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THE HYDROLOGIC AND BIOGEOCHEMICAL FUNCTIONS OF FIVE EAST TEXAS BOTTOMLAND HARDWOOD WETLANDS USING THE U.S. CORPS OF ENGINEERS HYDROGEOMORPHIC ASSESSMENT TECHNIQUE

by

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Presented to the Faculty of the Graduate School of
Stephen F. Austin State University
in Partial Fulfillment
of the Requirements

For the Degree of
Master of Science in Forestry

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ABSTRACT

Five bottomland hardwood wetland sites in East Texas were selected for the purpose of assessing their functional characteristics using the United States Corps of Engineers' Guidebook for the Application of Hydrogeomorphic Assessments to Riverine Wetlands. Functions assessed were: dynamic surface water storage, removal of imported elements and compounds, organic carbon export, retention of particulates, and nutrient cycling. The assessment technique requires the selection of a normal or above normal functioning wetland, otherwise known as a reference wetland. The reference wetland chosen was Harrison Bayou, which is located within the Longhorn Army Ammunition Plant, Karnack, Texas. Harrison Bayou was selected for use as a reference wetland due to its undisturbed nature, a desirable trait for reference wetlands. The functional characteristics of the four target wetlands were compared against the functional characteristics found within Harrison Bayou. For the sake of comparison, the target wetlands were also used as reference wetlands. A Geographic Information System database was developed to give a visual relationship between function level and landscape position. Due to variation in flooding regimes between wetlands, Harrison Bayou was determined to be an inappropriate reference. Three of the four target wetland sites had higher frequencies of flood events than the reference wetland, resulting in lower indices of function for those wetlands that actually functioned at a higher level. When more appropriate reference wetlands were used, estimations of function capacity were different and more accurate. More research is needed on the selection of riverine reference wetlands before the technique can become a well-defined assessment method.

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Finally, I wish to express my deepest thanks to my parents, whose support was fundamental to me in the completion of this project.

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INTRODUCTION

When settlers first came to America, most perceived the great variety of undisturbed coastal and inland wetlands that were present as nuisances. Legislation was passed to reclaim these lands; for example, in 1849, Congress granted to Louisiana the whole of those swamps or overflowed lands which may be, or are found to be unfit for cultivation. The revenue from the sale of these lands was meant to be used exclusively for the purpose of draining and filling wetlands (Dana and Fairfax 1980). However, with the passage of Section 404 of the Clean Water Act in 1977, activities in wetlands are now regulated. As a result, a permit must be obtained from the U.S. Army Corps of Engineers (USCOE) before any dredged or fill material can be discharged into an area designated as a wetland. In addition, with the passage of the National Environmental Policy Act (NEPA) in 1970, environmental assessments and impact statements are required for those federal projects which significantly affect the quality of the human environment (Jain et al. 1993).

Resource managers must evaluate the impacts of a proposed project on a specific wetland or a series of wetlands. In order to describe what wetland functions could be reduced or lost by a proposed project, one must know what functions are performed by the wetland and at what level they perform under normal conditions. Therefore, resource managers require accurate, simple, and expedient methods for assessing wetland functions. Assessment techniques are either quantitative or qualitative and often compare one wetland to another. Some of the techniques available are the Wetland Evaluation Technique (Adamus et al. 1991), the Indicator Value Assessment Technique (Hruby et al. 1995), and the Guidebook for Application of Hydrogeomorphic Assessments to Riverine Wetlands (Brinson et al. 1995).

At this time, the Hydrogeomorphic (HGM) Assessment Technique is still being refined by the USCOE for use in assessing wetland functions. It is a function assessment procedure that was developed for the purpose of meeting the requirements of the 404 Regulatory Program as stated by Section 404 of the Clean Water Act. Different Hydrogeomorphic Assessment Techniques are given for each class of wetland described in Brinson's (1993) Hydrogeomorphic Classification for Wetlands. For example, bottomland hardwood wetlands are classified hydrogeomorphically as riverine wetlands. The Hydrogeomorphic Assessment Technique offers general guidance on the procedures for assessing wetland functions. Ideally, a multidisciplinary team adapts the general information in the guidebook to develop an assessment approach specific to the physiographic and hydrologic conditions within that region.

Determining the level at which wetlands perform certain functions is useful in the permitting process, especially in determining mitigation requirements. The use and development of functional assessment procedures also can help increase the understanding of wetland functions and the factors that influence them. Although it has its disadvantages, the HGM assessment method shows great promise in becoming a comprehensive assessment technique for evaluating function capacity for use by Corps personnel and non-Corps natural resource managers. This study implements the method and examines its procedures and results.

LITERATURE REVIEW

Bottomland Hardwood Ecology

Bottomland hardwood ecosystems are considered to be riparian wetlands and have a high species diversity and high species richness (Mitsch and Gosselink 1993). They occupy the floodplains flanking many Southeastern streams that have been formed by sediment accretion through overbank deposition (Wharton et al. 1982). Bottomland hardwood ecosystems are dominated by water flow timing and intensity. High water flows occur in high precipitation months during winter and spring, and low flows occur during high evapotranspiration months of summer (Wharton et al. 1982).

Like other wetland types, bottomland hardwoods are capable of performing a variety of functions. For example, they can perform hydrologic and biogeochemical functions such as dynamic surface water storage, groundwater recharge, nutrient cycling, organic carbon export, retention of particulates, and the removal of imported elements and compounds, in addition to other equally important functions such as recreation, aesthetics, and wildlife habitat (Mitsch and Gosselink 1993). Not all of these functions are performed by all bottomland hardwood wetlands, nor are they performed at equal rates between wetlands.

Function Description

Due to the multiple roles they play in large ecosystems, wetlands are acknowledged as highly significant components of our landscape. As regulation and the need for protection grows, so does the need for functional assessment and classification techniques. Although wetlands perform many functions on which both fauna and flora rely, this study is restricted to the assessment of five hydrologic and biogeochemical functions in forested wetlands (i.e. bottomland hardwood forests).

Dynamic Surface Water Storage

Dynamic surface water storage is that process performed by a wetland that helps downstream areas avoid sudden and severe inundation. As storm waters from upstream areas are intercepted by a wetland, water is released slowly over a period of time, resulting in more consistent peak flows downstream (Adamus et al. 1991). A wetland's effectiveness in storing floodwater depends on its elevation relative to an adjacent stream and also those factors that determine the degree of roughness, such as microtopographic relief and vegetation density (Smith et. al. 1995). Wetlands are most effective in dynamic surface water storage when not inundated with surface water at the time they are needed to store incoming water. Although downstream areas are spared from damaging flooding conditions, those areas adjacent to the storage wetland, which are typically infrequently flooded, may become inundated. This function has a high economic value, especially to those areas downstream of the storage wetland that are urban areas, croplands, or pastures (Wilkinson et al. 1987). The usefulness of this function increases with wetland area, size of flood event, and the lack of other upstream storage areas (Mitsch and Gosselink 1993).

Nutrient Cycling

In the context of this study, nutrients involved in this function are nitrogen and phosphorus. Primarily a recycling process, nutrient cycling involves abiotic and biotic processes that convert elements from one form to another (Brinson et al. 1995). These processes are facilitated by periods of inundation and dry-down (Wharton et al. 1982). Important nutrient transformations such as denitrification take place when the soil is saturated or under water (Mitsch and Gosselink 1993). When denitrifying bacteria are present under aerobic and anaerobic conditions, nitrate is reduced to gaseous nitrogen (Smith et. al. 1995). The execution of the nutrient cycling function allows the wetland ecosystem to maintain a supply of nutrients which in turn supports a level of net primary productivity and detrital turnover.

Removal of Imported Elements and Compounds

Chemical contaminants and toxicants are dangerous to all ecosystems and can cause harm and inconvenience to animals and people. If heavy metals and pesticides are allowed to infiltrate a groundwater aquifer, those contaminants may exist in the aquifer for a relatively long time (Watson and Burnett 1993). Elements are nutrients such as nitrogen, phosphorus, and potassium and herbicides and pesticides are considered to be compounds (Brinson et al. 1995).

Wetlands allow contaminants to be removed from the incoming water source and transformed or stored before they can pollute groundwater supplies. Wetlands can trap and store contaminants the same way they trap and store sediment. In most cases, wetlands act as sinks for elements and compounds due to their positions in depositional landscapes (Brinson 1993b). Elements and compounds can be removed from incoming water by denitrification, sorption, sedimentation, burial, and uptake into long-lived vegetation (Brinson et al. 1995). Those contaminants that are attached to sediment particles upon their entry into a wetland will often precipitate out of the water column with their host particle as floodwater velocity slows. Furthermore, some pollutants can be extracted from water by ion-exchange on the soil surface (U.S. Fish and Wildlife Service 1985). Pollutants that enter wetlands and become temporarily trapped in wetland areas often are broken down, immobilized, or locked in an inert form with other compounds.

Retention of Particulates

As water flows out of its channel and onto a floodplain, its velocity is greatly reduced. This results in the deposition of suspended sediments onto the floodplain from the overlying water column since sediment retention capacity decreases as flow rate decreases (Brinson 1993). The slowing of the water as it enters the floodplain is an example of dissipation of an erosive force (Adamus et al. 1991). Furthermore, the root systems of live vegetation helps prevent erosion by stabilizing soil particles. Dead vegetation such as fallen limbs, trunks and logs also contribute to the slowing of water velocity (U.S. Fish and Wildlife Service 1985). This is a useful function performed by wetlands since it helps alleviate sediment deposition in downstream reservoirs and channels.

Organic Carbon Export

The organic carbon that is flushed from a wetland is a result of net annual primary and secondary productivity (Adamus et al. 1991). Dissolved organic matter that is exported from a wetland is composed mostly of humic substances leached from soil and leaf litter (Wharton et al. 1982). The high productivity that is common to most wetlands with an alternating wet/dry cycle is a result of high rates of annual leaf fall, high detrital decomposition rates, high rates of nutrient turnover, and periodic flushing of organic detritus and metabolic by-products (U.S. Fish and Wildlife Service 1985). Forested wetlands with a pulsing hydroperiod have a greater net primary productivity than those wetlands that are continuously inundated (Mitsch 1988). This is due to relatively slow organic matter decomposition under anaerobic conditions that predominate in inundated conditions (Wharton et al. 1982). The organic carbon that is flushed from a wetland is usually consumed by organisms within an aquatic ecosystem; however, it is difficult to determine the exact utilization of exported organic carbon due to spatial and temporal separation in production and utilization. It is believed, however, that organic carbon is useful to downstream ecosystems and is an important source of energy to microbial food webs (Brinson 1993).

Classification Techniques

The classification of wetlands by region and type has always been recognized as useful by resource managers and landowners; however, the early development of classification systems was intended to determine which wetlands would be most productive as cropland if drained. Currently, classification systems are used to aid in the recognition and protection of some of the valuable ecological functions of wetlands (Mitsch and Gosselink 1993). Wetland classification not only improves consistency in decision making from region to region, but also improves awareness of wetlands with superior functional capacity (the degree to which a wetland performs a specific function). In addition, classification systems that group together functionally similar wetlands are extremely useful in the development and execution of assessment techniques. For example, when functionally similar wetlands are grouped together, assessment techniques can be designed for each group, which can lead to more specific and perhaps more accurate results.

One of the most commonly used nationwide classification systems is the Classification of Wetlands and Deepwater Habitats of the United States by

Cowardin et al. (1979). In this classification system, wetlands and deepwater habitats are classified using vegetative cover, substrate material, and flooding regime. Habitats are separated into five systems: Marine, Estuarine, Riverine, Lacustrine, and Palustrine, with all but Palustrine having two or more subsystems. The Riverine system is described as those wetlands and deepwater habitats contained within a channel, with the exception of those wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens. The Palustrine system is described as being nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses or lichens, and includes ponds, river floodplains, and islands in lakes or rivers. The Palustrine system includes the class Forested Wetland which in the southeastern U.S. is more commonly known as bottomland hardwoods. This classification system was used to create National Wetland Inventory maps because it is based on characteristics that can be readily identified with remote sensing techniques (Smith 1993).

Although vegetation can be very helpful in classification techniques, Brinson (1993a) believed that vegetative cover and structure should only be used to provide clues to hydrologic and geomorphic characteristics. Classifying wetlands solely by their vegetative characteristics can result in functionally different wetlands being put in the same class (Smith 1993). Wetlands are often characterized only by their frequency and depth of flooding (Brinson 1993b). Although hydrology is an important factor in determining reasons behind changes in the functional capacity of a wetland, it should not be the only factor under consideration (Brinson 1993b). Other abiotic factors, such as position of the wetland in a drainage network, size of the wetland, sources of water, and biogeochemical inflows and outflows should also be considered in explaining changes in functional capacity.

The Hydrogeomorphic Classification system classifies wetlands according to three components: water source and transport vector, geomorphic setting, and hydrodynamics (Brinson 1993a). The purpose of the Hydrogeomorphic Classification system is to aggregate wetlands that may perform the same or similar functions. Water source can be precipitation, surface or near-surface flow, or groundwater discharge. Geomorphic setting refers to the topographic location of the wetland within its surrounding landscape. Hydrodynamics refers to the direction of water flow and the strength of its movement in a wetland. Since wetlands would be classified by abiotic factors only, the hydrogeomorphic classification system will be suitable for use in almost any situation in the United States. This classification system has been developed in order to lay a foundation to the development of the Hydrogeomorphic Assessment technique for wetland functions.

Assessment Techniques

For the most part, functional assessment techniques are engineered so that they can be performed in a relatively short period of time, using indirect methods such as visual surveys instead of actual direct measurements. Also, most functional assessment techniques assume that the user is somewhat experienced in environment-related measurements. Several assessment techniques have been developed, but only one, the Hydrogeomorphic Assessment Technique, is suitable for use in the context of the 404 Regulatory Program (Brinson et al. 1995). Earlier methods were too subjective, had a limited geographic scope, considered a limited number of wetland functions, or required too much time and resources for implementation (Smith 1993).

One of the earlier assessment techniques (Larson 1976) deals with identifying physical characteristics of wetlands that provide wildlife, visual-cultural, and groundwater values. Wildlife values are rated predominantly on the diversity of wetland types and the dominant wetland type. Visual-cultural values are evaluated subjectively, using landform contrast and diversity for variables. Contributions to groundwater mainly involve the physiographic region where the wetland is located. Furthermore, any wetland containing rare, restricted, endemic, or relict flora or fauna is to be considered as an outstanding wetland and should be considered for preservation, according to Larson (1976). This technique is not specific, limited in its scope, and not completely effective outside of a region or state.

The Wetland Evaluation Technique (Adamus et al. 1991) was designed to be implemented nationwide on all wetland types, and only those factors that all wetlands have in common can be used. Nationwide-common predictors are used to determine whether a wetland would have the opportunity to perform certain functions, and if so, to determine their effectiveness. A rationale, or brief discussion is given as to why the predictor is related to its function. The predictors also are ranked for confidence, and how directly the predictors could be measured. This manual is perhaps one of the most comprehensive in terms of being applicable nationwide to any wetland type. However, this method is too broad to be used on a small scale and often leads to inconclusive results (Smith 1993).

A method for functional assessment that is limited to a certain area is the Method for the Comparative Evaluation of Nontidal Wetlands in New Hampshire (Ammann and Stone 1991). It is very similar to the hydrogeomorphic assessment technique in terms of numerically scoring a wetland's functional capacity.

Most assessment techniques rate functional capacity levels relative to other wetlands, rather than qualitative ratings such as of "high" or "low", which is the rating system used in the Wetland Evaluation Technique (Adamus et al. 1991). The practice of scoring performance levels numerically is questionable due to the lack of quantitative data concerning the relationship between functions and indicators (Hruby et al. 1995). However, it is believed that numerical rating is currently the most effective method, allowing for assessments of value that can in turn be used to establish mitigation acreage.

In the Indicator Value Assessment Technique (Hruby et al. 1995), there are three types of numeric representations for wetland function indicators. They are additive, multiplicative, and fractional. Additive indicators are positive integers and represent incremental increases in performance. Multiplicative indicators are those that are associated with significant increases in performance and are scored as numbers greater than 1. Fractional indicators are numbers less than 1 and are associated with decreases in performance. The level of performance is calculated by multiplying the sum of scores of the additive indicators by the product of the multiplicative and fractional indicators. It is recommended by Hruby et al. (1995) that wetlands are classified using the Hydrogeomorphic Classification for Wetlands (Brinson 1993a) to determine what indicators should be used for local functions.

A more specific wetland-type method for assessing the level at which wetlands function is the Guidebook for Application of Hydrogeomorphic Assessments to Riverine Wetlands (Brinson et al. 1995) which applies only to riverine wetlands (as classified by the Hydrogeomorphic Classification for Wetlands) throughout the United States. Natural wetland processes that constitute valuable and productive resources important to the public interest are called wetland functions. Functional capacity denotes the level at which a wetland performs a specific function. Values assigned to functions are the benefits, goods, and services that result from the performance of wetland functions (Smith 1993). This method is used only to determine wetland functional capacity and cannot be used to assign a value to wetland functions.

The Guidebook for the Application of Hydrogeomorphic Assessments to Riverine Wetlands contains general assessment information about riverine wetlands that must be adapted for use in a specific physiographic region. This adaptation is normally done by an "A-team", a multidisciplinary group of individuals with knowledge of hydrology, geomorphology, soil science, plant ecology, etc. This team must identify the geographic boundaries of the regional subclass under consideration (reference domain) and determine which wetlands within the reference domain exhibit the highest level of functioning (reference standard sites). Within a reference domain are reference wetlands. These are selected to represent the range of functioning found within the subclass and can include former wetlands for which restoration is possible. The reference standard sites chosen from the reference domain are preferably undisturbed or the least disturbed wetlands. It is assumed that those wetlands that have the least amount of long-term anthropogenic disturbance will have the highest and most sustainable functional capacity (Smith et. al. 1995). In some cases, however, a wetland that has been altered is capable of achieving a higher level of functional capacity than can be found in an undisturbed wetland. This is usually not sustainable over the long term or operates at the expense of reduced capacity for other functions (Smith et. al. 1995).

This method employs the use of variables, which are factors that may or may not need be present for the function to take place. The variables are scaled from 0-1, and the index decreases as conditions in the wetland deviate from conditions found within the reference wetland. Since the direct measure of variables is often time-consuming and not always cost-effective, indicators of the presence of variables are commonly used in the place of direct measurement. For example, where overbank flooding is a variable, indicators such as drift lines or water marks can be used in lieu of actual data from a gaging station.

Some variables are more significant than others in determining functional capacity. Therefore, a model for each function weighs the value of each variable according to its importance and is classified in one of four categories of index of function. These categories are 1.0, 0.5, 0.1, and 0.0 with 1 being the nearest to the conditions found in the reference wetland.

The hydrogeomorphic assessment technique has been used to formulate a bottomland hardwood wetland impact assessment of a flood control project on the Big Sunflower River, Mississippi (Spencer 1991). Function capacity units, ranging from 0 to 1, signify the level of a wetland's functional capacity, with 1 being the highest. These units are determined using different equations for each function which in turn have their own indices. For example, the calculation of the functional capacity index for short term water storage is the product of a duration index and a storage index for the wetland. The duration index is the quotient of flooding duration with maintenance and pre-project flood duration. The storage index is 1 for forested, 0.5 for farmed, and 0 for a filled wetland.

OBJECTIVES

The purpose of this study was to qualitatively assess the functional capacity of selected bottomland hardwood wetland sites in East Texas. Harrison Bayou, within the confines of the Longhorn Army Ammunition Plant near Karnack, Texas, served as a reference wetland. Harrison Bayou was chosen as a reference wetland based on its undisturbed nature, which is stipulated in the HGM method.

