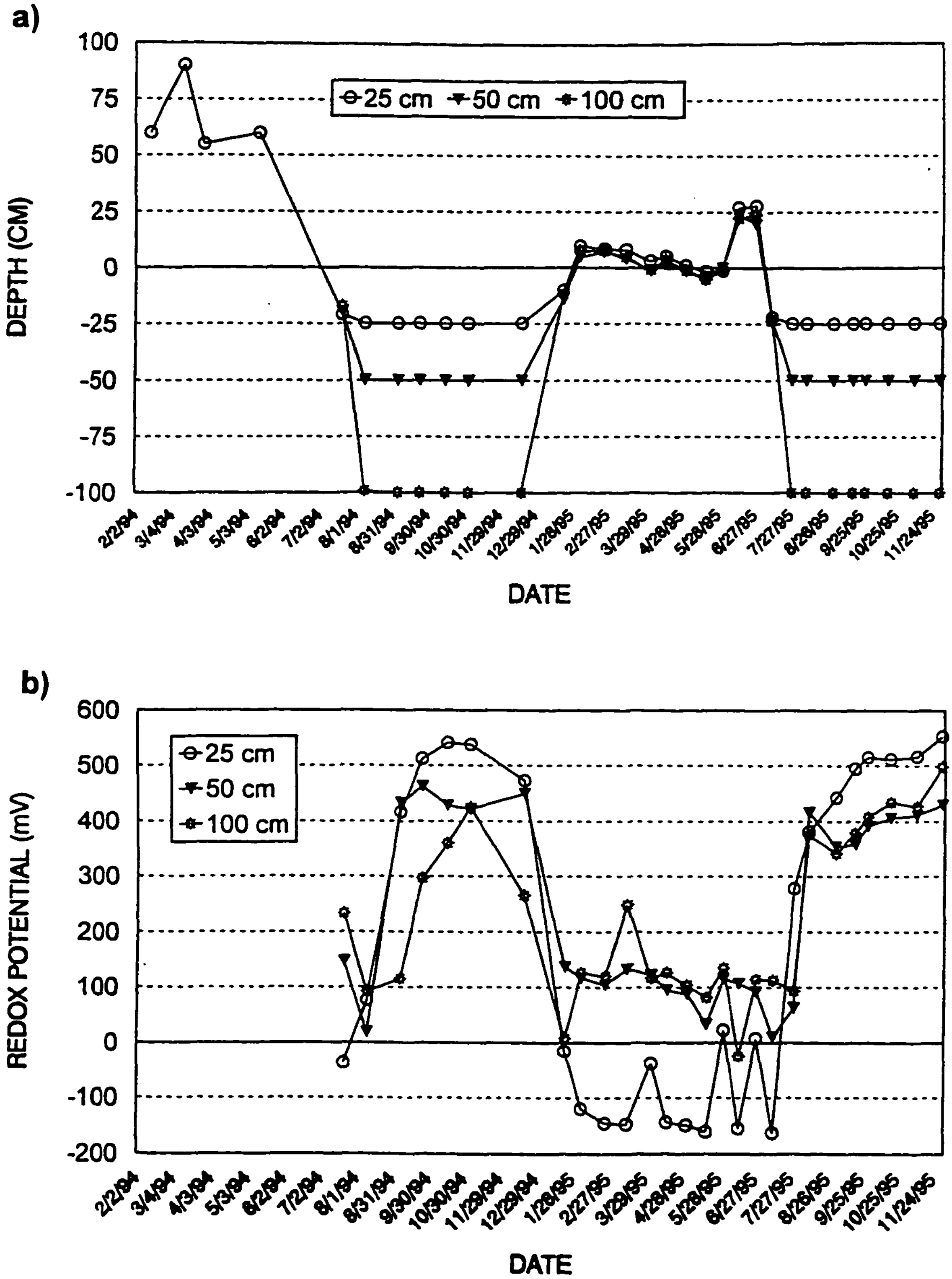

Figure 30. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Black Willow forest type plot RR-F-4, Fausse clay mapping unit on Red River Wildlife Management Area.

