RIPARIAN AREA

The Sabine River Riparian Area: A Definition and GIS Based Methodology for Delineation.

FINAL

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METHODOLOGY FOR DEFINING AND ASSESSING RIPARIAN AREAS
TABLE OF CONTENTS

EXECUTIVE SUMMARY 9
INTRODUCTION 12
Riparian Areas 12
Policy in Managed Flooding Disturbances 13
The Difficulty in Defining 14
RIPARIAN AREA DEFINITIONS 17
Choosing a Definition 17
Applicable Definition 19
RIPARIAN AREAS OF THE SOUTHEAST AND SOUTHWEST U.S. 19
FUNCTIONS AND VALUES OF RIPARIAN AREAS 23
Delineation by Function 23
Important Riparian Area Functions 24
RIPARIAN SOILS OF THE EAST TEXAS RIVER BASINS 26
THE VEGETATION OF RIPARIAN AREAS WITH SPECIAL ATTENTION TO TEXAS 30
Sabine River Basin Vegetation 32
Neches River Basin Vegetation 33
Trinity River Basin Vegetation 34
Sulphur River Basin Vegetation 34
Nueces River Basin Vegetation 35
Leona River Riparian Vegetation 36
Sabinal River Riparian Vegetation 36
Guadalupe River Riparian Vegetation 37

San Antonio River Riparian Vegetation 38
Middle Rio Grande River Riparian Area 38
THE HYDROLOGY OF RIPARIAN AREAS 39
Hydrologic Regime 39
Seed Dispersal in Riparian Areas 41
REVIEW OF RIPARIAN AREA SURVEY METHODS 62
Classification Techniques 62
Classification Schemes 63
Ecological Based Guidebooks 67
The Energy Theory 70
Functional Assessments 72
RIPARIAN BOUNDARY DELINEATION 79
STUDY SITE 82
Sabine River: Toledo Bend Reservoir 82
Technique 1 84
Methods 84
Data Acquisition 84
GIS Riparian Soils 84
Classification 90
Remote Sensing Model Development 97
Soils 98
Hydrology 98
Vegetation 98
Determining Number of Control Points 99
Ground Truthing 101

Statistical Analysis ... 101
Results of Technique 1 ... 102
Discussion ... 109
Technique 2 ... 111
Background ... 111
FLOW REQUIREMENTS ... 111
Ecology and Geomorphology ... 111
Forest Hydrology ... 112
Riparian Vegetation Ecophysiological Response ... 112
Methods ... 114
Flood Recurrence Interval ... 114
Results of Technique 2 ... 125
Discussion ... 132
Technique 3 ... 133
Methods ... 133
Results ... 134
Discussion ... 141
Analysis of Combining First and Third Techniques ... 142
Method ... 142
Discussion ... 144
Conclusion ... 145
Riparian Ecological Effects Downstream of Dams ... 147
Flood Pulsing ... 148
Pre and Post Toledo Bend Dam Flow Regime ... 149
PROBABILITY OF INUNDATION CURVE ... 159

LITERATURE CITED 160
APPENDIX.. 172
A1 Seedling Characteristics. Ciatations for Tables 3-22……………...………….………161
A2. Riparian Area Definitions Reviewed……………………………………………..179
B1. Discharge of Flood Event Corresponding to Image Acquistion Date……………...186
B2. Coordinates of control points assessed and not assessed…………………………..198
B3. Site characteristics of east Texas bottomland hardwood species…………………..201

LIST OF TABLES

Table 1. Soil associations of riparian areas within East Texas. 28
Table 2. Soil associations of riparian areas within East Texas continued. 29
Table 3. Seedling characteristics of dominant native trees in East Texas riparian areas. 43
Table 4. Seedling characteristics of dominant native trees in East Texas riparian areas continued. 44
Table 5. Seedling characteristics of dominant native trees in East Texas riparian areas. 45
Table 6. Seedling characteristics of dominant native trees in East Texas riparian areas continued. 46
Table 7. Seedling characteristics of dominant native trees in East Texas riparian areas. 47
Table 8. Seedling characteristics of dominant native trees in East Texas riparian areas continued. 48
Table 9. Seedling characteristics of dominant trees in East Texas riparian areas. 49
Table 10. Seedling characteristics of dominant native trees in East Texas riparian areas continued. 50
Table 11. Seeding characteristics of dominant native shrubs in East Texas riparian areas. 51
Table 12. Seedling characteristics of dominant native shrubs in East Texas riparian areas continued. 52
Table 13. Seeding characteristics of dominant native shrubs in East Texas riparian areas. 53
Table 14. Seeding characteristics of dominant native shrubs in East Texas riparian areas continued. 54
Table 15. Seeding characteristics of dominant native shrubs and herbaceous plants in East Texas riparian areas. 55
Table 16. Seeding characteristics of dominant shrubs and herbaceous plants in East Texas riparian areas continued. 56
Table 17. Seeding characteristics of dominant native herbaceous plants in East Texas riparian areas. 57
Table 18. Seeding characteristics of dominant native herbaceous plants in East Texas riparian areas continued. 58
Table 19. Seeding characteristics of dominant native herbaceous plants in East Texas riparian areas. 59