The objectives of this study were to:

1. Implement the USCOE Hydrogeomorphic Assessment Technique on the selected wetland sites to determine their functional capacity by plant community. The functions assessed were:
    a. dynamic surface water storage
    b. nutrient cycling
    c. removal of imported elements and compounds
    d. retention of particulates
    e. organic carbon export
2. Create a GIS database to obtain a visual relationship between functional characteristics and plant communities of the wetland study sites.

METHODS

Location and Description of Study Sites

The Hydrogeomorphic Assessment technique has been performed on five wetland sites within Texas, including the reference wetland, Harrison Bayou.

Harrison Bayou

Harrison Bayou is a bottomland hardwood wetland which has experienced minimal man-made disturbance for the last 50 years. The portion of Harrison Bayou which was studied lies within the boundaries of the Longhorn Army Ammunition Plant (LHAAP). The Bayou runs about 5 kilometers within the LHAAP and is located on the eastern side of the plant (Figure 1). The plant itself is just east of Karnack, Texas, which is approximately 25 kilometers northeast of Marshall, Texas. Harrison Bayou was generally inaccessible to logging equipment before being incorporated into the LHAAP and after the Bayou became part of the LHAAP, the area was not available for logging (Walker 1983).

Big Cypress Bayou

The wetland study site on Big Cypress Bayou is just north of Lake O' the Pines Reservoir in Camp County, Texas (Figure 2). It is owned by the USCOE and is currently used only for hunting.

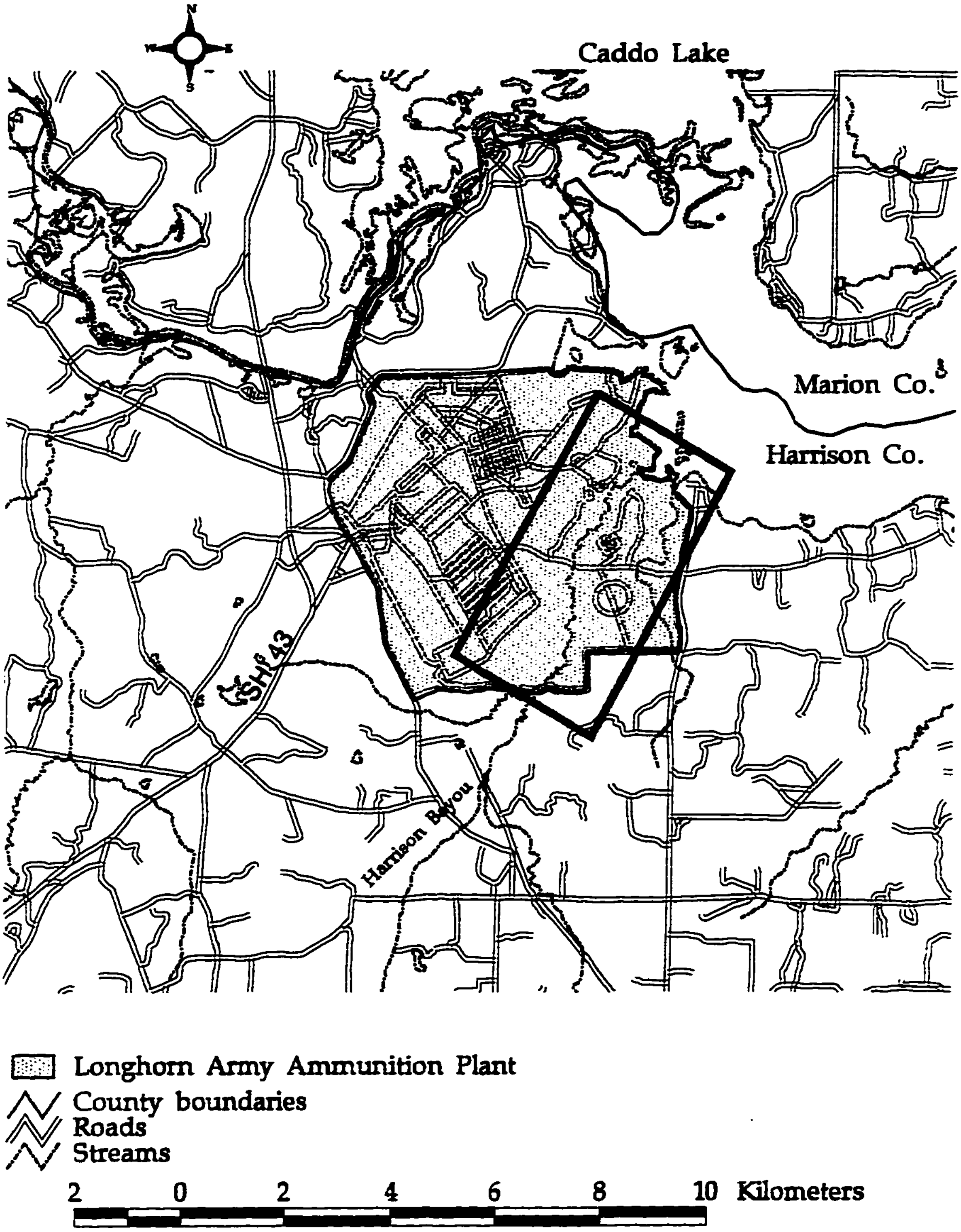


Figure 1. General location of Harrison Bayou wetland study site (enclosed in box).

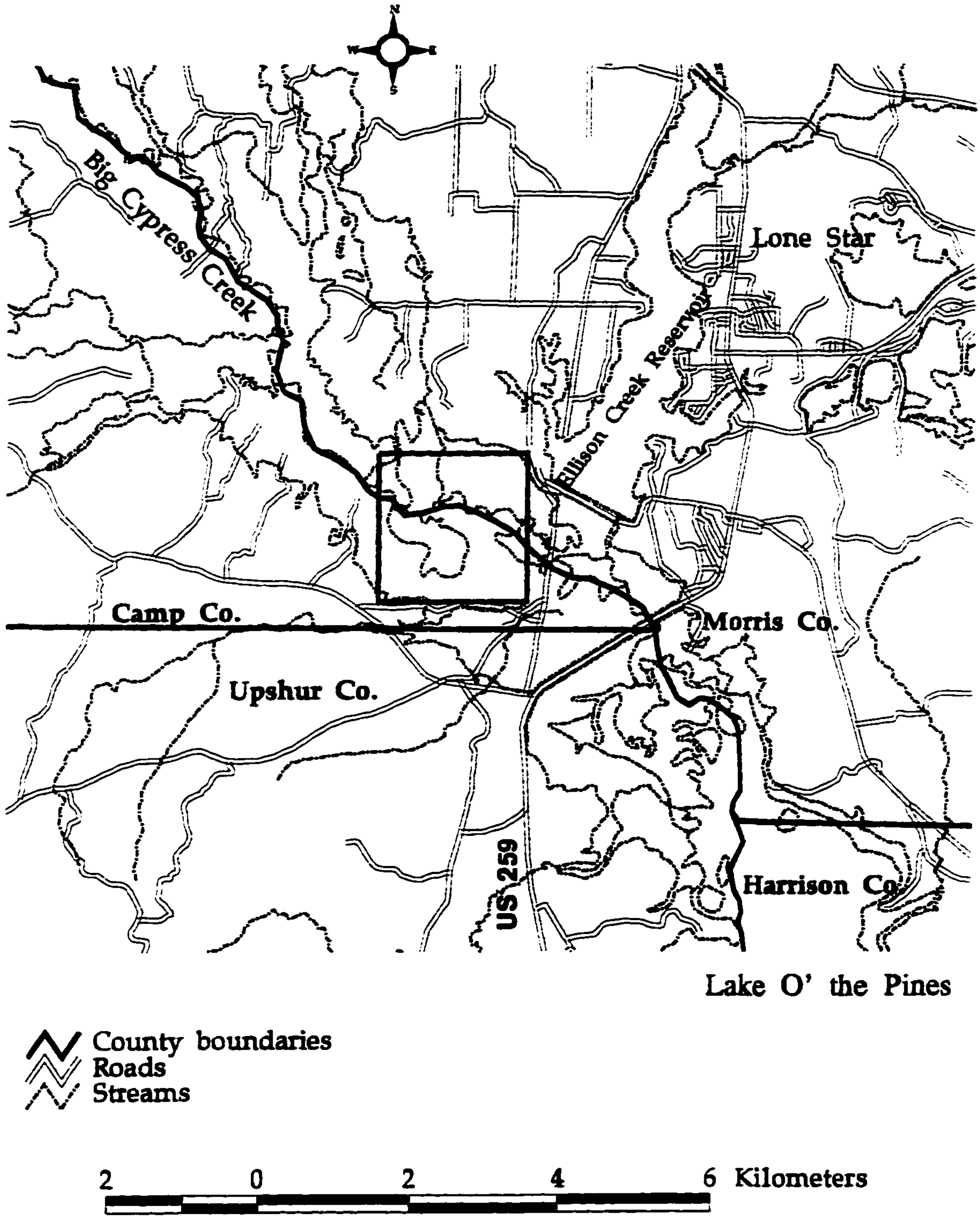


Figure 2. General area of Big Cypress Bayou study site (enclosed in box).

Black Cypress Bayou

The study site on Black Cypress Bayou is owned and managed by International Paper Company and is located about 8 kilometers northwest of Jefferson, Marion County, Texas (Figure 3). Adjacent to the wetland study site are two clearcuts, one three years old and the other two years. Both clearcuts have been burned and planted in loblolly pine (*Pinus taeda* L.).

Cherokee Ridge

The Cherokee Ridge study site is owned and managed by International Paper and is a bottomland hardwood wetland clearcut on the Cherokee Ridge Hunting Club, Cherokee County, Texas (Figure 4). The clearcut, about 114 hectares in size, was composed of a mixture of bottomland hardwood species which were harvested in 1993. Included in the study site is a Streamside Management Zone (SMZ), which is assumed to contain conditions similar to those found in the clearcut area before it was harvested.

Alazan Bayou

An abandoned pasture located in the Alazan Bayou Wildlife Management Area in Nacogdoches County, is owned by the Texas Parks and Wildlife Department and is the last wetland study site (Figure 5). Used as cropland and then as pasture, the site has had no management for the past three years.

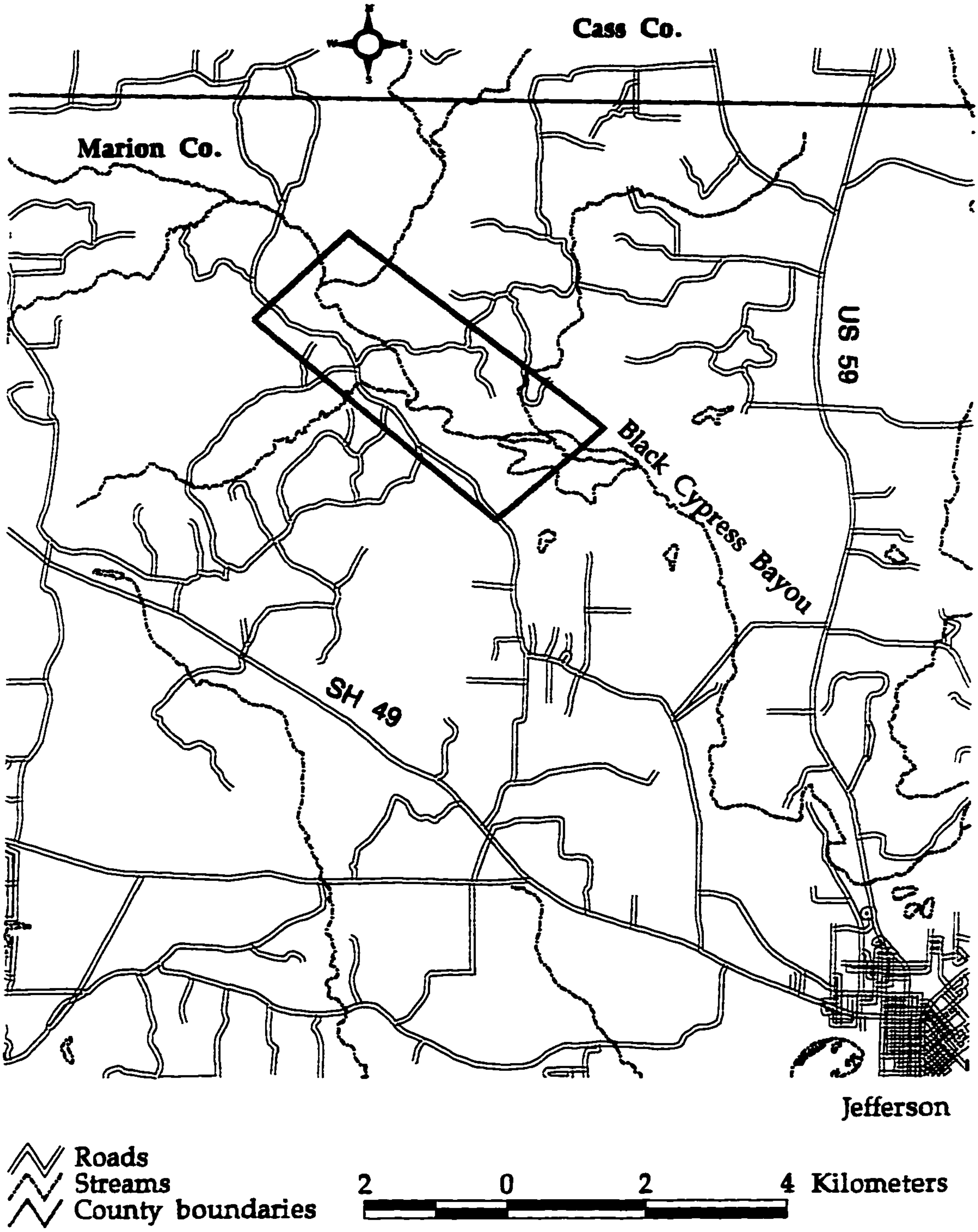


Figure 3. General location of Black Cypress Bayou study site (enclosed in box).

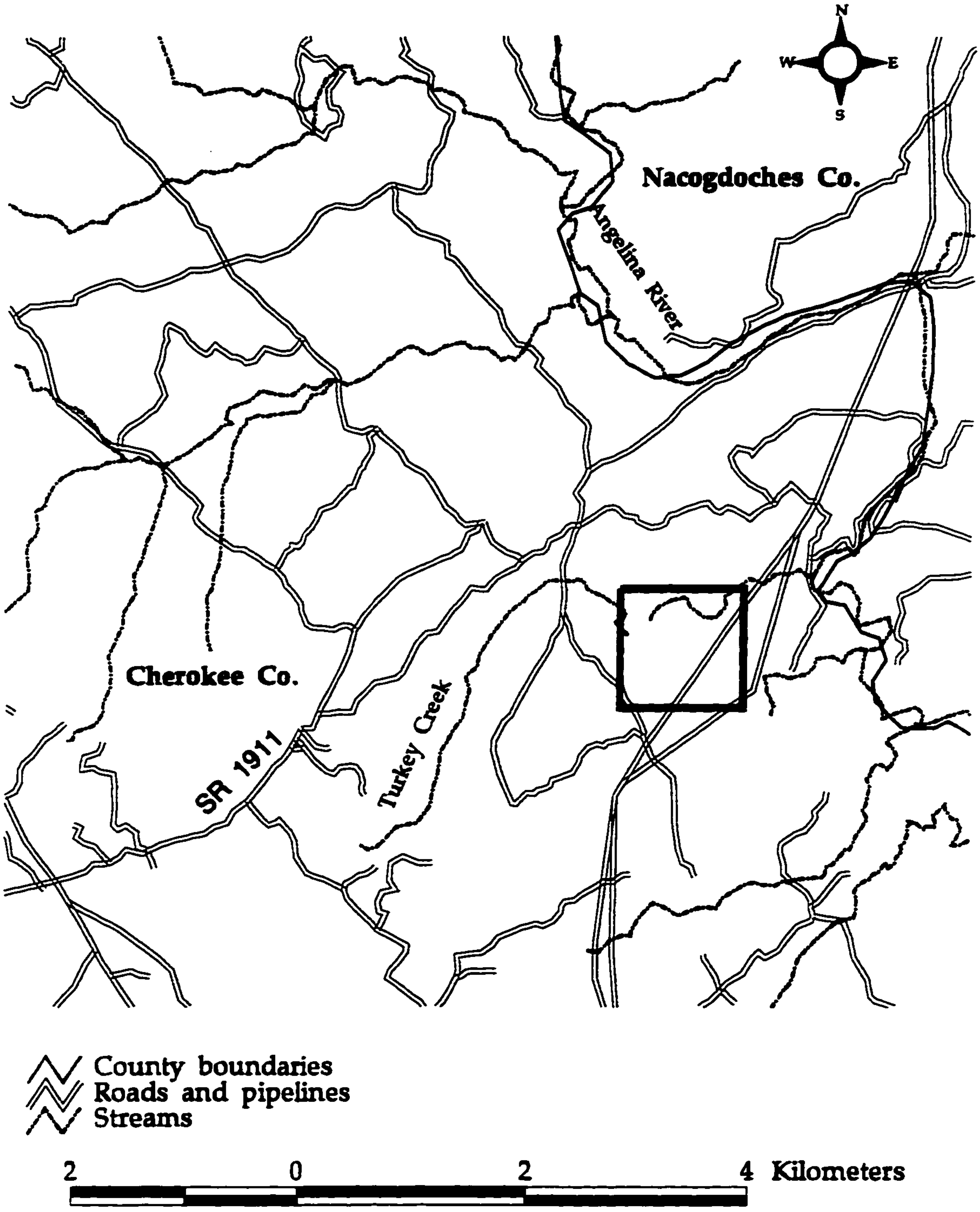


Figure 4. General location of Cherokee Ridge study site (enclosed in box).