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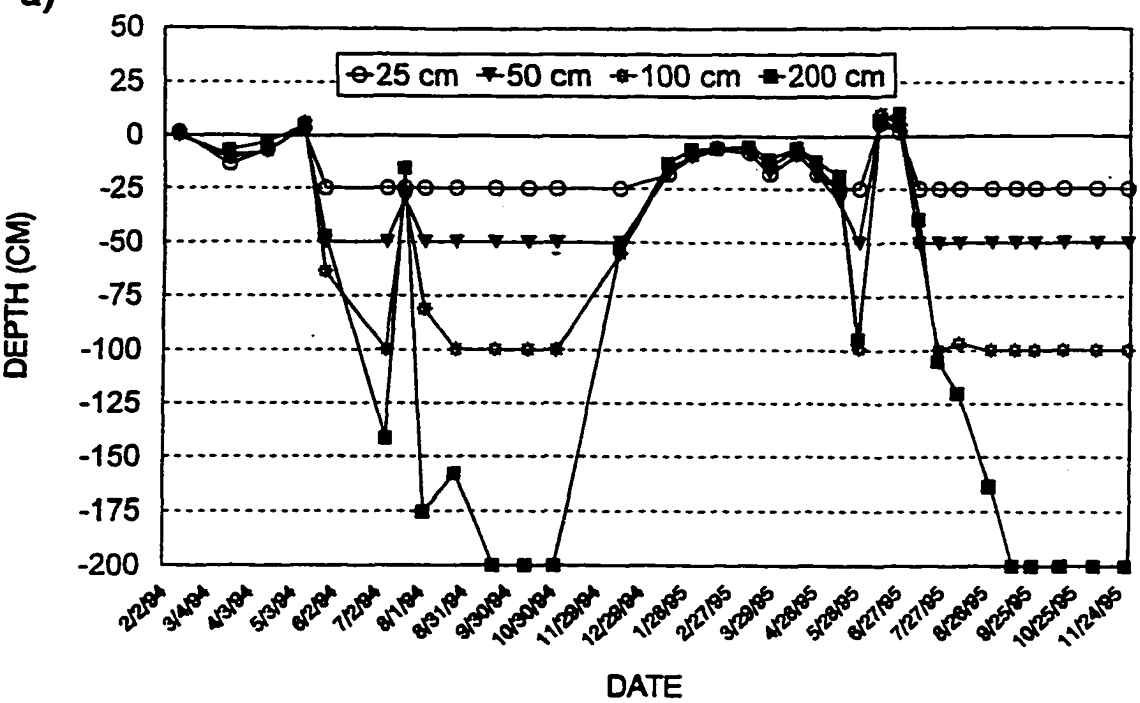
a)



b)

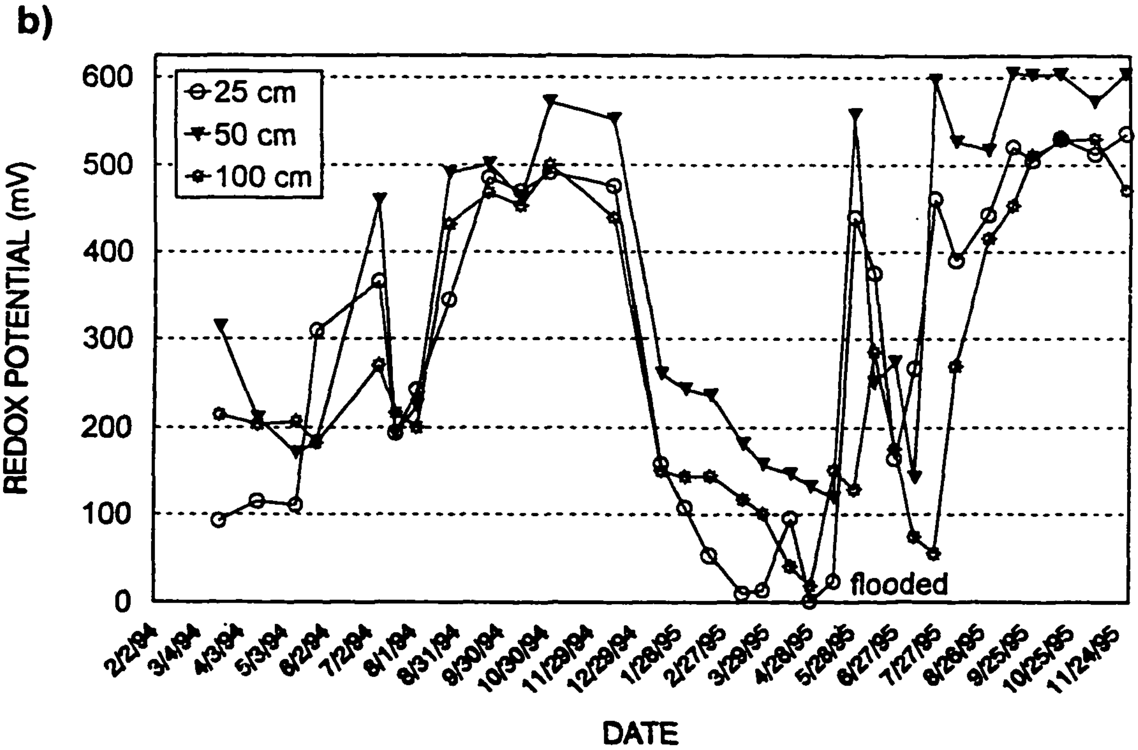


Figure 31. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Sugarberry forest type plot GL-SO-3, Sharkey clay, occasionally flooded mapping unit on Grassy Lake Wildlife Management Area.