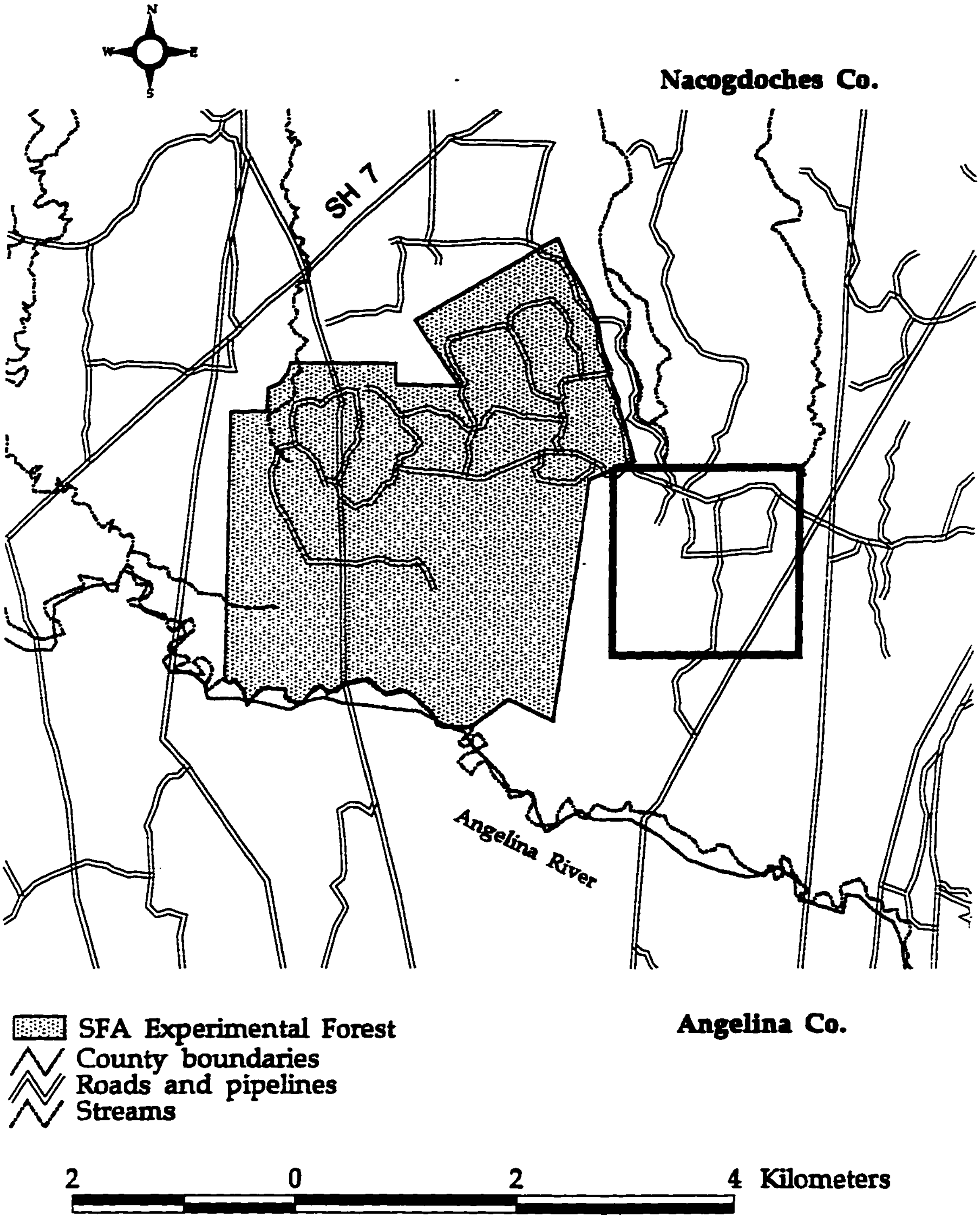


Figure 5. General location of Alazan Bayou wetland study site (enclosed in box).

Identification of Wetland Sites

Study areas within all sites have been sampled to determine if they are wetlands. The identification procedure was performed in accordance to the guidelines defined in the 1987 Corps of Engineers Wetlands Delineation Manual (Environmental Laboratory 1987). Plant community boundaries were first identified and then a representative observation point was placed at random within each community. At these representative observation points, the presence of hydrophytic vegetation, hydric soils, and wetland hydrology was determined. If the representative observation point had all three of these wetland parameters, the plant community was identified as a wetland plant community.

GIS Database Development

In order to determine the general location of the wetland plant communities and graphically depict the differences in function capabilities between wetland plant communities and between the wetland study sites, a GIS database was developed. The database was created on a UNIX computer platform using GIS-related software such as ArcInfo, ArcView, and Imagine. This software was run on a IBM AIX RS/6000 computer which used a UNIX operating system version AIX 3.2.5. Satellite imagery and aerial photography of the areas was utilized along with exterior data sources that were digitized, such as soil surveys and topographic maps. Digitizing was performed on a 4 foot by 5 foot digitizing table.

Maps containing information on roads, pipelines, streams, and community boundaries were created for the purpose of field work. These maps enabled the principal researcher to plot a reconnaissance survey utilizing compass and pacing techniques. After the function assessment procedure was completed, the field maps for each study site were modified to contain information on function capacity by community.

Assessment Technique

In determining the level at which the five wetland sites perform water quality functions, the Guidebook for Application of Hydrogeomorphic Assessments to Riverine Wetlands was utilized (Brinson et al. 1995). In executing the procedure for assessing wetland functions, the principal researcher has performed a reconnaissance survey through each plant community on each wetland study site. The information gathered in this process determined the dominant vegetative characteristics of each community (Appendix Figures 1 and 2).

Function Assessment

Dynamic Surface Water Storage

To determine the level at which a wetland performs the function of dynamic surface water storage, five variables must be measured (Appendix

Table 1). These are: annual frequency of overbank flow (V_{of}), average depth of inundation (V_{di}), microtopographic complexity (V_{mc}), woody vegetation roughness (V_{wvr}), and the amount of coarse woody debris (V_{cwd}).

The first variable, V_{of}, is assessed in two different ways. The first is by determining a flooding frequency for each wetland in years and rate their flooding frequencies with a 1, 2, or 3. A rating of 1 means that the wetland floods every one to two years. A rating of 2 denotes that the wetland floods every 2 to 5 years. A rating of 3 denotes that the wetland floods every 5 to 10 years. Flooding frequencies for each wetland study site are shown in Table 1. All plant communities within the wetland will receive the same flooding score, regardless of location on the landscape. The scores for the target and reference wetland are compared, and if they are between 75%-125% similar, the function score will be 1. If the two wetlands are between 125%-150% or 35%-75% similar, the function score is 0.5. If the percent relativity is >150% or <35%, the function score is 0.1.

Table 1. Flooding frequencies by study site.

Study site	Frequency of overbank floodflow	Rating	Pers. Comm.
Black Cypress Bayou	1/2 years	1	Mary Cay Jones
Cherokee Ridge	1/2 years	1	David Whitehouse
Big Cypress Bayou	2/5 years	2	Robert Henderson
Harrison Bayou	5/10 years	3	Lanis Rieger
Alazan Bayou	5/10 years	3	Lee Davis

The second method of determining the function score for $V_{\alpha f}$ is to examine frequency of floodflow evidence in the wetland by visual assessment for each vegetation community. The presence or absence of water marks, silt lines, alternating layers of leaves and fine sediment, drift and/or wrack lines, sediment scour, sediment deposition, and directionally bent vegetation between compared plant communities was used to determine $V_{\alpha f}$. If the presence or absence of one of the above indicators in the target wetland matched the presence or absence of the corresponding indicator in the reference wetland, the target wetland received a score. The total score the target wetland received was divided by 7 (total number of matches possible) to give the percent relativity to conditions found in the reference wetland. If the percent relativity was >75%, then $V_{\alpha f}$ received a 1.0. If relativity was between

25% and 75%, then the index for V_{of} is 0.5. If relativity is <25%, then the index is 0.1. However, if none of the indicators for frequency of overbank flooding are present and there is evidence of alteration affecting the variable, then the index is 0.0.

To determine V_{di} in a plant community, a reconnaissance survey was performed to determine the average height of watermarks on trees in that community. If the height of watermarks was 60% to 200% of the height of watermarks found in the reference standard, then the variable had an index of 1.0. If the height of watermarks were 20% to 60% or 200% to 400% of the reference standard, the variable was assigned a value of 0.5. Should the height of the watermarks have not met the above criteria but had related indicators suggesting depth of inundation, then the variable had a score of 0.1.

V_{mc} is inversely proportional to the rate of water flow through a wetland. A subjective, relative scale ranging from 1 to 5 was established based on the range of conditions observed in all wetland study sites. The scale was used for comparing relative amounts of microtopographic complexity between the reference wetland and the target wetlands. Those cover types with a degree of surface roughness 80% to 120% similar to the reference standards received a score of 1.0. Those cover types with a degree of surface roughness between 30% and 80% or greater than 120% of the reference standards received a score of 0.5. Those areas where microtopographic complexity was <30% received a score of 0.1, and those areas lacking microtopographic complexity received a score of 0.0.

V_{wvr} is a variable that measures the number of woody stems of trees and shrubs. Three plots representative of the cover type were established in which the number of shrub stems per plot and tree basal area were determined and then averaged between the three plots. Basal area was determined using a 10-factor basal area prism and the shrub stem count was performed within a 250 m^2 plot. The shrub stems per plot and basal area was averaged over the three plots and then added together to form a numerical representation of V_{wvr}. Those cover types in which the stem density was between 80% to 120% of the reference standard received an index of 1.0. If the stem density was between 10% and 80% or 120% and 190% of the reference standard, the cover type had an index of 0.5. Should the cover type have had a stem density less than 10% or greater than 190% of the reference standard, it had an index of 0.1. If no woody vegetation was present, nor would ever be present, then the area received an index of 0.0.

The frequency of fallen stems is used to determine V_{cwd} within each cover type. A scale from 1 to 5 was established to relate the frequency of downed woody debris greater than 10 cm in diameter within the target wetland sites to the reference standard. Those cover types in which the biomass was greater than 75% of the reference standard had an index of 1.0. Those cover types which had between 25% to 75% of the biomass found in the reference standard had indices of 0.5. Those cover types which had <25% of the biomass found in the reference standard received an index of 0.1. If no biomass was present, the cover type received an index of 0.0.

The model for determining the function level for dynamic surface water storage depends on the presence of overbank flooding. If the value for overbank flooding is zero, then the index of function is zero. The variables are combined to depict the index of function in the following manner:

Index of Function:

$$\left(V_{of}\left(\frac{V_{di}+V_{mc}+V_{wvr}+V_{cwd}}{4}\right)\right)^{\frac{1}{2}}$$

where: V_{of} = frequency of overbank flow

V_{di} = average depth of inundation

V_{mc} = microtopographic complexity

V_{wvr} = woody vegetation roughness

V_{cwd} = coarse woody debris

Nutrient Cycling

Nutrient cycling is characterized by two variables: net primary productivity (V_{npp}) and detritus turnover (V_{dt}). The first indicates the level at which plants take up available nutrients and the second indicates the rate at which nutrients decompose and are made available to plants.

V_{npp} was determined by visual assessment for each wetland cover type on the wetland study sites. The canopy, subcanopy, shrub and ground covers within each cover type were assessed separately on a percent basis, divided by

4, and then added for a total percent cover which ranged from 0 - 100%. For those cover types with a percent cover of all strata (canopy, subcanopy, shrub, ground cover) between 75% and 125% of the reference standard, an index of 1.0 was assigned. For those cover types where percent cover was >125% or between 25% to 75% of the reference standard, an index of 0.5 was given. Cover types which had a percent cover between 1% to 25% had an index of 0.1 and those areas which had no living biomass and no potential for recovery had an index of 0.0.

The second variable, annual detritus turnover (V_{dt}), was determined by visual assessment and a scoring method. Cover types were assigned a score between 1 and 5 depending on their relative amounts of snags, downed dead woody debris, leaf litter, fermentation and humus layers, and fungal fruiting bodies. For those cover types which scored between 75% to 125% of the above factors relative to the reference standard, the index was 1.0. Those areas which were 25% to 75% of the reference standard had an index of 0.5. Cover types in which stocks of detrital and soil organic matter were between 1% and 25% of the reference standard or absent but have the potential to recover had an index of 0.1. Those cover types with no soil organic matter or detrital stocks and had no potential for recovery had an index of 0.0.

If $V_{npp} > V_{dt}$, then the index of function for nutrient cycling is V_{dt}. If not, then the index of function is V_{npp}.

where: V_{npp} = aerial net primary productivity

V_{dt} = annual turnover of detritus

Since this is a cyclic process, both variables should be roughly in balance with one another. Taking the lesser variable as the index of function should insure that the index is not overestimated. If one variable is significantly less than the other, the function is not performing normally.

Removal of Imported Elements and Compounds

Six variables must be taken into account for the determination of the level at which a wetland can remove imported nutrients, contaminants, and other elements. The first, overbank flooding frequency (V_{of}), has already been described under the function of dynamic surface water storage.

The second variable, riparian source (V_{rs}), is a determination of the source of water that feeds a wetland in addition to the main riparian channel. By examining the topography and aerial photos of both the impacted wetland sites and the reference wetland, the additional water source for both wetland groups was determined. If the water sources are for the most part identical in intensity and type (such as overland flow or groundwater discharge), then the index was 1.0. If sources were dissimilar and/or less in intensity, then the index was 0.0.

The third variable, microtopographic complexity, (V_{mc}), has been previously described under dynamic surface water storage.

The fourth variable, available surfaces for microbial activity, (V_{sma}), was determined by cover type using a rating system ranging from 1 through 5. Those areas with high levels of litter layer, humus stratum, woody debris, and floating, submerged and herbaceous emergents received higher scores. Those cover types in which the score was 75% to 125% of the reference standard had an index of 1.0. Cover types for which scores were 25% to 75% or 125% to 175% of the reference standard had an index of 0.5. Cover types in which the above indicators were absent with potential for recovery or those areas in which there was no potential for recovery were 0.1 and 0.0, respectively.

The index of the fifth variable, sorptive properties of soils, (V_{sps}), was determined by the similarity of soil texture and organic material content by cover type between each impacted wetland site and the reference standard. Using a soil map of both areas, a representative soil type was found for each cover type of both the impacted and reference wetland sites and physical properties were determined for the A, E, and B (where applicable) horizons. Using the gradient of soil textures described in Brady (1990), soil textures were scored from 1-14, with 1 being sand and 14 clay. If the soil texture in the A horizon was 75% to 125% similar to the reference standard, then the index was 1.0. If the score was 25% to 75% or between 125% to 175% of the conditions in the reference standard, then the index was 0.5. If the soil had major departures from the reference standard in terms of texture (<25%,

>175%), the index is 0.1. If no soil was present or had been altered by the presence of concrete or asphalt, the index was 0.0.

The last variable for the function of element removal is tree basal area (V_{tba}). The index for this variable was determined using three plots for each cover type on both Harrison Bayou and the target wetlands. If the total basal area for a cover type was greater than 75% of the corresponding cover type in the reference wetland, the cover type had an index of 1.0. If the basal area was between 25% and 75% of the reference standard or was between 0% and 25% of the reference standard, then the index was 0.5 or 0.1, respectively. If the area was cleared without potential for recovery, then the index is 0.0.

The variables are separated into two categories. The first are those variables involving hydrologic transport mechanisms that are responsible for bringing nutrients into the wetland (V_{of} and V_{rs}). The other four variables are in the category that is responsible for contributing to the removal of imported elements and compounds. The index of function is determined in the following manner:

$$\left(\frac{\left(\frac{V_{of}+V_{rs}}{2}\right)+\left(\frac{V_{mc}+V_{sma}+V_{sps}}{3}\right)+V_{tba}}{3}\right)$$

If the characteristic vegetation is herbaceous, then V_{tba} can be removed:

$$\left(\frac{\left(\frac{V_{of}+V_{rs}}{2}\right)+\left(\frac{V_{mc}+V_{sma}+V_{sps}}{3}\right)}{2}\right)$$

where: V_{of} = frequency of overbank flow

V_{rs} = riparian source

V_{mc} = microtopographic complexity

V_{sma} = surfaces for microbial activity

V_{sps} = sorptive properties of soils

Retention of Particulates

The function of retention of particulates is determined by seven variables. V_{of}, V_{wvr}, V_{cwd} and V_{mc} have been previously described under the function of dynamic surface water storage. Also, V_{rs} has been described under the function of element and compound removal.

The variable of herbaceous vegetation roughness (V_{hvr}) was determined for each wetland cover type within Harrison Bayou and the target wetland sites using a scale ranging from 1-5. Scores from this scale for each cover type were determined through a visual assessment of each cover type. If the herbaceous plant cover was > 75% similar to the reference standard, the index of V_{hvr} was 1.0. If it was between 25% to 75% similar to the reference standard, the index was 0.5. If it was between 1% to 25% of the reference standard, the index was 0.1. If herbaceous plant cover was lacking and restoration was not possible, the index of V_{hvr} was 0.0.

The index of the variable of retained sediments (V_{rsed}) was determined for vegetation communities through visual assessment of the reference and target wetland sites. If the depth of silt or sediment layering on surfaces or buried root collars or buried levees for a cover type was > 75% of the silt depths of the reference standard, the index will be 1.0. If the cover type has sediment depths that are between 25% to 75% or between 1% and 25% of the reference standard, the index was 0.5 and 0.1, respectively. Should sedimentation characteristics be absent due to hydrologic alteration, the index was 0.0.

The variables depict the function in the following manner:

$$\left(\left(\frac{V_{of} + V_{rsed}}{2}\right)\left(\frac{V_{wvr} + V_{hvr} + V_{mc} + V_{cwd}}{4}\right)\right)^{\frac{1}{2}}$$

where: V_{of} = frequency of overbank flow

V_{rsed} = retained sediments

V_{wvr} = woody vegetation roughness

V_{mc} = microtopographic complexity

V_{hvr} = herbaceous vegetation roughness

V_{cwd} = coarse woody debris

Organic Carbon Export

Determining the index of function for organic carbon export requires the use of four variables, two of which have already been described (V_{rsed}, V_{of}). The variable describing the presence of surface hydraulic connection with the main channel (V_{shc}) was determined using topographic maps, aerial photos, and visual assessment to determine the presence of internal drainage channels within a plant community. If internal drainage channels were present and connected to the main channel in a plant community, that community received a score of 1. If internal drainage channels were absent, the plant community received a score of 0.0. If a plant community has internal drainage patterns and is compared to a reference standard plant community that also had surface hydraulic connections with the main channel, then the score was 1. If the plant community had a score of 0 (no internal drainage patterns) and the reference standard had a score of 1, then the index for V_{shc} would be 0.0. If the plant community had a score of 0 and the reference standard had a score of 0, then the index for V_{shc} would be 1.

The index of the variable that describes the amount of organic matter in the wetland, V_{om}, was determined through visual assessment by cover type. A scale ranging from 1-5 was established to denote the amount of organic matter in a wetland. If the amount of litter, coarse woody debris, live woody vegetation, dead or live herbaceous vegetation and/or organic rich mineral soils were between 75% to 125% of the reference standard, the index was 1.0. If the above characteristics were between 25% to 75% or > 125% of the reference standard, the index will be 0.5. If characteristics were between 1% to 25% of the reference standard, the index was 0.1. If no organic matter was present in the wetland and there was no potential for recovery, then the index was 0.0.

The index of function can be calculated as:

$$\left(\left(\frac{V_{of}+V_{rsed}+V_{shc}}{3}\right)(V_{om})\right)^{\frac{1}{2}}$$

where: V_{of} = frequency of overbank flow

V_{rsed} = retained sediments

V_{shc} = surface hydraulic connection

V_{om} = organic matter

If V_{om} is 0, then the function of organic carbon export is absent.

RESULTS

Function Variables

For most comparisons, frequency of overbank flow and depth of inundation in the target wetlands varied greatly from conditions found within the reference wetland. The variables of coarse woody debris and woody vegetation roughness did not differ much between target and reference wetland.

Function Assessment

The data collected were grouped by vegetative communities for each wetland study site (Table 2). The function data from each wetland study site were compared to the function data of the reference wetland by plant community. Selecting the plant communities to be compared depended on the similarities of the dominant plant species and landscape position. Plant community size was not taken into account in the selection procedure.

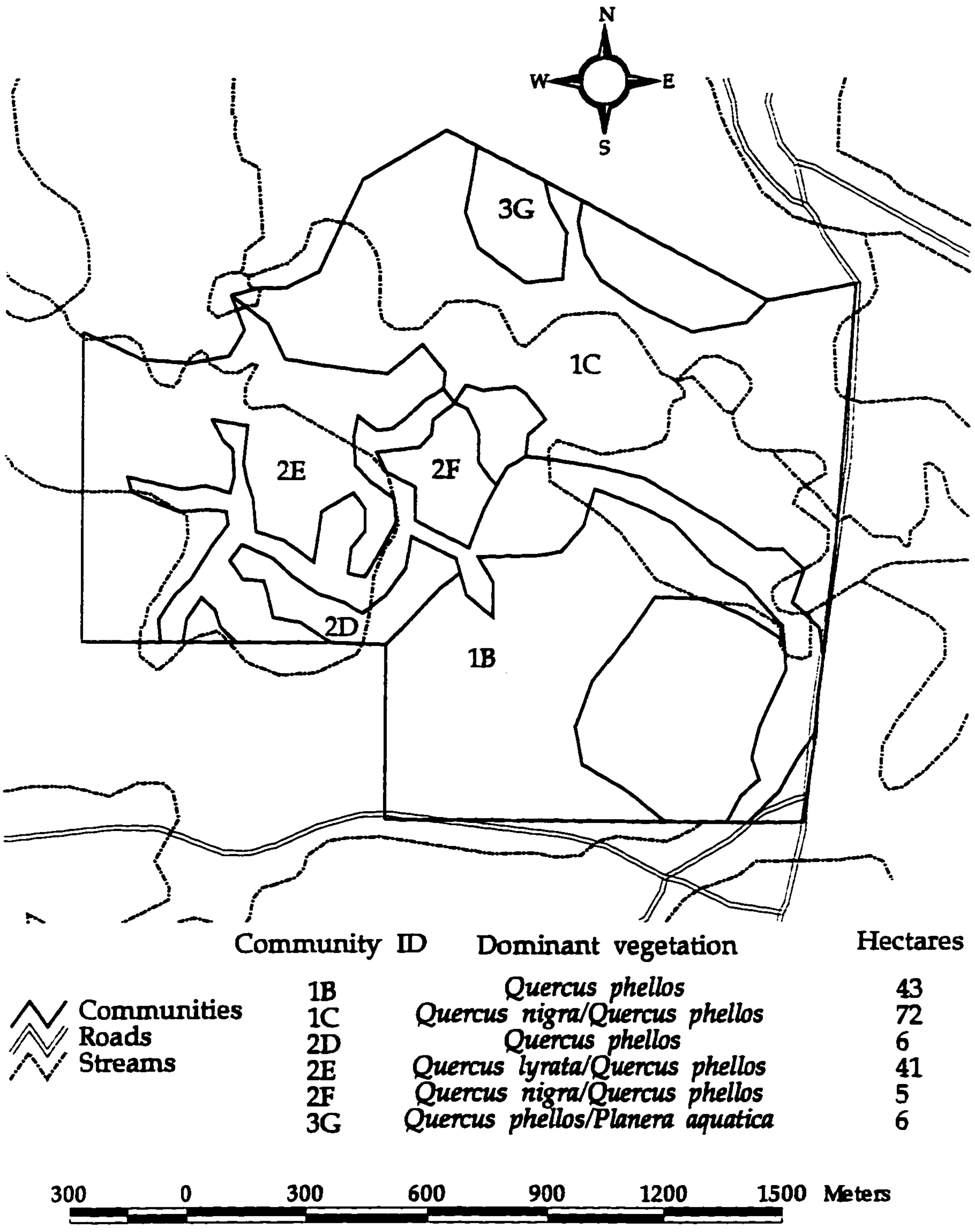
Table 2. Description and size of wetland plant communities in each study site.

Community (Acronym)	Dominant vegetation	Hectares
Harrison Bayou 1A (Hb1A)	*Quercus lyrata* Walt.	95
Harrison Bayou 1B (Hb1B)	*Celtis laevigata* Willd./*Ulmus* spp.	8
Harrison Bayou 1C (Hb1C)	*Quercus lyrata* / *Taxodium distichum* (L.) Rich	9
Harrison Bayou 2E (Hb2E)	*Quercus laurifolia* Michx.	7
Harrison Bayou 3F (Hb3F)	*Quercus laurifolia*	35
Harrison Bayou 3G (Hb3G)	*Quercus phellos* L./*Planera aquatica* (Walt.) J.F. Gmel.	24
Harrison Bayou 4J (Hb4J)	*Quercus lyrata*/*Quercus laurifolia*	46
Big Cypress 1B (Bigcyp1B)	*Quercus phellos*	43
Big Cypress 1C (Bigcyp1C)	*Quercus nigra* L./*Quercus phellos*	72
Big Cypress 2D (Bigcyp2D)	*Quercus phellos*	6
Big Cypress 2E (Bigcyp2E)	*Quercus lyrata*/*Quercus phellos*	41
Big Cypress 2F (Bigcyp2F)	*Quercus nigra*/*Quercus phellos*	5
Big Cypress 3G (Bigcyp3G)	*Quercus phellos*/*Planera aquatica*	6
Black Cypress 1A (Blkcyp1A)	*Quercus phellos*/*Quercus lyrata*	11
Black Cypress 1B (Blkcyp1B)	*Quercus phellos*/*Liquidambar styraciflua* L.	108
Black Cypress 1C (Blkcyp1C)	*Taxodium distichum*/*Quercus lyrata*	88
Black Cypress 1D (Blkcyp1D)	*Quercus lyrata* /*Quercus phellos*	27
Black Cypress 2E (Blkcyp2E)	*Taxodium distichum*/*Quercus lyrata*	12
Black Cypress 2F (Blkcyp2F)	*Quercus lyrata*/*Taxodium distichum*	18
Black Cypress 3G (Blkcyp3G)	*Quercus phellos*/*Liquidambar styraciflua*	63
Cherokee Ridge 1 (CR1)	*Quercus nigra*/*Quercus phellos* (clearcut)	25
Cherokee Ridge 2 (CR2)	*Liquidambar styraciflua*/*Quercus nigra*	4
Alazan Bayou 1A (Alb1A)	*Solidago canadensis* L./ *Arundinaria gigantea* (Walt.) Muhl.	7
Alazan Bayou 1B (Alb1B)	*Arundinaria gigantea*	2
Alazan Bayou 1C (Alb1C)	*Solidago canadensis* / *Eupatorium capillifolium* (Lam.) Small	5

Big Cypress Bayou

This study site contained six plant communities from which data were collected (Figure 6). The function indices for dynamic surface water storage differ slightly between the two V_{of} assessment techniques (Tables 3 and 4). In most comparisons, use of the visual assessment method results in a higher index of function for dynamic surface water storage. For the purposes of this study, the visual assessment method is assumed to be more precise in evaluating V_{of} and is used for final reporting of the function of dynamic surface water storage except in the Cherokee Ridge and Alazan Bayou study sites.

A graphical representation of Big Cypress Bayou's dynamic surface water storage capacity by plant community (using Harrison Bayou as a reference wetland) shows that in general, the function performs at a higher level near the main channel (Figure 7). A more accurate assessment of this function, however, might be revealed if Black Cypress Bayou were used as a reference wetland, since the flooding regimes of the two study sites coincide more closely (Table 1). However, communities that would be expected to perform at a higher rate due to their landscape position actually have the lowest indices for dynamic surface water storage (Figure 8). This indicates that the low-scoring communities did not conform very closely to conditions found in communities in Black Cypress Bayou with similar landscape



Community ID	Dominant vegetation	Hectares
1B	*Quercus phellos*	43
1C	*Quercus nigra/Quercus phellos*	72
2D	*Quercus phellos*	6
2E	*Quercus lyrata/Quercus phellos*	41
2F	*Quercus nigra/Quercus phellos*	5
3G	*Quercus phellos/Planera aquatica*	6

Figure 6. Identification of communities within Big Cypress Bayou.

Table 3. Function indices by community for Big Cypress Bayou, using Harrison Bayou as a reference wetland.

		Functions					
Target wetland	Reference wetland	Nutrient cycling	Dynamic surface water storage (flooding scores)	Dynamic surface water storage (visual assessment)	Removal of elements and compounds♥	Retention of particulates♥	Organic carbon export♥
BIGCYP1B*	HB3G†	0.5	0.71	0.71	0.86	0.81	0.91
BIGCYP1C	HB1A	0.5	0.66	0.94	0.86	0.75	0.58
BIGCYP2D	HB4J	0.5	0.61	0.61	0.81	0.75	0.58
BIGCYP2E	HB3F	0.5	0.57	0.57	0.82	0.75	0.58
BIGCYP2F	HB2E	0.5	0.66	0.66	0.86	0.81	0.65
BIGCYP3G	HB1B	0.5	0.57	0.81	0.86	0.70	0.65

*BIGCYP = Big Cypress Bayou

†HB = Harrison Bayou

♥ = function indices determined using the visually assessed variable for frequency of overbank flooding (V_{od})

Table 4. Function indices by community for Big Cypress Bayou, using Black Cypress Bayou as a reference wetland.

		Functions					
Target wetland	Reference wetland	Nutrient cycling	Dynamic surface water storage (flooding scores)	Dynamic surface water storage (visual assessment)	Removal of elements and compounds✓	Retention of particulates✓	Organic carbon export✓
BIGCYP1B*	BLKCYP1B†	1.00	0.57	0.57	0.76	0.81	0.91
BIGCYP1C	BLKCYP1B	1.00	0.51	0.51	0.76	0.75	0.82
BIGCYP2D	BLKCYP3G	0.50	0.66	0.94	0.89	0.87	0.65
BIGCYP2E	BLKCYP1D	1.00	0.51	0.72	0.94	0.79	0.71
BIGCYP2F	BLKCYP1A	1.00	0.62	0.88	0.94	0.94	1.00
BIGCYP3G	BLKCYP2F	0.50	0.62	0.62	0.86	0.70	0.91

*BIGCYP = Big Cypress Bayou

†BLKCYP = Black Cypress Bayou

✓ = function indices determined using the visually assessed variable for frequency of overbank flooding (V_{od})

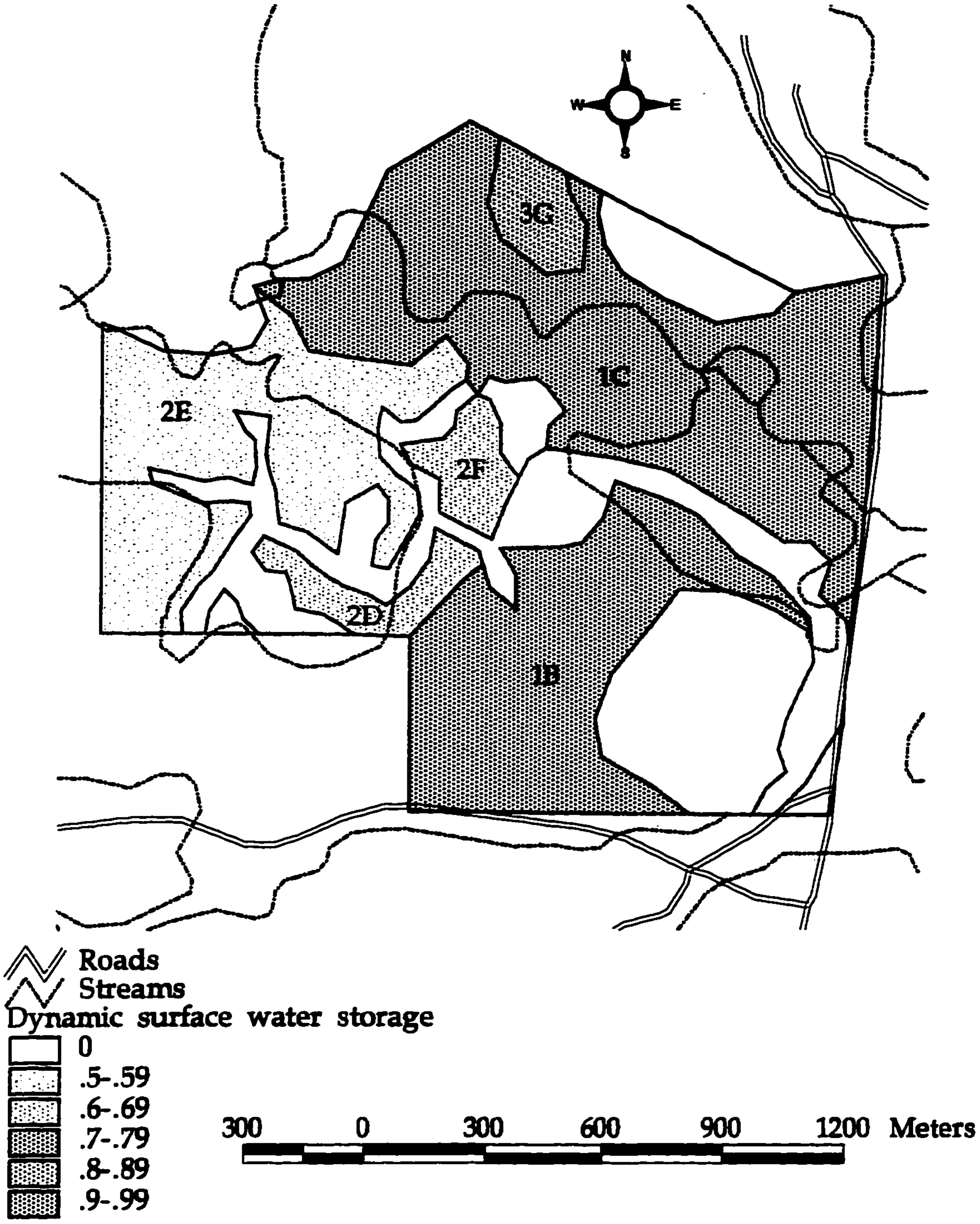


Figure 7. Function indices of dynamic surface water storage for Big Cypress Bayou by community, using Harrison Bayou as a reference wetland.

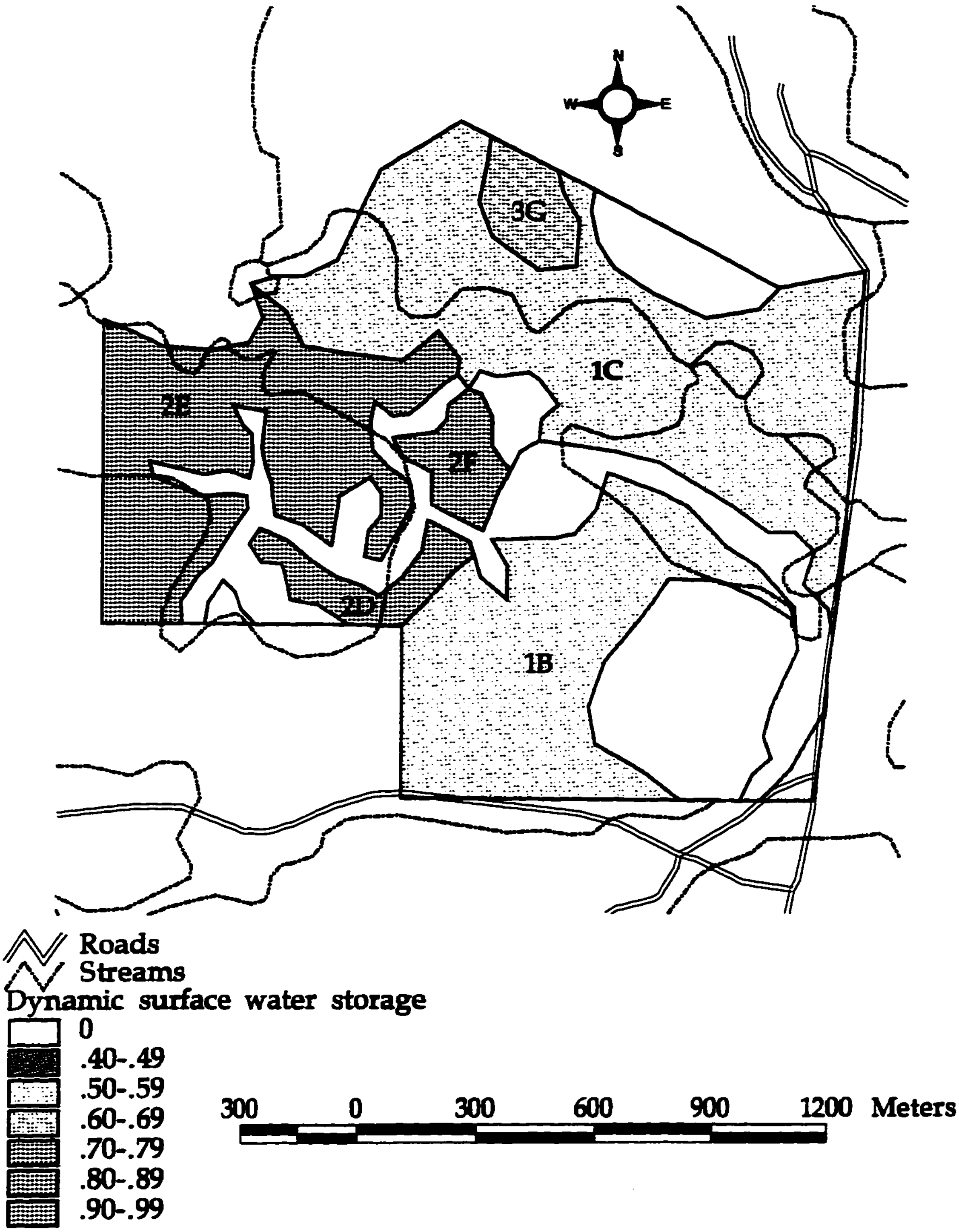


Figure 8. Function indices of dynamic surface water storage for Big Cypress Bayou by community, using Black Cypress Bayou as a reference wetland.

position. In most cases, conditions for V_{di} in Big Cypress Bayou differed greatly from those found in Black Cypress Bayou.

When Harrison Bayou is used as a reference wetland for Big Cypress Bayou, the indices of function for nutrient cycling are relatively low. This is due to Harrison Bayou consistently having a higher rate of net primary productivity (higher percentages of canopy, subcanopy, shrub and ground cover) in all communities. When Harrison Bayou is used as the reference wetland for Big Cypress Bayou, the indices of function for organic carbon export tend to be lower. This is due to Harrison Bayou generally having a greater amount of organic matter (leaf litter, coarse woody debris, live woody vegetation, and herbaceous vegetation) in most communities, especially those flanking the main channel. The organic matter conditions in Black Cypress Bayou are more comparable to the conditions in Big Cypress Bayou.