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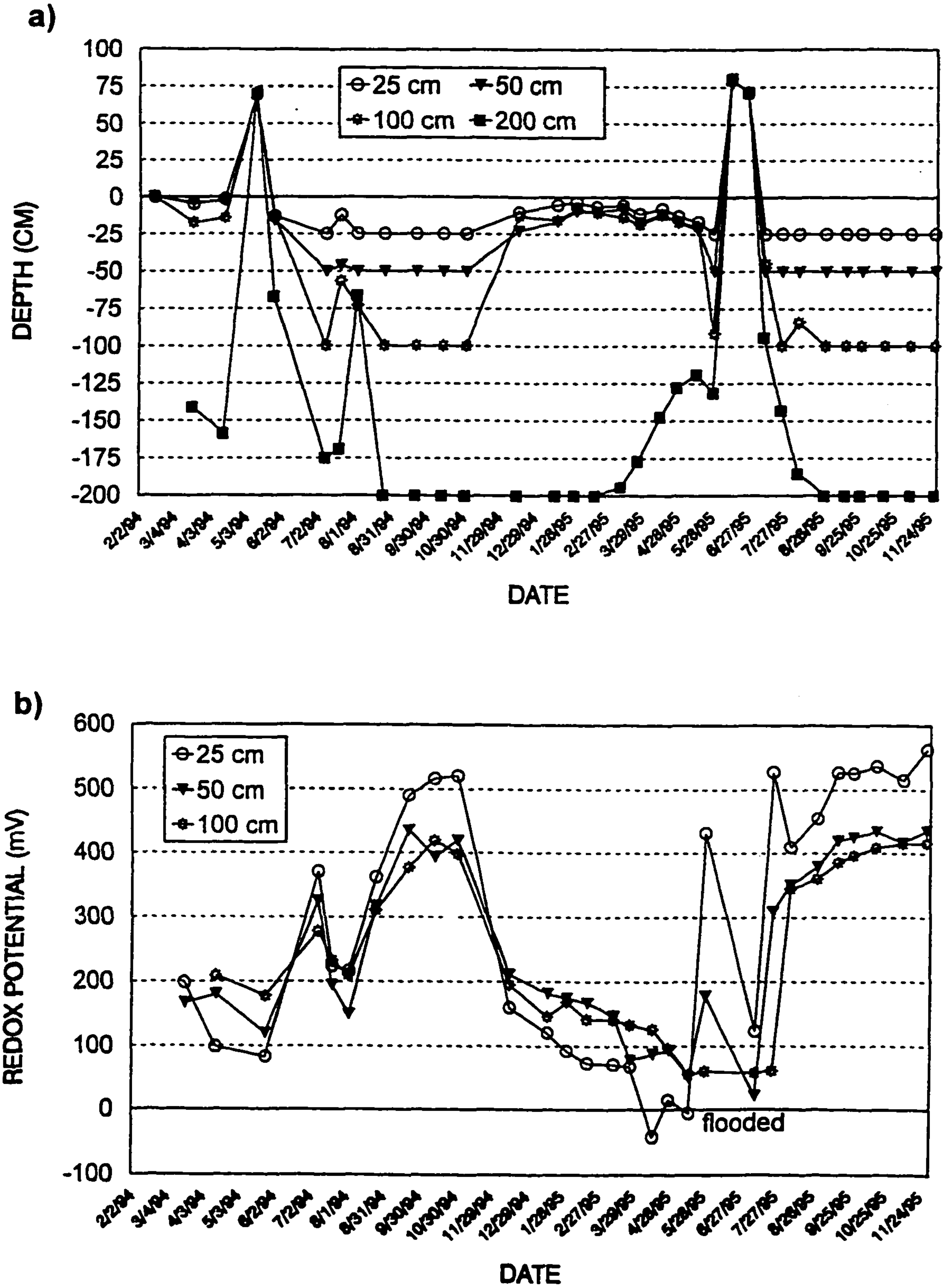

Figure 32. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Water Hickory forest type plot GL-SF-4, Sharkey clay, frequently flooded mapping unit on Grassy Lake Wildlife Management Area.