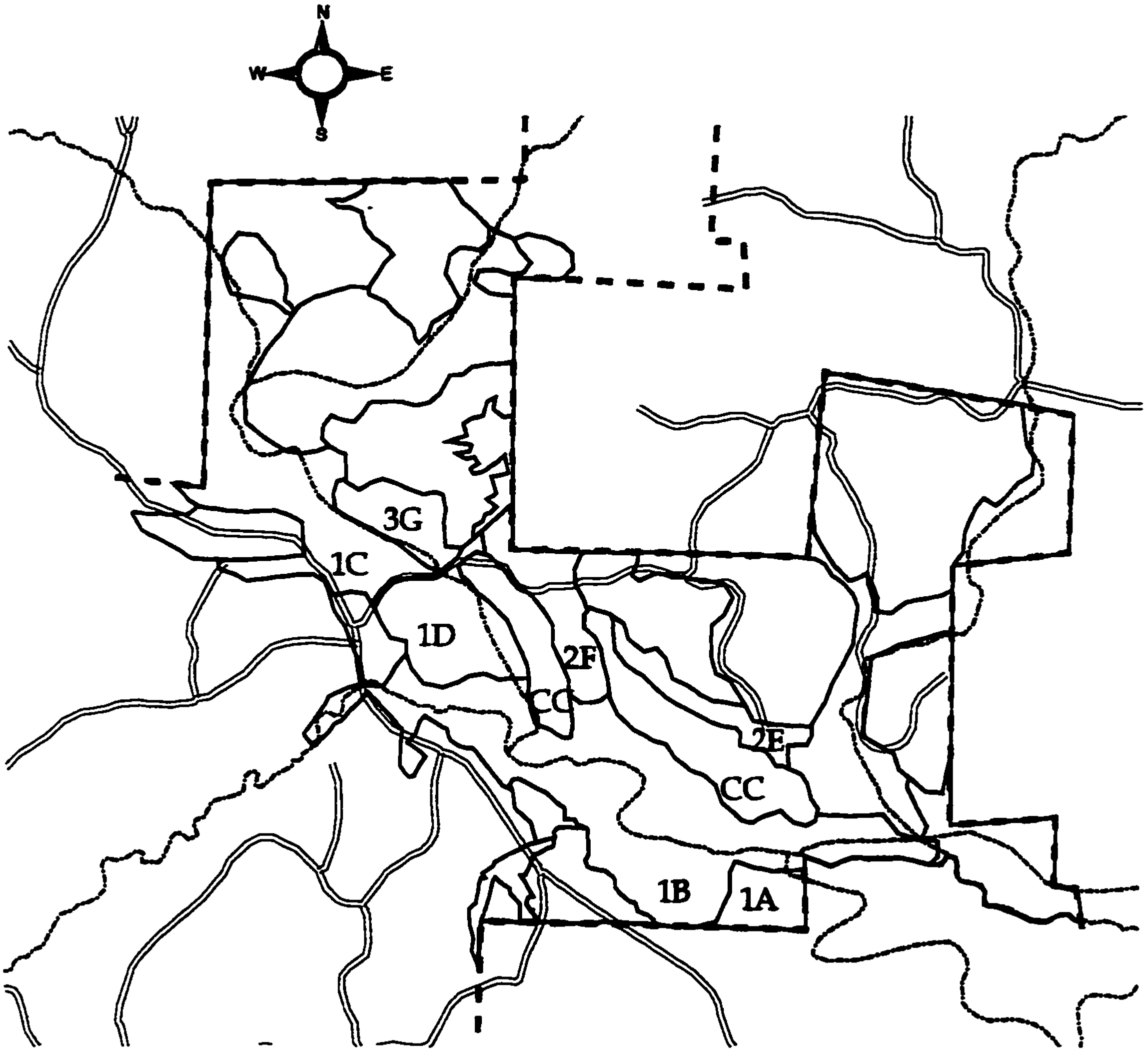
Indices of function for the removal of elements and compounds and retention of particulates do not deviate significantly when different reference wetlands are used. This is probably due to both of the functions having a relatively large number of variables involved in their assessment. The variable of microtopographic complexity (V_{mc}) did not vary much when Harrison Bayou was used as a reference wetland, but V_{mc} conditions between Black Cypress Bayou and Big Cypress Bayou were found to be very different. In most communities, V_{mc} scores were greater in Big Cypress Bayou.

Black Cypress Bayou

Data were collected from seven communities in Black Cypress Bayou (Figure 9). This study site is assumed to have the highest frequency of overbank flow out of the three forested study sites, as determined by visual assessment and personal communication. Therefore, it is difficult to compare this study site to another wetland that exhibits the same level of flooding frequency. Cherokee Ridge floods as often as Black Cypress Bayou, if not more, but will not be used as a reference wetland since the stand ages are different.

Comparing Black Cypress Bayou to Harrison Bayou and Big Cypress Bayou for the function of dynamic surface water storage reveals generally what would be expected (Tables 5 and 6). The indices of function are relatively low where they should be close to 1, especially in those communities flanking the main channel (Figures 10 and 11). This indicates that similar communities in Harrison Bayou and Big Cypress Bayou did not exhibit similar dynamic surface water storage conditions. The variable of frequency of overbank flooding in Harrison and Big Cypress Bayou is very different from conditions found in Black Cypress Bayou, creating a lower index of function for dynamic surface water storage.

The function of nutrient cycling using Harrison Bayou as a reference wetland is relatively low due to Harrison Bayou generally having greater net primary productivity. Most of the variables for the function of removal of



IP property boundaries
Roads
Black Cypress Bayou
Communities

CC - clearcuts

Community ID	Dominant vegetation	Hectares
1A	*Quercus phellos/Quercus lyrata*	11
1B	*Quercus phellos/Liquidambar styraciflua*	108
1C	*Taxodium distichum/Quercus lyrata*	88
1D	*Quercus lyrata/Taxodium distichum*	27
2E	*Taxodium distichum/Quercus lyrata*	12
2F	*Quercus lyrata/Taxodium distichum*	18
3G	*Quercus phellos/Liquidambar styraciflua*	63

1000 0 1000 2000 3000 Meters

Figure 9. Identification of communities within Black Cypress Bayou.

Table 5. Function indices by community for Black Cypress Bayou, using Harrison Bayou as a reference wetland.

Target wetland	Reference wetland	Functions					
		Nutrient cycling	Dynamic surface water storage (flooding scores)	Dynamic surface water storage (visual assessment)	Removal of elements and compounds^{v}	Retention of particulates^{v}	Organic carbon export^{v}
BLKCYP1A*	HB1B†	1.00	0.32	0.71	0.86	0.81	0.91
BLKCYP1B	HB3F	0.50	0.20	0.45	0.86	0.61	0.91
BLKCYP1C	HB1A	0.50	0.25	0.57	0.86	0.70	0.65
BLKCYP1D	HB2E	0.50	0.23	0.51	0.92	0.68	0.91
BLKCYP2E	HB2E	0.50	0.25	0.57	0.72	0.66	0.50
BLKCYP2F	HB1C	0.50	0.25	0.56	0.81	0.68	0.91
BLKCYP3G	HB3G	1.00	0.30	0.94	0.89	0.94	1.00

*BLKCYP = Black Cypress Bayou

†HB = Harrison Bayou

^{v} = function indices determined using the visually assessed variable for frequency of overbank flooding (V_{od})

Table 6. Function indices by community for Black Cypress Bayou, using Big Cypress Bayou as a reference wetland.

		Functions					
Target wetland	Reference wetland	Nutrient cycling	Dynamic surface water storage (flooding scores)	Dynamic surface water storage (visual assessment)	Removal of elements and compounds^{v}	Retention of particulates^{v}	Organic carbon export^{v}
BLKCYP1A*	BIGCYP1A†	0.50	0.57	0.57	0.86	0.70	0.82
BLKCYP1B	BIGCYP1C	1.00	0.57	0.57	0.81	0.81	0.82
BLKCYP1C	BIGCYP1C	1.00	0.62	0.62	0.92	0.81	0.82
BLKCYP1D	BIGCYP2E	0.50	0.51	0.72	0.83	0.79	0.71
BLKCYP2E	BIGCYP2D	0.50	0.45	0.45	0.62	0.50	0.71
BLKCYP2F	BIGCYP2E	0.50	0.71	1.00	0.84	1.00	0.91
BLKCYP3G	BIGCYP2D	0.50	0.66	0.94	1.00	0.87	0.91

*BLKCYP = Black Cypress Bayou

†BIGCYP = Big Cypress Bayou

^{v} = function indices determined using the visually assessed variable for frequency of overbank flooding (V_{od})

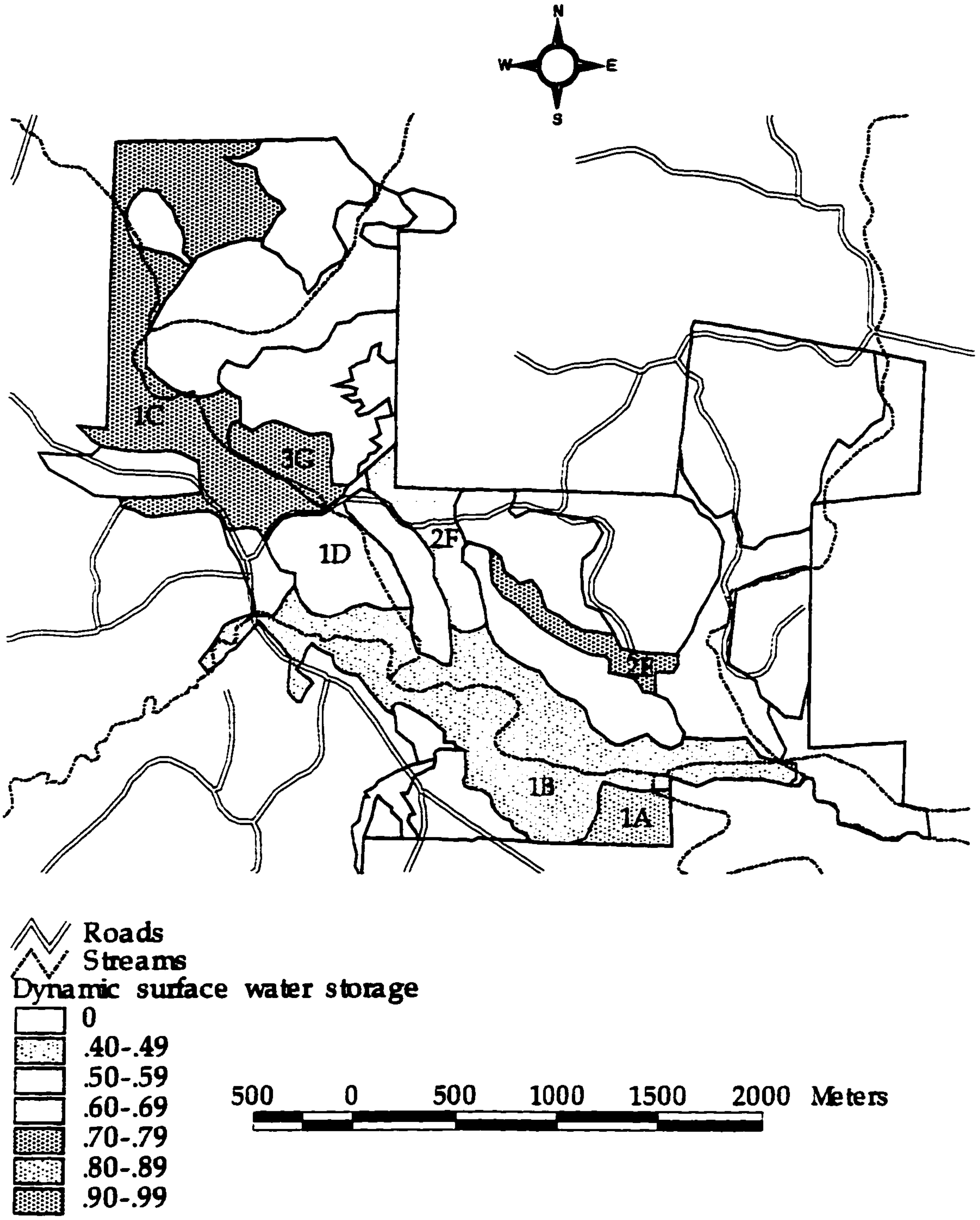


Figure 10. Function indices of dynamic surface water storage for Black Cypress Bayou, using Harrison Bayou as a reference wetland.

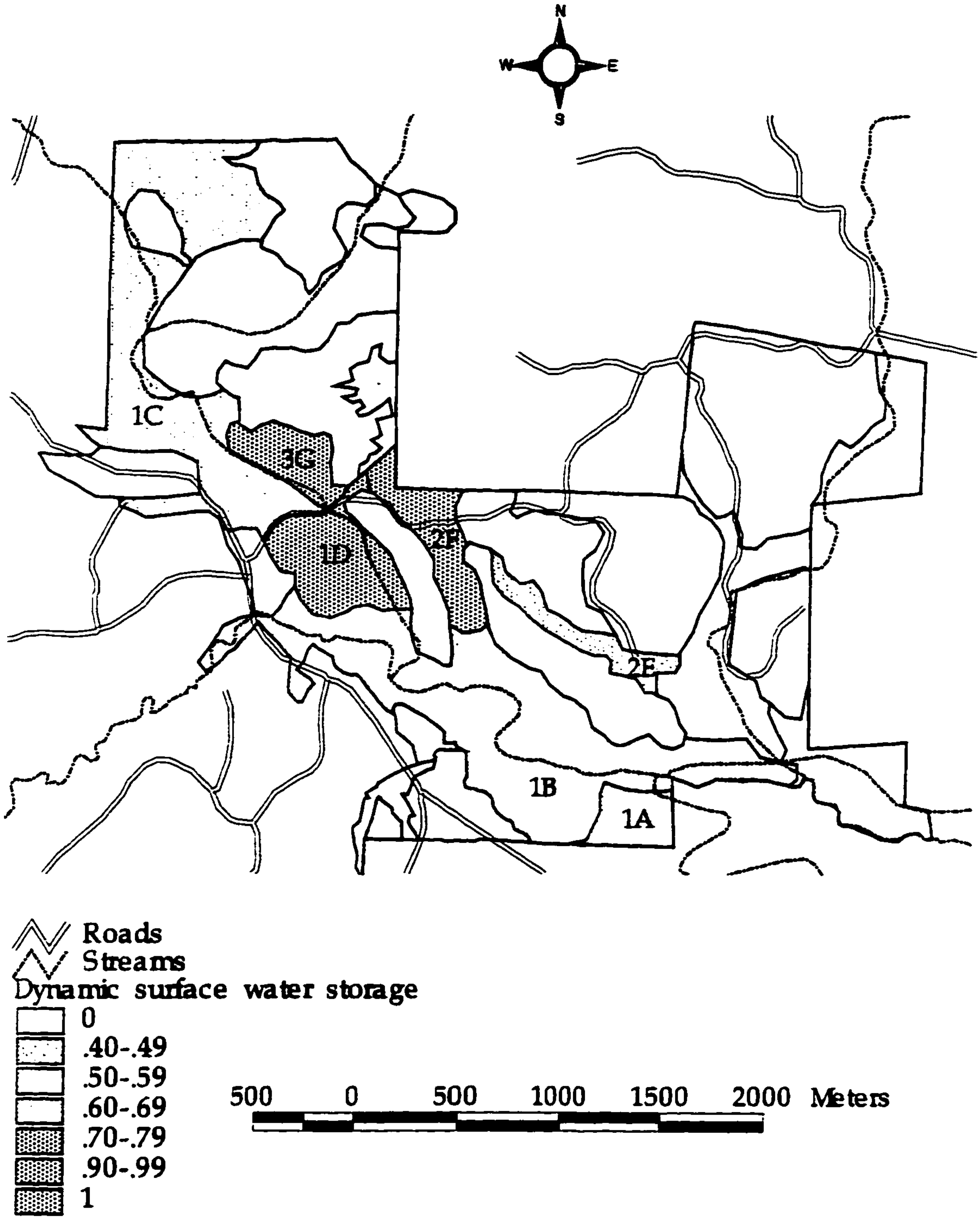
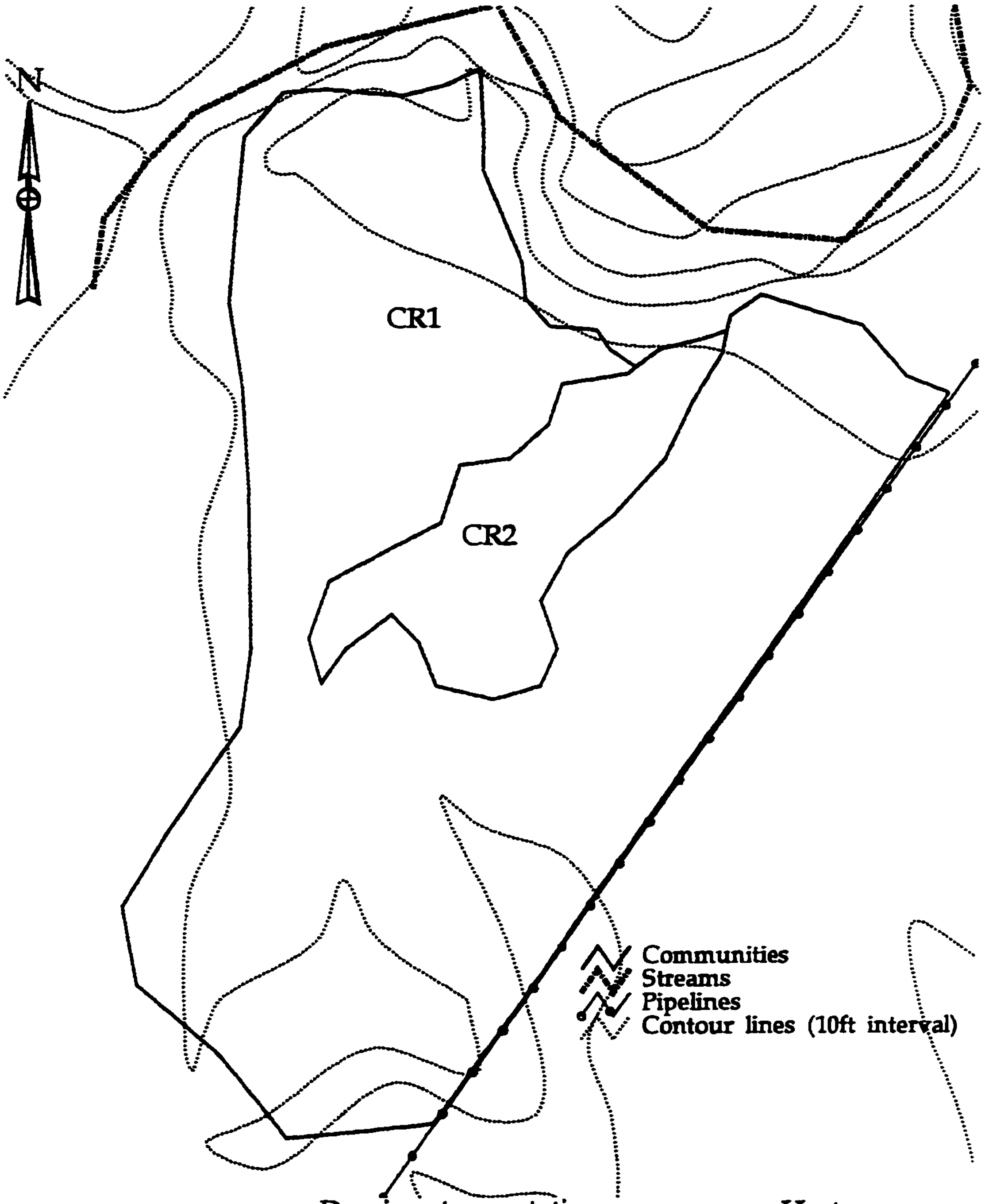


Figure 11. Function indices of dynamic surface water storage for Black Cypress Bayou, using Big Cypress Bayou as a reference wetland.

elements and compounds were similar to conditions found in Big Cypress Bayou; however, when a variation did occur, it was found in V_{src}. Most of the variables for the function of retention of particulates were also similar to conditions within Big Cypress Bayou except for V_{sed}. The level of retained sediments was generally higher in Black Cypress Bayou than in Big Cypress Bayou. For the function of organic carbon export, V_{shc} varied from conditions found in Big Cypress Bayou. In most communities, Big Cypress Bayou was lacking in surface hydraulic connections with the main channel.

Cherokee Ridge

Due to the fact that the majority of the Cherokee Ridge study site is a clearcut, V_{of} is assessed with flooding frequency scores since the variable relies on the presence of trees (Figure 12). When Cherokee Ridge is compared to Harrison Bayou, the function indices for dynamic surface water storage are relatively low, as expected (Table 7 and Figure 13). This is because Cherokee Ridge floods more frequently than Harrison Bayou, and therefore the overbank flooding indicators in the two sites are not similar to each other. When conditions in the reference and target wetlands are not similar to one another, this results in lower variable scores which in turn results in lower indices of function. The function indices are greater when Black Cypress is used as a reference wetland, since the levels of flooding frequency are more similar (Table 8 and Figure 14). The function index for dynamic surface water



Community ID	Dominant vegetation	Hectares
CR1	*Quercus nigra/Quercus phellos (clearcut)*	25
CR2	*Liquidambar styraciflua/Quercus nigra*	4

Figure 12. Identification of communities within Cherokee Ridge.

Table 7. Function indices by community for Cherokee Ridge, using Harrison Bayou as a reference wetland.

		Functions					
Target wetland	Reference wetland	Nutrient cycling	Dynamic surface water storage (flooding scores)	Dynamic surface water storage (visual assessment)	Removal of elements and compounds[v]	Retention of particulates[v]	Organic carbon export[v]
CR1*	HB2E†	1.00	0.25	0.57	0.44	0.69	0.84
CR2	HB4J	1.00	0.28	0.62	0.79	0.69	0.84

*CR = Cherokee Ridge

†HB = Harrison Bayou

[v] = function indices determined using flooding frequency scores for assessing the variable for frequency of overbank flooding (V_{od})

Table 8. Function indices by community for Cherokee Ridge, using Black Cypress Bayou as a reference wetland.

		Functions					
Target wetland	Reference wetland	Nutrient cycling	Dynamic surface water storage (flooding scores)	Dynamic surface water storage (visual assessment)	Removal of elements and compounds[v]	Retention of particulates[v]	Organic carbon export[v]
CR1*	BLKCYP1B†	0.50	0.79	0.56	0.59	0.79	0.65
CR2	BLKCYP1B	0.50	0.87	0.87	0.89	0.94	1.00

*CR = Cherokee Ridge

†BLKCYP = Black Cypress Bayou

[v] = function indices determined using flooding frequency scores for assessing the variable for frequency of overbank flooding (V_{od})

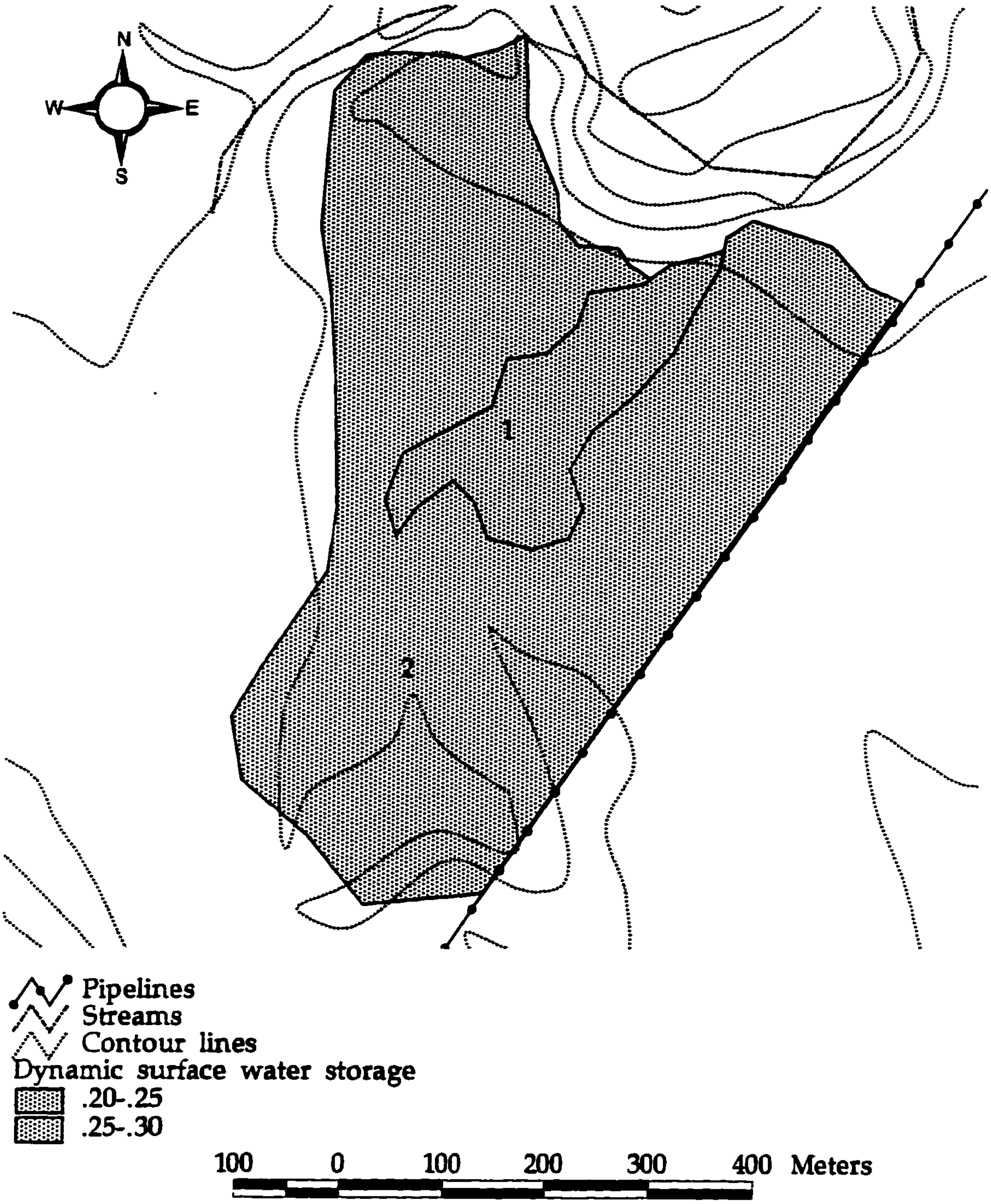


Figure 13. Function indices of dynamic surface water storage for Cherokee Ridge by community, using Harrison Bayou as a reference wetland.

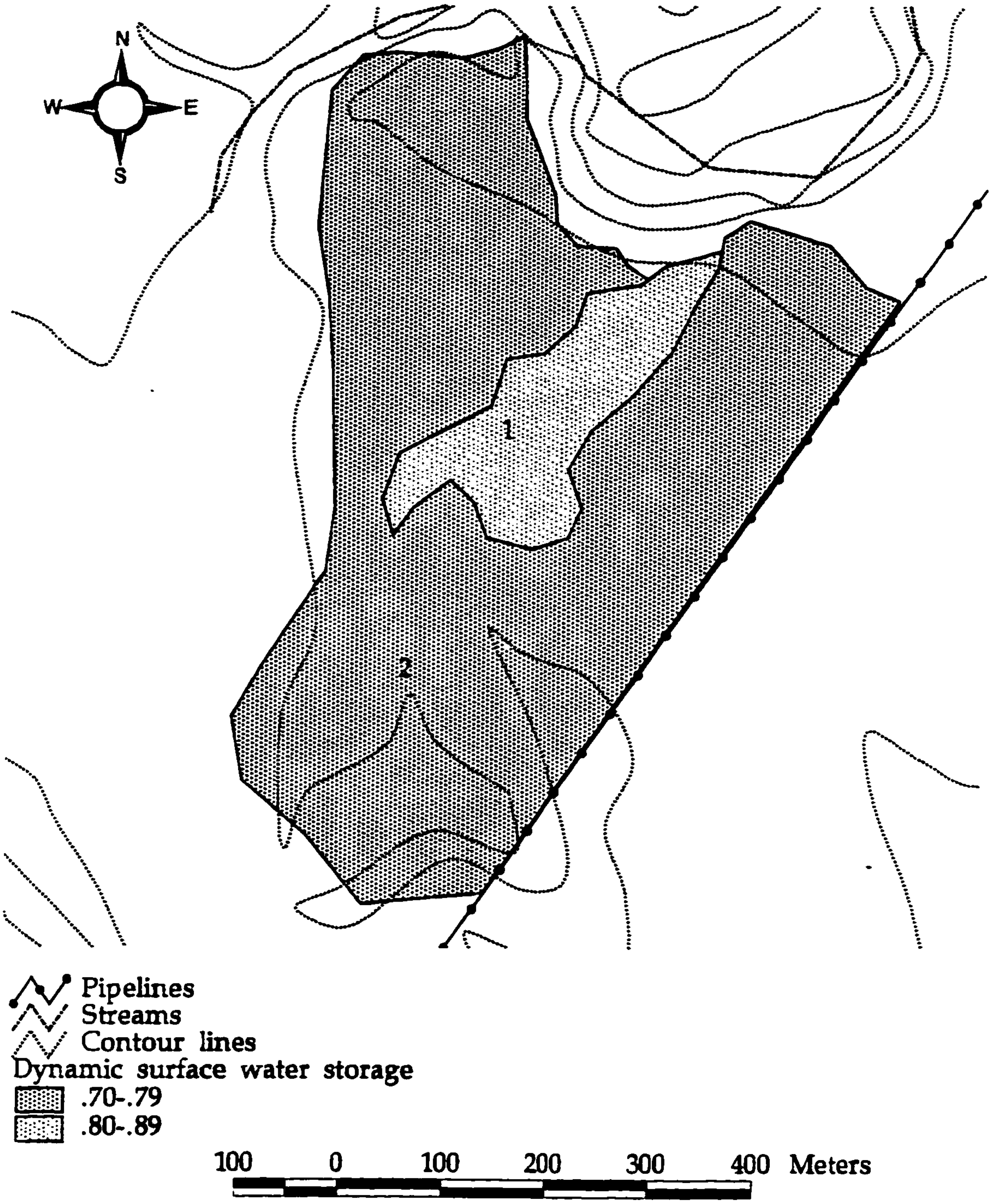


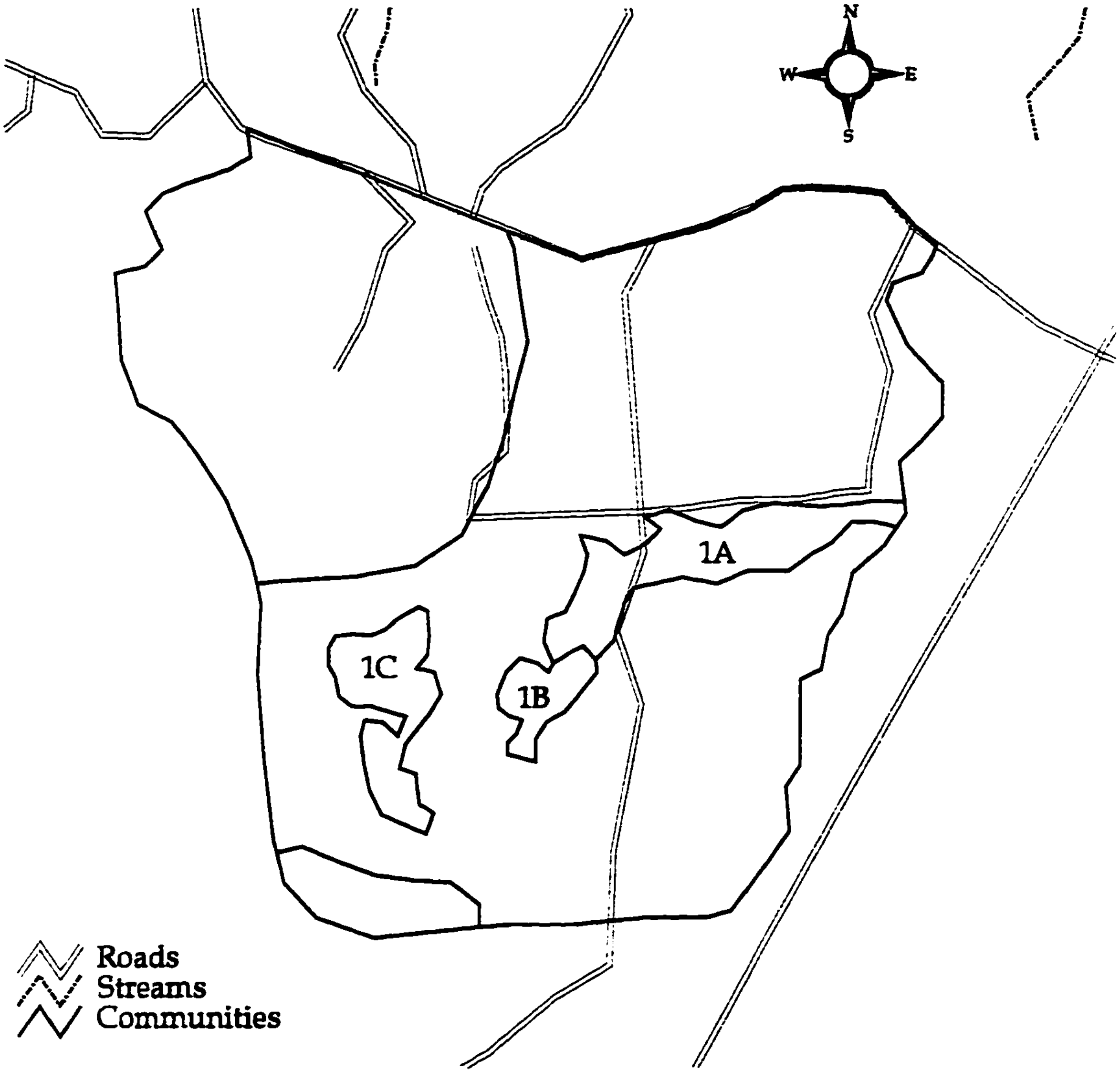
Figure 14. Function indices of dynamic surface water storage for Cherokee Ridge by community, using Black Cypress Bayou as a reference wetland.

storage is greater in the SMZ, due to the higher occurrence of woody vegetation roughness.

The indices of function for nutrient cycling are relatively low when Black Cypress Bayou is used as a reference wetland. Black Cypress Bayou has less snags, downed and dead woody debris, and fewer fungal fruiting bodies than both communities of Cherokee Ridge. The fact that conditions are different between the two sites result in a lower index of function. Also, Black Cypress Bayou exhibited less microtopographic complexity than that found in Cherokee Ridge, which lowers the functions of removal of elements and compounds and retention of particulates. When using Black Cypress Bayou as a reference, the index of function for organic carbon export is less in the clearcut than it is in the SMZ. This is due to the clearcut having less leaf litter and live woody vegetation than the corresponding community in Black Cypress Bayou.

Alazan Bayou

Data were collected for each community in Alazan Bayou (Figure 15). For the determination of V_{of} in Alazan Bayou, flooding frequency scores instead of visual assessment was used due to the absence of trees (Table 9). In this situation, Harrison Bayou was an appropriate reference wetland in terms of V_{of} for the function of dynamic surface water storage since it exhibits only slightly higher flooding frequencies (Figure 16). This gives Alazan Bayou a



Community ID	Dominant vegetation	Hectares
1A	*Solidago canadensis/Arundinaria gigantea*	7
1B	*Arundinaria gigantea*	2
1C	*Solidago canadensis/Eupatorium capillifolium*	5

500 0 500 1000 Meters

Figure 15. Identification of communities within Alazan Bayou Wildlife Management Area.

Table 9. Function indices by community for Alazan Bayou, using Harrison Bayou as a reference wetland.

Target wetland	Reference wetland	Functions					
		Nutrient cycling	Dynamic surface water storage (flooding scores)	Dynamic surface water storage (visual assessment)	Removal of elements and compounds^{v}	Retention of particulates^{v}	Organic carbon export^{v}
ALB1A*	HB2E†	0.50	0.81	0.57	0.64	0.81	0.58
ALB1B	HB4J	0.50	0.63	0.45	0.53	0.72	0.71
ALB1C	HB3G	0.50	0.81	0.57	0.59	0.81	0.32

*ALB = Alazan Bayou

†HB = Harrison Bayou

^{v} = function indices determined using flooding frequency scores for assessing the variable for frequency of overbank flooding (V_{of})

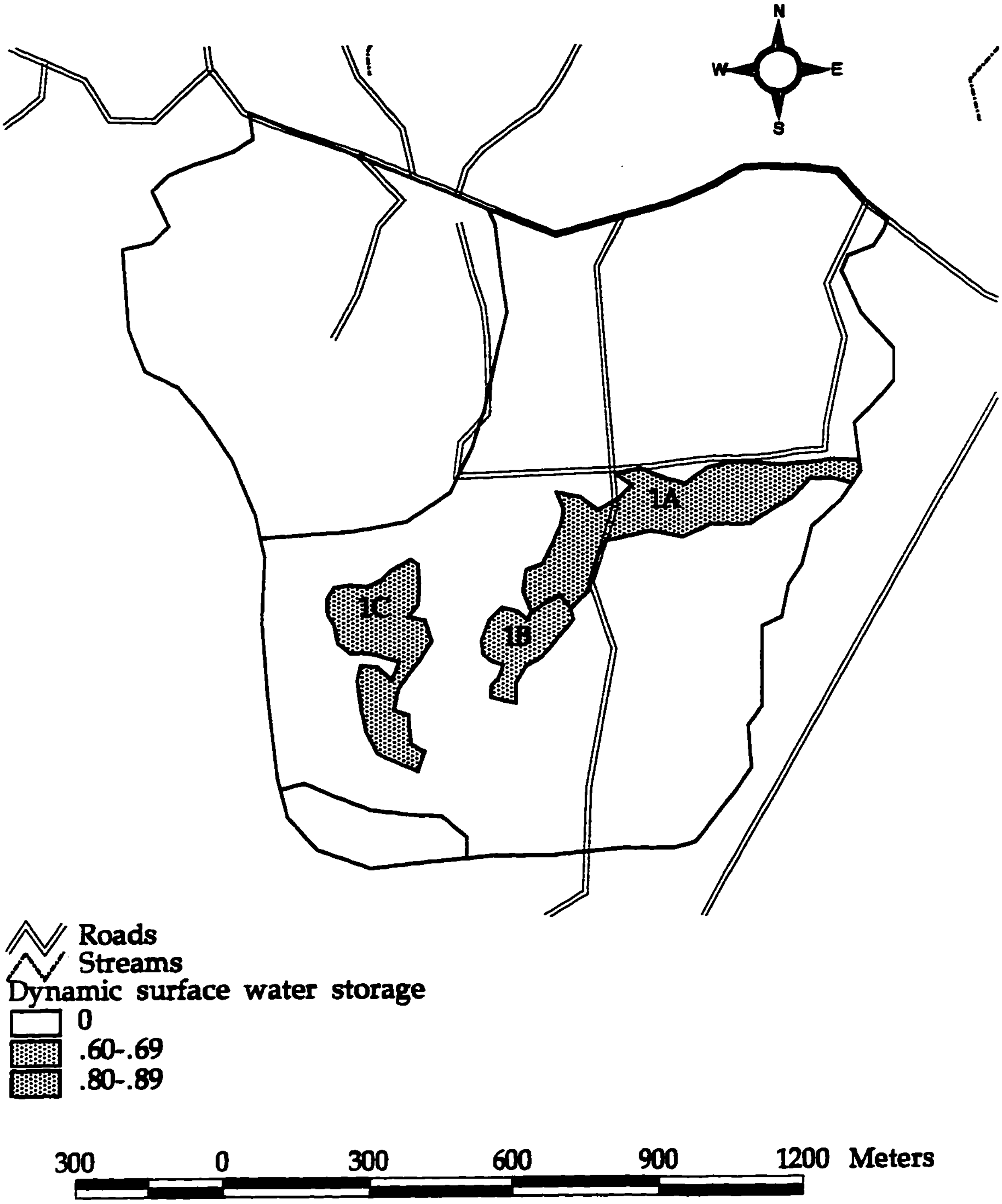


Figure 16. Function indices of dynamic surface water storage for Alazan Bayou, using Harrison Bayou as a reference wetland.

standard for reference that has similar flooding frequencies, resulting in a more precise estimate of function capacity.

The function of nutrient cycling is relatively low due to Harrison Bayou exhibiting more opportunity for detritus turnover and net primary productivity. Furthermore, V_{cwd} is absent in all communities of Alazan Bayou, resulting in lower indices of function for dynamic surface water storage and retention of particulates. Function indices for the removal of elements and compounds is relatively low due to the absence of trees in Alazan Bayou. Harrison Bayou also exhibits greater amounts of organic matter such as leaf litter, coarse woody debris, and live woody vegetation, which decreases the function of organic carbon export.