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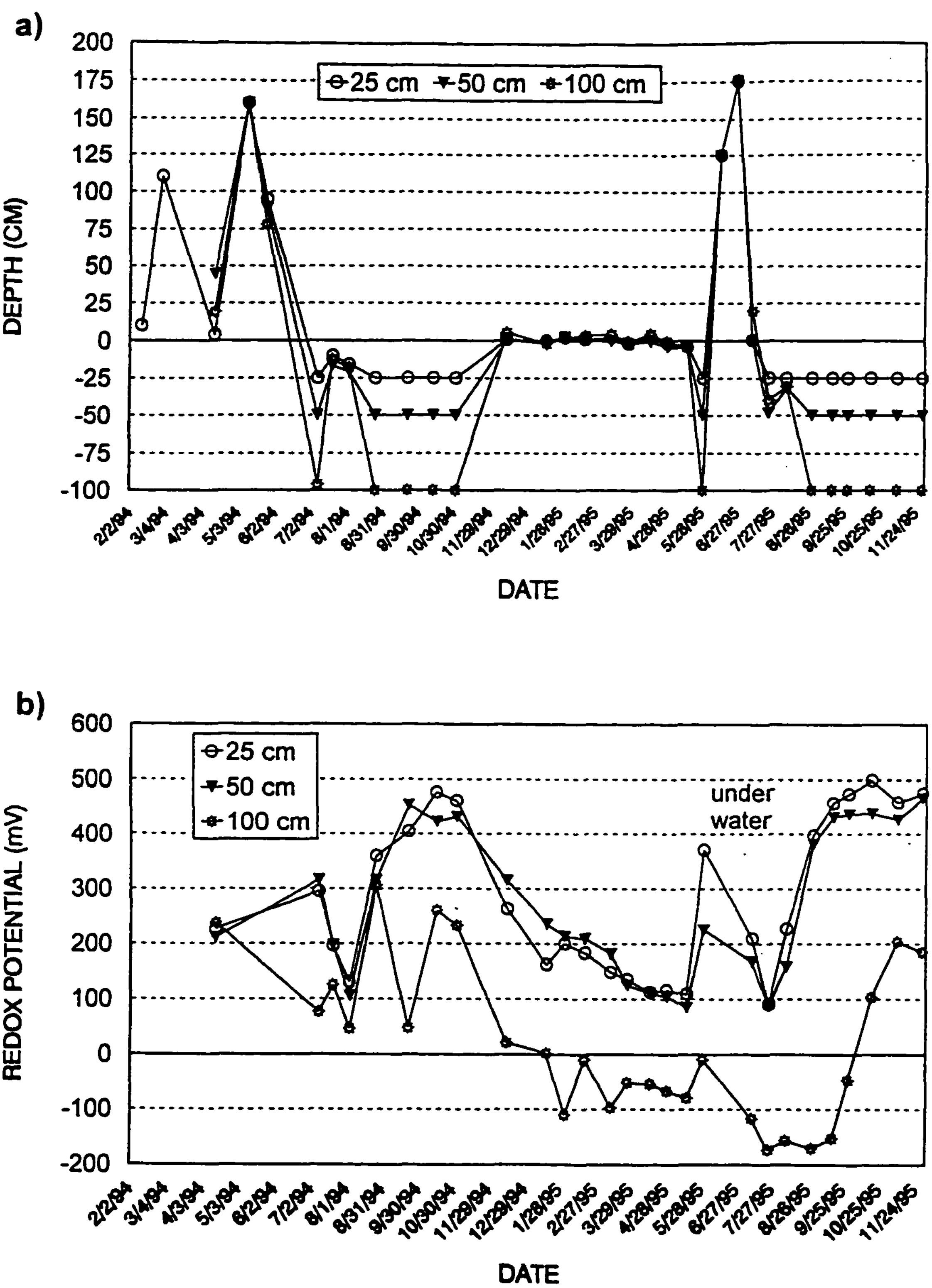

Figure 33. The 1994 and 1995 growing season a) piezometer data, and b) soil redox potential data for Baldcypress forest type plot GL-F-2, Fausse clay mapping unit on Grassy Lake Wildlife Management Area.

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VITA

William Brown Patterson, the son of Dr. W. Brown and Evelyn B. Patterson, grew up in Davidson, North Carolina. He graduated from Episcopal High School in Alexandria, Virginia, in June, 1979. He graduated from Davidson College in North Carolina in May 1983 with a bachelor of arts degree in sociology and anthropology. At Davidson Bill became interested in biology, and after graduation, undertook postgraduate studies in biology, forestry, and sciences at the University of the South in Sewanee, Tennessee, his new home. In August, 1989, he earned a master of science degree in ecology with a minor in plant and soil science from the University of Tennessee, Knoxville. He then worked almost one year as a soil scientist on the Grainger County, Tennessee Soil Survey before coming to Louisiana State University in August, 1990. Bill accepted a position as Assistant Professor of Forest Soils and Watershed Management in the School of Forestry at Louisiana Tech University.

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DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: William Brown Patterson

Major Field: Forestry

Title of Dissertation: Vegetation, Soils, and Hydrology of Central Louisiana Bottomland Hardwood Forest Types

Approved:

Major Professor and Chairman

Dean of the Graduate School

EXAMINING COMMITTEE:

Date of Examination:

October 16, 1997

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IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6"

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