Harrison Bayou

Data were collected from seven communities in Harrison Bayou (Figure 17). Characteristics of the wetland plant communities in Harrison Bayou differed greatly from conditions found in the wetland plant communities of Black Cypress Bayou and Big Cypress Bayou. In Harrison Bayou, most plant communities had a large understory and/or herbaceous component that was not found in the other two forested wetland sites. It is this difference, along with a lower frequency of flooding, that causes Harrison Bayou to have such low indices of function when compared to Big Cypress Bayou or Black Cypress Bayou (Tables 10 and 11). In Harrison Bayou, the

Community ID	Dominant vegetation	Hectares
1A	*Quercus lyrata*	95
1B	*Celtis laevigata/Ulmus spp.*	8
1C	*Quercus lyrata/Taxodium distichum*	9
2E	*Quercus laurifolia*	7
3F	*Quercus laurifolia*	35
3G	*Quercus phellos/Planera aquatica*	24
4J	*Quercus lyrata/Quercus laurifolia*	46

1000 0 1000 2000 Meters

Figure 17. Identification of communities within Harrison Bayou.

Table 10. Function indices by community for Harrison Bayou, using Big Cypress Bayou as a reference wetland.

Target wetland	Reference wetland	Functions					
		Nutrient cycling	Dynamic surface water storage (flooding scores)	Dynamic surface water storage (visual assessment)	Removal of elements and compounds[v]	Retention of particulates[v]	Organic carbon export[v]
HB1A*	BIGCYP1C†	0.5	0.66	0.94	0.94	0.87	0.65
HB1B	BIGCYP3G	0.5	0.66	0.94	0.94	0.94	0.91
HB1C	BIGCYP2E	0.5	0.51	0.51	0.75	0.68	0.58
HB2E	BIGCYP2E	0.5	0.57	0.57	0.69	0.75	0.65
HB3F	BIGCYP2E	0.5	0.57	0.57	0.69	0.75	0.82
HB3G	BIGCYP1C	0.5	0.66	0.66	0.86	0.75	0.58
HB4J	BIGCYP2D	0.5	0.61	0.61	0.76	0.75	0.58

*HB = Harrison Bayou

†BIGCYP = Big Cypress Bayou

[v] = function indices determined using the visually assessed variable for frequency of overbank flooding (V_{al})

Table 11. Function indices by community for Harrison Bayou, using Black Cypress Bayou as a reference wetland.

		Functions					
Target wetland	Reference wetland	Nutrient cycling	Dynamic surface water storage (flooding scores)	Dynamic surface water storage (visual assessment)	Removal of elements and compounds[v]	Retention of particulates[v]	Organic carbon export[v]
HB1A*	BLKCYP1C†	0.50	0.25	0.57	0.86	0.75	0.65
HB1B	BLKCYP1A	1.00	0.32	0.71	0.86	0.81	0.91
HB1C	BLKCYP2F	1.00	0.23	0.51	0.64	0.68	0.91
HB2E	BLKCYP1D	0.50	0.23	0.51	0.92	0.68	0.91
HB3F	BLKCYP1B	0.50	0.23	0.51	0.86	0.68	0.91
HB3G	BLKCYP3G	0.50	0.30	0.94	0.68	0.94	1.00
HB4J	BLKCYP1D	0.50	0.25	0.57	0.86	0.75	0.82

*HB = Harrison Bayou

†BLKCYP = Black Cypress Bayou

[v] = function indices determined using the visually assessed variable for frequency of overbank flooding (V_{od})

communities adjacent to the main channel should have received the most flooding but did not exhibit a high occurrence of driftlines, watermarks, or sediment layering (Figures 18 and 19).

The function of nutrient cycling is lower when Big Cypress Bayou is used as a reference due to Harrison Bayou generally having a higher score of V_{npp}. In the function of removal of elements and compounds, Harrison Bayou generally conforms to conditions found within Big Cypress Bayou. However, where function indices are relatively low, it is due to Big Cypress Bayou having greater V_{tba}. The function of retention of particulates is also generally similar to conditions within Big Cypress Bayou except for V_{hvr} and V_{sed}. Herbaceous vegetation roughness is greater in Harrison Bayou and sediment retention is generally less. When using Big Cypress Bayou for determining the function of organic carbon export, the greatest deviations originate from V_{om} and V_{shc}. In general, V_{om} is greater in Big Cypress Bayou and V_{shc} is less.

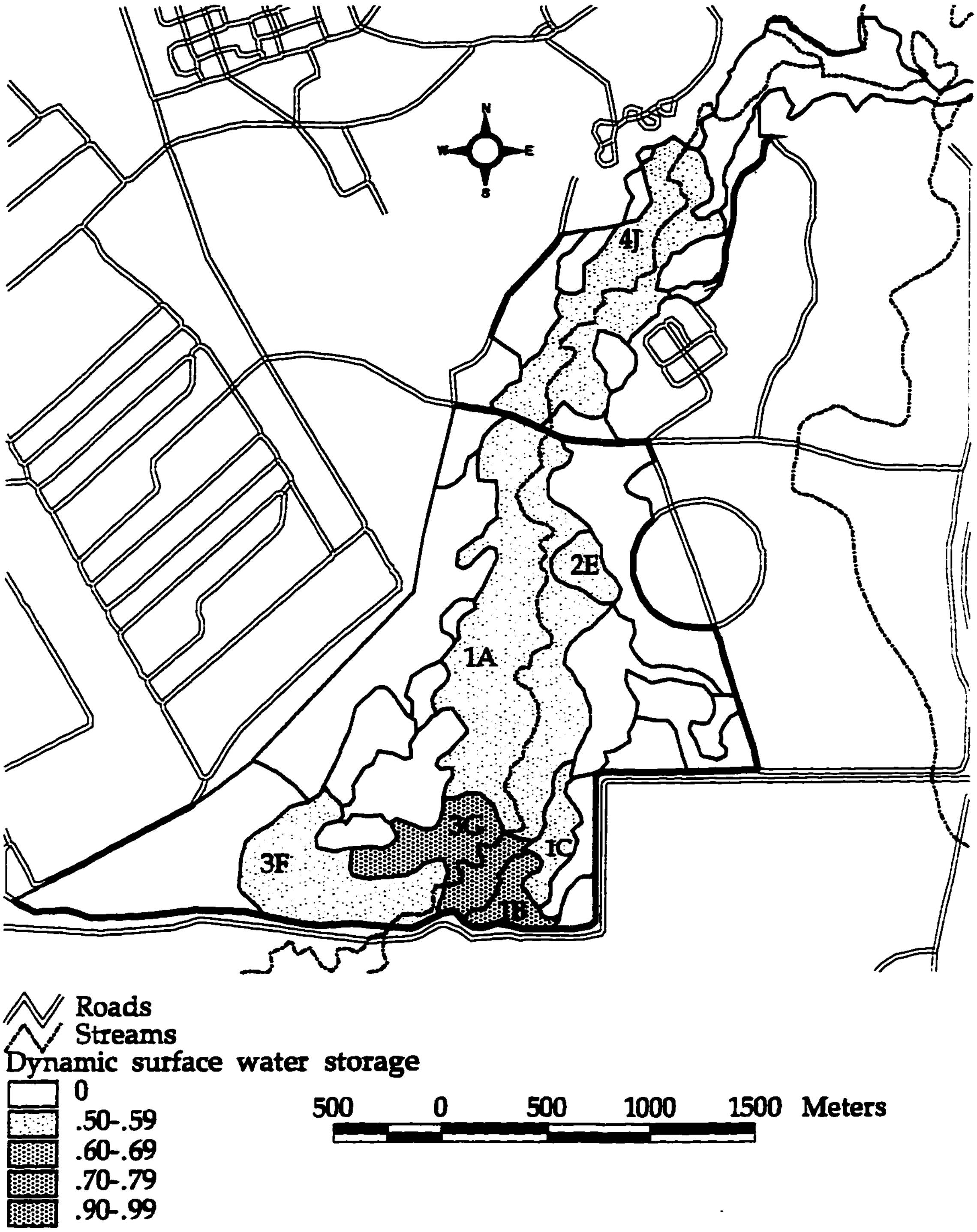


Figure 18. Function indices of dynamic surface water storage for Harrison Bayou by community, using Black Cypress Bayou as a reference wetland.

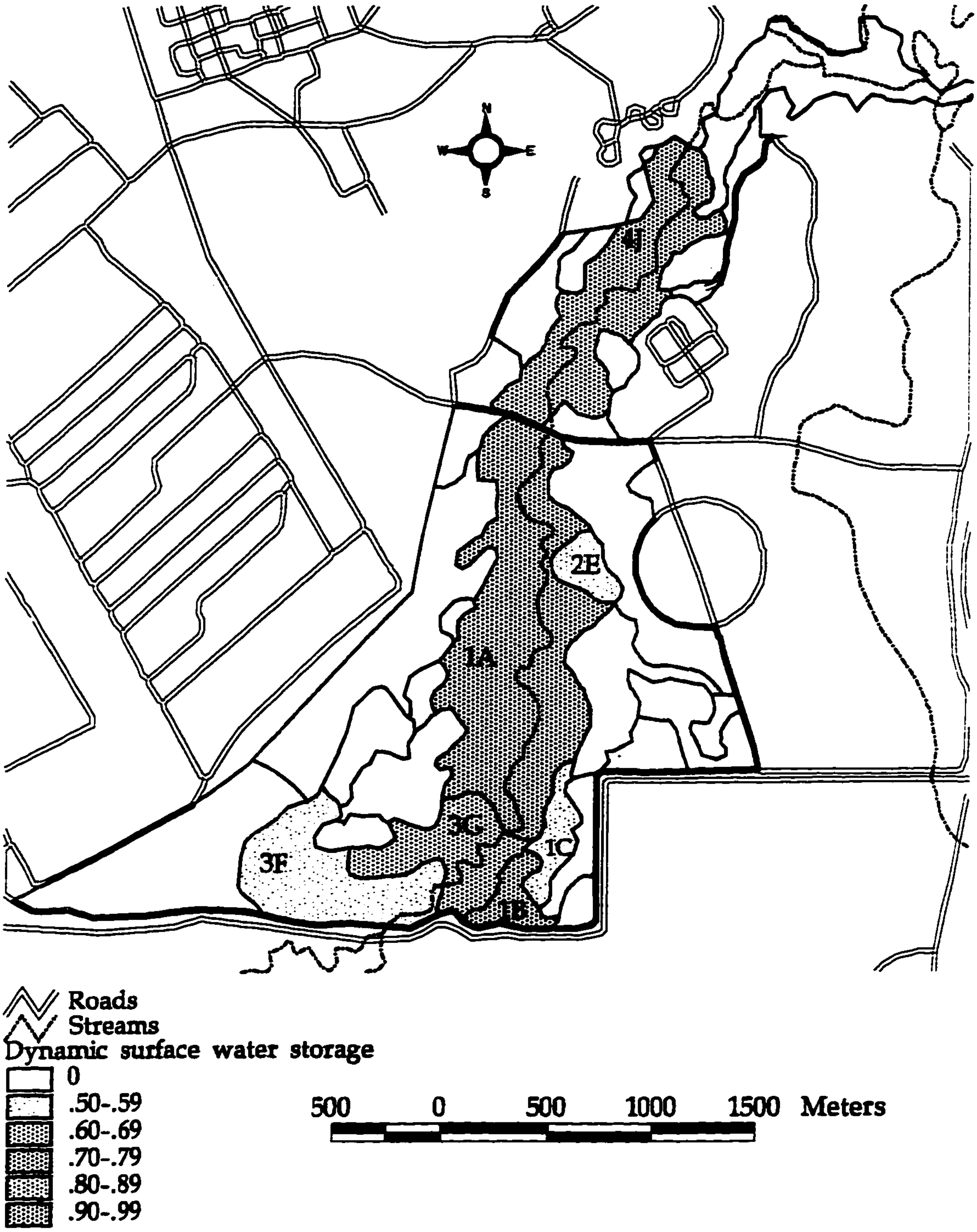


Figure 19. Function indices of dynamic surface water storage for Harrison Bayou by community, using Big Cypress Bayou as a reference wetland.

DISCUSSION

The Hydrogeomorphic Assessment Technique

Reference standards for use in the HGM assessment method are still being developed in each region by the Corps of Engineers. The development of reference standards for each region of the U.S. will allow users of the HGM method to compare their data from wetlands in that region to established regional standards which will result in more consistent results throughout that physiographic region. As of this date, reference standards have been established by the Louisville District in Kentucky for riverine, low gradient, forested wetlands for the reference domain of the eastern Interior Coal Province.

The most difficult variable to determine for all of the functions presented in this study is frequency of overbank flooding (V_{of}). Although analyzed by two different methods, both methods can be considered to introduce error in estimating V_{of}. The first, assigning a flooding frequency score for each wetland, is obviously flawed because the frequency of flooding for each plant community in a particular wetland is dependent on its location in relation to the flooding source. Therefore, each wetland plant community has its own flooding frequency depending on its position in the landscape;

however, the resulting variable score does not reflect this fact.

The second method of evaluating V_{of}, however, takes into account the individuality of each plant community by assigning each its own score relative to conditions in its corresponding reference standard plant community. This method is only a measure of the presence or absence of indicators, however, and does not take into account the nature of each indicator. For example, an indicator in a target plant community may also exist in its corresponding reference plant community but the two may not be similar. Watermarks can be at different heights, drift lines can be more or less frequent, or sediment deposition can occur at a greater or less rate. Furthermore, indicators such as watermarks and drift lines do not reveal when or for how long overbank flooding occurred, just that it happened at some time in the past. Although comparing individual communities in the target and reference wetlands results in more precise assessments of V_{of}, this method is far from accurate. It does not reveal how similar the flooding regimes in the target and reference wetland are in terms of frequency and depth.

The HGM assessment method for riverine wetlands can be a complicated and intricate procedure when it takes into account the diversity and uniqueness of riverine wetland ecosystems. Due to the extreme diversity found in riverine wetland systems, a rapid, comprehensive assessment method may never be developed. Reference standards for riverine systems may be difficult to develop and will probably never encompass the full range of hydrogeomorphic conditions found. Perhaps a constant mitigation ratio should simply be used to determine riverine wetland mitigation acreage. This method would be simpler to apply and less time consuming than the HGM assessment method. Those wetlands which contain unique hydrologic or habitat characteristics could receive a higher mitigation ratio than those that are not. The HGM method would not be needed to determine if a wetland is unique or not, since uniqueness is a value judgment and the HGM method determines wetland function, not value. However, although a mitigation ratio of 2:1 would ensure that total wetland area would never decrease, it would not prevent the loss of wetland function.

Reference Wetland Selection

The reference wetlands selected are meant to be chosen based on their undisturbed nature. The fact that the selected reference standards are undisturbed by man assumes that the conditions within the reference wetlands reflect the potential functional capacity of all wetlands of that type in a specific physiographic region, even those wetlands that have been disturbed.

In the beginning stages of this study, only one reference standard wetland was selected: Harrison Bayou. As data were collected from all four wetland study sites, it was discovered that Harrison Bayou by itself provided an inappropriate set of reference standards due to a low frequency of overbank flooding. Under these conditions, V_{α} scores will be low, decreasing the index of function for dynamic surface water storage, removal of elements and compounds, retention of particulates, and organic carbon export. It is the target wetlands' considerable deviance from the reference wetland that result in a lower index of function, even though the target wetland can be considered to function at a higher rate due to more frequent occurrences of overbank flooding.

Further example of Harrison Bayou's inappropriateness as a reference wetland is shown when compared against those wetlands that do receive a high frequency of overbank flooding. A higher frequency of overbank flooding denotes a greater opportunity of that wetland to perform the function of dynamic surface water storage. When Harrison Bayou is compared against Black Cypress Bayou, it has relatively low indices of function (Table 11). These indices show that Harrison Bayou performs the function of dynamic surface water storage only about half as well as Big Cypress Bayou and Black Cypress Bayou, when Harrison Bayou, as a reference wetland, should have much higher indices.

The selection of a reference wetland or wetlands for use in reference standards should be similar to the conditions found in the target wetlands. Conditions that should be taken into account are water velocity, volume, watershed size, stream order, dominant vegetative communities and the presence of upstream dams. The development of a set of reference standards is intended to encompass national variation so that man-made disturbances can be recognized (Brinson et. al. 1997).

The establishment of a set of reference standards for a region as opposed to using one reference wetland for an assessment can alleviate the problem of dissimilar wetland conditions. Reference standards are the conditions exhibited by a group of reference wetlands that correspond to the highest level of functional capacity for all functions. The range of variability found in target wetlands can be compensated for, since the reference standards are developed from conditions in more than one wetland,. For example, those conditions in Harrison Bayou that contributed to a high index of function would probably be included in a set of reference standards, but not those conditions that contributed to a low index of function.

Although Harrison Bayou has been determined to be an inappropriate reference wetland for evaluating hydrologic and biogeochemical functions, it could be considered an appropriate reference wetland for the assessment of those functions that do not rely on hydrologic characteristics. The HGM method can also be used to assess plant habitat and animal habitat functions for which Harrison Bayou would probably be highly suitable as a reference wetland. For example, Harrison Bayou exhibits high plant species diversity, abundance of very mature trees, abundance of beaver, and abundance of herptofauna.

Indices of function can be interpreted as percentages of similarity of conditions in a target wetland to conditions in a reference standard wetland. Since the data in all the wetland study sites were collected in the same manner, the indices of function are relative, and an index of function from one study site can be compared to another. One possible use of function indices is in determining functional capacity units (FCU) by using an index of function as a multiplicative factor. For example, a function index for a wetland can be multiplied by the number of acres in that wetland to yield the number of FCUs for that wetland. If this wetland is to be mitigated for whatever reason, the mitigation site should have or be able to attain the same number of FCUs to compensate for the loss of function from the original wetland.

As demonstrated in this study, reference wetland choice can greatly influence the resulting indices of function. Using Big Cypress Bayou as an example, it has been shown that the index of function for dynamic surface water storage differs greatly when Harrison Bayou and Black Cypress Bayou are used as reference wetlands (Tables 3 and 4). If Harrison Bayou were used as the reference wetland for Big Cypress Bayou, the FCUs for community 1C would be greatly overestimated (Figure 10). However, if Black Cypress Bayou were used as a reference wetland, the FCU estimation for the function of dynamic surface water storage for community 1C would be much more accurate and vastly different from the estimation obtained using Harrison

Bayou as a reference wetland (Figure 11). Using Black Cypress Bayou as a reference wetland will result in a more accurate assessment of dynamic surface water storage since Black Cypress Bayou has a more similar flooding regime than Harrison Bayou. This example shows that an inappropriately chosen reference wetland can have severe implications in determining mitigation acreage and function capacity.

CONCLUSION

More research is needed on reference wetland selection and frequency of overbank flooding evaluation before the HGM technique can become an accepted method for evaluating wetland functions. Reference wetland selection must correspond to the watershed characteristics of the target wetlands for a valid comparison to be made. For the HGM technique to be effectively used by non-USCOE employees in the private sector, reference standards for each wetland subclass should be established by the USCOE.

This procedure is already underway, but will be a considerable undertaking, considering the variability of bottomland hardwood ecosystems in East Texas. Many streams are influenced by upstream dams to varying degrees, and the individualistic nature of riverine wetland ecosystems makes them difficult to standardize.

Although Harrison Bayou does not experience as frequent or intense flood events as other East Texas riparian wetlands, it remains a significant and unique ecosystem. Harrison Bayou continues to be valuable to society in terms of education, aesthetic properties, and research opportunities.

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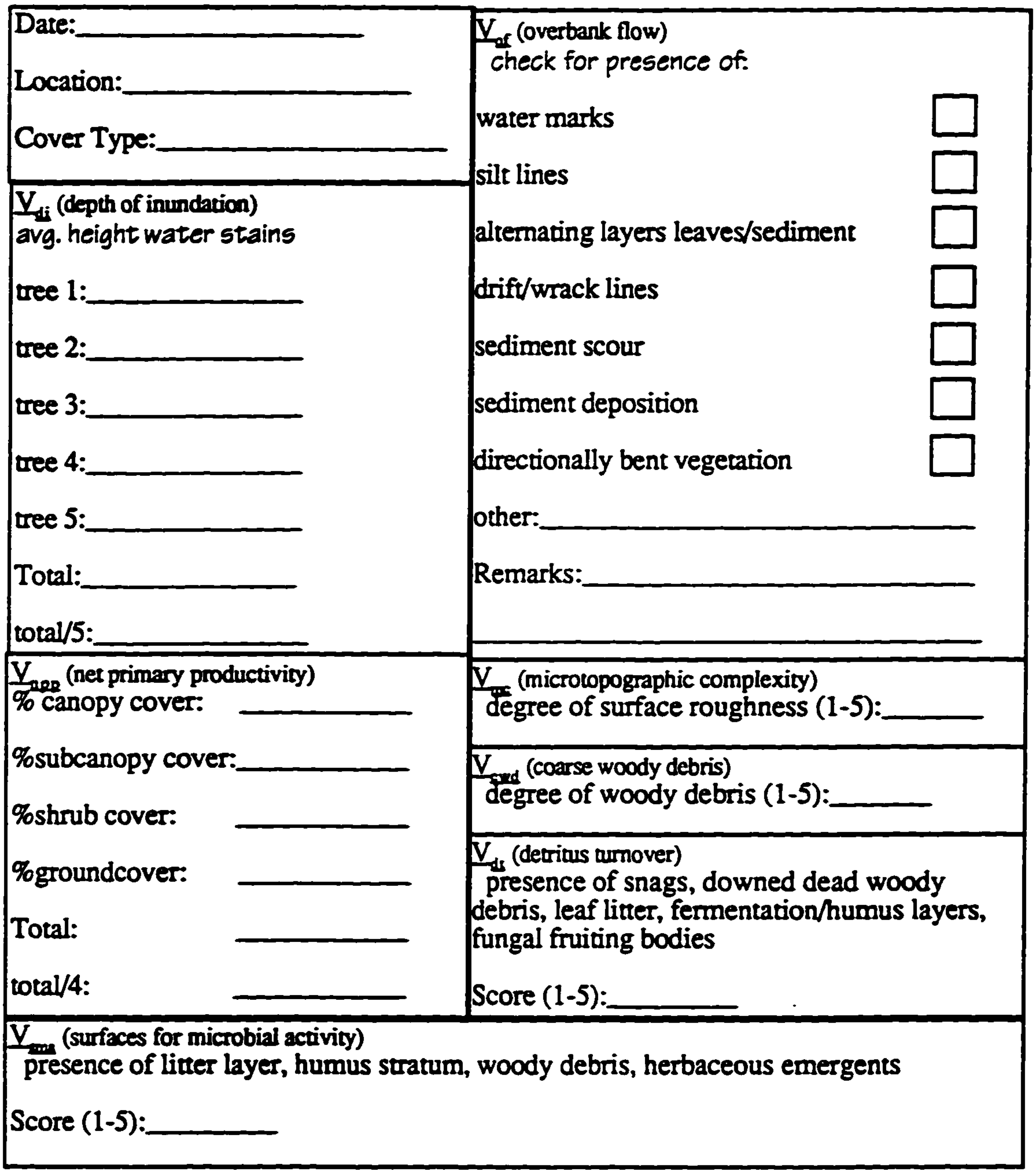
APPENDIX



Date: ______

Location: ______

Cover Type: ______

V_{di} (depth of inundation)
avg. height water stains

tree 1: ______

tree 2: ______

tree 3: ______

tree 4: ______

tree 5: ______

Total: ______

total/5: ______

V_{npp} (net primary productivity)
% canopy cover: ______

%subcanopy cover: ______

%shrub cover: ______

%groundcover: ______

Total: ______

total/4: ______

V_{of} (overbank flow)
check for presence of:

water marks ☐

silt lines ☐

alternating layers leaves/sediment ☐

drift/wrack lines ☐

sediment scour ☐

sediment deposition ☐

directionally bent vegetation ☐

other: ______

Remarks: ______

______

V_{mc} (microtopographic complexity)
degree of surface roughness (1-5): ______

V_{cwd} (coarse woody debris)
degree of woody debris (1-5): ______

V_{dt} (detritus turnover)
presence of snags, downed dead woody debris, leaf litter, fermentation/humus layers, fungal fruiting bodies

Score (1-5): ______

V_{sma} (surfaces for microbial activity)
presence of litter layer, humus stratum, woody debris, herbaceous emergents

Score (1-5): ______

Figure 1. Example data sheet for function assessment.

$\underline{V_{om}}$ (organic matter in wetland)
amount litter, coarse woody debris, live woody vegetation, dead/live herbaceous vegetation and/or organic rich soils

Score (1-5):________

$\underline{V_{sed}}$ (retained sediments)
sediment layering (y/n): _______

buried root collars (y/n):_______

buried levees (y/n): _______

average depth of silt: _______

Remarks:____________________

____

$\underline{V_{hvr}}$
herbaceous vegetation roughness (1-5):______

Comments:

Figure 1. (continued)

Function Scoring for Soils and V_{wvr}

Date:________________________

Location:________________________

Cover Type:____________________

V_{wvr} (woody vegetation roughness)

stems/acre ____________

basal area ____________

Plot 1

V_{sps} (sorptive properties of soil) Soil Series Name:

Horizon	Color	Depth	Texture
A			
E			
B			

Remarks:

Plot 2

V_{wvr} (woody vegetation roughness)

stems/acre ____________ basal area ____________

V_{sps} (sorptive properties of soil) Soil Series Name:

Horizon	Color	Depth	Texture
A			
E			
B			

Remarks:

Plot 3

V_{wvr} (woody vegetation roughness)

stems/acre ____________ basal area ____________

V_{sps} (sorptive properties of soil) Soil Series Name:

Horizon	Color	Depth	Texture
A			
E			
B			

Remarks:

Figure 2. Example data sheet for V_{wvr} and V_{sps} assessment.

Table 1. Function variable abbreviations and definitions.

Variable abbreviation	Abbreviation meaning
V_{cwd}	coarse woody debris
V_{di}	average depth of inundation
V_{dt}	annual turnover of detritus
V_{hvr}	herbaceous vegetation roughness
V_{mc}	microtopographic complexity
V_{npp}	aerial net primary productivity
V_{of}	frequency of overbank flow
V_{om}	organic matter
V_{rs}	riparian source
V_{rsed}	retained sediments
V_{shc}	suface hydraulic connection
V_{sma}	surfaces for microbial activity
V_{sps}	sorptive properties of soils
V_{wvr}	woody vegetation roughness

Table 2. Metadata for GIS files used in the creation of maps and figures for the Harrison Bayou study site.

Name:	hb_comm3.cov
Description:	Boundaries of the plant communities identified in the Masters Thesis: "The Planning Level Plant Community and Wetland Identification of Harrison Bayou Within the Bounds of Longhorn Army Ammunition Plant, Karnack, Texas."
File type:	ArcInfo coverage (polygon)
Path:	/tries/b/tries5/arc/hb_comm3.cov
Source:	Polygons created using "Imagine" heads-up-digitizing over registered and rectified Landsat imagery (Landsat file name: overview.img)
Projection:	UTM Zone 15
Units:	meters
Attribute Table Items:	Community-id: community classification as assigned by B. Tracy Wet_soil?: indicates presence or absence of hydric soil conditions (as defined by the 1987 USCOE Wetland Delineation Manual) Wet_hyd?: indicates presence or absence of wetland hydrology (as defined by the 1987 USCOE Wetland Delineation Manual) Wet_veg?: indicates presence or absence of hydric vegetation (as defined by the 1987 USCOE Wetland Delineation Manual) Functions assessed by community for Harrison Bayou: nutrient cycling dynamic surface water storage removal of elements and compounds retention of particulates organic carbon export Big_ : Big Cypress Bayou used as a reference wetland Blk_ : Black Cypress Bayou used as a reference wetland

Name:	hydrology.cov
Description:	Major bodies of water and rivers and streams surrounding and including Caddo lake.
File type:	ArcInfo coverage (line)
Path:	/tries/b/tries5/hydrology.cov
Source:	exact origin unknown. Gifted to SFASU GIS Lab by Caddo Lake Institute.
Projection:	UTM Zone 15
Units:	meters
Attribute Table	none

Name:	roads.cov
Description:	Roads surrounding and Caddo lake.
File type:	ArcInfo coverage (polygon)
Path:	/tries/b/tries5/roads.cov
Source:	exact origin unknown. Gifted to SFASU GIS Lab by Caddo Lake Institute.
Projection:	UTM Zone 15
Units:	meters
Attribute Table	none

Table 3. Metadata for GIS files used in the creation of maps and figures for the Big Cypress Bayou study site.

Name:	bigcyp1_comm.cov
Description:	Boundaries of plant communities in Big Cypress Bayou study site as described in the Master's thesis "The Hydrologic and Biogeochemical Functions of Five East Texas Bottomland Hardwood Wetlands Using the USCOE Hydrogeomorphic Assessment Technique"
File type:	ArcInfo coverage (polygon)
Path:	/app1/jennifer/coverages/bigcyp1_comm.cov
Source:	created in ArcInfo using heads-up digitizing over registered and rectified color IR aerial photograph (app1/jennifer/images/bigcyp1r.img)
Projection:	UTM Zone 15
Units:	meters
Attribute Table Items:	Functions assessed by community for Big Cypress Bayou: nutrient cycling dynamic surface water storage removal of elements and compounds retention of particulates organic carbon export Hb_ : Harrison Bayou used as a reference wetland Blk_ : Black Cypress Bayou used as a reference wetland
Name:	hydrology.cov
Description:	Major bodies of water and rivers and streams surrounding and including Caddo lake.
File type:	ArcInfo coverage (line)
Path:	/tries/b/tries5/hydrology.cov
Source:	exact origin unknown. Gifted to SFASU GIS Lab by Caddo Lake Institute.
Projection:	UTM Zone 15
Units:	meters
Attribute Table	none
Name:	roads.cov
Description:	Roads surrounding and Caddo lake.
File type:	ArcInfo coverage (polygon)
Path:	/tries/b/tries5/roads.cov
Source:	exact origin unknown. Gifted to SFASU GIS Lab by Caddo Lake Institute.
Projection:	UTM Zone 15
Units:	meters
Attribute Table	none

Table 3. (continued)

Name:	bigcyp1r.img
Description:	Registered and rectified color infrared aerial photograph of Big Cypress Bayou study site as described in the Masters thesis "The Hydrologic and Biogeochemical Functions of Five East Texas Bottomland Hardwood Wetlands using the U.S. Corps of Engineers Hydrogeomorphic Assessment Technique"
File type:	Imagine .img file
Path:	/mango_app1/jennifer/images/bigcyp1r.img
Source:	scanned
Projection:	UTM Zone 15
Units:	meters
Attribute Table	none

Table 4. Metadata for GIS files used in the creation of maps and figures for the Black Cypress Bayou study site.

Name:	blkcyp_comm.cov
Description:	Boundaries of plant communities in Black Cypress Bayou study site as described in the Master's thesis "The Hydrologic and Biogeochemical Functions of Five East Texas Bottomland Hardwood Wetlands Using the USCOE Hydrogeomorphic Assessment Technique"
File type:	ArcInfo coverage (polygon)
Path:	/app1/jennifer/coverages/blkcyp_comm.cov
Source:	created in ArcInfo using heads-up digitizing over registered and rectified color IR aerial photograph (app1/jennifer/images/blkcyp_photor&r.img)
Projection:	UTM Zone 15
Units:	meters
Attribute Table Items:	Functions assessed by community for Black Cypress Bayou: nutrient cycling dynamic surface water storage removal of elements and compounds retention of particulates organic carbon export Hb_ : Harrison Bayou used as a reference wetland Big_ : Big Cypress Bayou used as a reference wetland

Name:	hydrology.cov
Description:	Major bodies of water and rivers and streams surrounding and including Caddo lake.
File type:	ArcInfo coverage (line)
Path:	/tries/b/tries5/hydrology.cov
Source:	exact origin unknown. Gifted to SFASU GIS Lab by Caddo Lake Institute.
Projection:	UTM Zone 15
Units:	meters
Attribute Table	none

Table 4. (continued)

Name:	roads.cov
Description:	Roads surrounding and Caddo lake.
File type:	ArcInfo coverage (polygon)
Path:	/tries/b/tries5/roads.cov
Source:	exact origin unknown. Gifted to SFASU GIS Lab by Caddo Lake Institute.
Projection:	UTM Zone 15
Units:	meters
Attribute Table	none
Name:	bigcyp1r.img
Description:	Registered and rectified color infrared aerial photograph of Black Cypress Bayou study site as described in the Masters thesis "The Hydrologic and Biogeochemical Functions of Five East Texas Bottomland Hardwood Wetlands using the U.S. Corps of Engineers Hydrogeomorphic Assessment Technique"
File type:	Imagine .img file
Path:	/mango_app1/jennifer/images/blkcyp_photor&r.img
Source:	scanned
Projection:	UTM Zone 15
Units:	meters
Attribute Table	none

Table 5. Metadata for GIS files used in the creation of maps and figures for the Cherokee Ridge study site.

Name:	crcomm01
Description:	Boundaries of plant communities in Cherokee Ridge study site as described in the Master's thesis "The Hydrologic and Biogeochemical Functions of Five East Texas Bottomland Hardwood Wetlands Using the USCOE Hydrogeomorphic Assessment Technique"
File type:	ArcInfo coverage (polygon)
Path:	/tries/b/tries2/coverages/crcomm01
Source:	created in ArcInfo using heads-up digitizing over registered and rectified color IR aerial photograph (tries/b/tries2/images/crphoto_rr.img)
Projection:	UTM Zone 15
Units:	meters
Attribute Table Items:	Functions assessed by community for Cherokee Ridge: nutrient cycling dynamic surface water storage removal of elements and compounds retention of particulates organic carbon export Hb_ : Harrison Bayou used as a reference wetland Blk_ : Black Cypress Bayou used as a reference wetland

Table 5. (continued)

Name:	crroads05
Description:	Roads and pipelines covering the Cherokee Ridge study site as described in the Masters thesis "The Hydrologic and Biogeochemical Functions of Five East Texas Bottomland Hardwood Wetlands using the U.S. Corps of Engineers Hydrogeomorphic Assessment Technique"
File type:	ArcInfo coverage (line)
Path:	/tries/b/tries2/coverages/crroads05
Source:	digitized from a topographic map of area
Projection:	UTM Zone 15
Units:	meters
Attribute Table	none

Name:	crstream03
Description:	Rivers and streams covering the Cherokee Ridge study site as described in the Masters thesis "The Hydrologic and Biogeochemical Functions of Five East Texas Bottomland Hardwood Wetlands using the U.S. Corps of Engineers Hydrogeomorphic Assessment Technique"
File type:	ArcInfo coverage (polygon)
Path:	/tries/b/tries2/coverages/crstream03
Source:	digitized from a topographic map of area
Projection:	UTM Zone 15
Units:	meters
Attribute Table	none

Name:	crphoto_rr.img
Description:	Registered and rectified color infrared aerial photograph of Cherokee Ridge study site as described in the Masters thesis "The Hydrologic and Biogeochemical Functions of Five East Texas Bottomland Hardwood Wetlands using the U.S. Corps of Engineers Hydrogeomorphic Assessment Technique"
File type:	Imagine .img file
Path:	/tries/b/tries2/images/crphoto_rr.img
Source:	scanned
Projection:	UTM Zone 15
Units:	meters
Attribute Table	none

Name:	crtopo01
Description:	Topographic lines of the Cherokee Ridge study site as described in the Masters thesis "The Hydrologic and Biogeochemical Functions of Five East Texas Bottomland Hardwood Wetlands using the U.S. Corps of Engineers Hydrogeomorphic Assessment Technique"
File type:	ArcInfo coverage (polygon)
Path:	/tries/b/tries2/coverages/crtopo01
Source:	digitized from a topographic map of area
Projection:	UTM Zone 15
Units:	meters
Attribute Table	none

Table 6. Metadata for GIS files used in the creation of maps and figures for the Alazan Bayou study site.

Name:	alcomm.cov
Description:	Boundaries of plant communities in Alazan Bayou study site as described in the Master's thesis "The Hydrologic and Biogeochemical Functions of Five East Texas Bottomland Hardwood Wetlands Using the USCOE Hydrogeomorphic Assessment Technique"
File type:	ArcInfo coverage (polygon)
Path:	/appl/jennifer/coverages/alcomm.cov
Source:	created in ArcInfo using heads-up digitizing over registered and rectified color IR aerial photograph (appl/jennifer/images/albayou_r.img)
Projection:	UTM Zone 15
Units:	meters
Attribute Table Items:	Functions assessed by community for Cherokee Ridge: nutrient cycling dynamic surface water storage removal of elements and compounds retention of particulates organic carbon export Hb_ : Harrison Bayou used as a reference wetland Big_ : Big Cypress Bayou used as a reference wetland
Name:	alrds_01
Description:	Roads and pipelines of the Alazan Bayou study site as described in the Masters thesis "The Hydrologic and Biogeochemical Functions of Five East Texas Bottomland Hardwood Wetlands using the U.S. Corps of Engineers Hydrogeomorphic Assessment Technique"
File type:	ArcInfo coverage (line)
Path:	/tries/b/tries2/coverages/alrds_01
Source:	digitized from a topographic map of area
Projection:	UTM Zone 15
Units:	meters
Attribute Table	none
Name:	alstr_01
Description:	Streams of the Alazan Bayou study site as described in the Masters thesis "The Hydrologic and Biogeochemical Functions of Five East Texas Bottomland Hardwood Wetlands using the U.S. Corps of Engineers Hydrogeomorphic Assessment Technique"
File type:	ArcInfo coverage (polygon)
Path:	/tries/b/tries2/coverages/alstr_01
Source:	digitized from a topographic map of area
Projection:	UTM Zone 15
Units:	meters
Attribute Table	none

Table 6. (continued)

Name:	crphoto_rr.img
Description:	Registered and rectified color infrared aerial photograph of Alazan Bayou study site as described in the Masters thesis "The Hydrologic and Biogeochemical Functions of Five East Texas Bottomland Hardwood Wetlands using the U.S. Corps of Engineers Hydrogeomorphic Assessment Technique"
File type:	Imagine .img file
Path:	/mango_appl/jennifer/images/albayou_r.img
Source:	scanned
Projection:	UTM Zone 15
Units:	meters
Attribute Table	none

VITA

Jennifer Susan Key was born on June 1, 1973, at Vandenberg Air Force Base, California. She is the only daughter of James E. Key, Jr. and Janet Sue Wise Key. Jennifer graduated from Lawrence D. Bell High School in Hurst, Texas, in May 1991. In August 1991, she enrolled at Stephen F. Austin State University and received the degree of Bachelor of Science in Forestry with an emphasis in Forest Hydrology in May 1995. Jennifer then immediately entered the graduate school at Stephen F. Austin State University to begin work on the degree of Master of Science of Forestry.

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This thesis has been written according to the style presented in *Forest Science.*