Table 20. Seeding characteristics of dominant native herbaceous plants in East Texas riparian areas continued. 60
Table 21. Seedings characteristics of dominant native herbaceous plants in East Texas riparian areas. 61
Table 22. Seedings characteristics of dominant native herbaceous plants in East Texas riparian areas continued. 61
Table 23. A Classification of Ecosystem Forms. *Source: adapted from Kangas (1990).* 71
Table 24. Map symbols and classification for soils in Newton and Jasper Counties. *Source:* 87
Table 25. Soil series meeting the criteria for floodplain soils in the study area. *Source: Neitsch 1982* 88
Table 26. Soil series meeting the criteria for floodplain soils in the study area continued. *Source: Neitsch 1982* 89
Table 27. Soil series not meeting the criteria for floodplain soils. *Source: Neitsch 1982* 89
Table 28. Strength of agreement by Kappa Statistic. *Source: Chuang 2001* 102
Table 29. Field assessment and model predictions results. 107
Table 30. Field assessment and model predictions results continued. 108
Table 31. Kappa statistic summary results. 108
Table 32. The terminology used by NOAA advanced hydrologic prediction service in describing stage events. 115
Table 33. Various Flood Stages for Burkeville, Bon Weir, and Ruliff Gages. 115
Table 34. Burkeville, TX. Flood return period or recurrence interval. 117
Table 35. Burkeville, TX. Flood return period or recurrence interval continued. 118
Table 36. Bon Weir, TX. Flood return period or recurrence interval. 119
Table 37. Bon Weir, TX. Flood return period or recurrence interval continued. 120
Table 38. Bon Weir, TX. Flood return period or recurrence interval continued. 121
Table 39. Ruliff, TX. Flood return period or recurrence interval. 122
Table 40. Ruliff, TX. Flood return period or recurrence interval continued. 123
Table 41. Ruliff, TX. Flood return period or recurrence interval continued. 124
Table 42. Comparison of Winter (January - March) Pre-Dam (1941 - 1960) and Post-Dam (1971 - 2005) flows of the Sabine River at Sabine Lake. 154

Table 43. Comparison of Spring (April - June) Pre-Dam (1941 - 1960) and Post-Dam (1971 - 2005) flows of the Sabine River at Sabine Lake.. 155
Table 44. Comparison of Summer (July – September) Pre-Dam (1941 – 1960) and Post-Dam (1971 – 2005) flows of the Sabine River at Sabine Lake. 156
Table 45. Comparison of Fall (October-December) Pre-Dam (1941- 1960) and Post-Dam (1971 - 2005) flows of the Sabine River at Sabine Lake. 157

LIST OF FIGURES

Figure 1. The natural ecoregions of Texas.. 15
Figure 2. An illustration displaying the distinct difference between the water table of floodplains in moist and dry climates. 21
Figure 3. The typical hydrologic regime through the different seasons for floodplains of the Southeastern U.S.. 42
Figure 4. Diagram illustrating the composition of the riparian area in comparison to the jurisdictional wetland based on site potential vegetation height. 80
Figure 5. Study site location along the Sabine River south of the Toledo Bend Reservoir Dam.83
Figure 6. Soil series map of the study area 85
Figure 7. The hydric and floodplain soils delineated apart from upland soils............................ 90
Figure 8. 2005 NAIP 2 meter natural color photo mosaic of the northern section of the Sabine 93
Figure 9. 2005 NAIP 2 meter natural color photo mosaic of the southern section of the Sabine 94
Figure 10. Classification of the northern portion of the Sabine River study area. 95
Figure 11. Classification of the southern portion of the Sabine River study area. 96
Figure 12. Sabine River riparian model sample points... 100
Figure 13. Sabine River riparian original model output. 103
Figure 14. Sabine River riparian first alternative model output. 104
Figure 15. Sabine River riparian second alternative model output.. 105
Figure 16. Original, first alternative, and second alternative models on 10 meter DEM. 106
Figure 17. Floodstage, moderate stage, and major stage for Burkeville Gage. 126
Figure 18. Floodstage, moderate stage, and major stage to river for Burkeville Gage. 127
Figure 19. Floodstage, moderate stage, and major stage for Bon Weir Gage. 128
Figure 20. Floodstage, moderate stage, and major stage to river for Bon Weir Gage.............. 129
Figure 21. 2, 5, and 10 Year Flood Event for Burkeville Gage. 130
Figure 22. 2, 5, and 10 Year Flood Event for Bon Weir Gage. 131
Figure 23. Landsat Satellite image taken on 2/19/74, 16 days following a 10 year flood event. 135
Figure 24. Landsat Satellite image taken on 12/07/79, a 2 year flood event (Bon Weir Gage).136

Figure 25. Landsat Satellite image taken on 12/07/79, a 2 year flood event (Burkeville and ... 137
Figure 26. Landsat Satellite image taken on 03/01/79, a 2 year flood event. ... 138
Figure 27. Digitized stand from 3/01/79 Landsat satellite image. ... 139
Figure 28. Digitized stand and digitized wet area from 3/01/79 Landsat Satellite image. ... 140
Figure 29. 3/1/79 digitized wet area overlaid on the original model output. ... 143
Figure 30. The annual peak flows for the period of record at the gage station near Burkeville, TX. ... 150
Figure 31. The annual peak flows for the period of record at the gage station near Bon Weir, TX. ... 151
Figure 32. The annual peak flows for the period of record at the gage station near Ruliff, TX. 152
Figure 33. The probability of inundation curve as it relates to the riparian area ... 159

EXECUTIVE SUMMARY

A literature review was conducted to determine an applicable definition for the riparian area, and a methodology for delineation based on the most appropriate definition for the Sabine River riparian area. The study outlined riparian areas in general with a focus on the study area located in the Western Gulf Coastal Plain Region along the Sabine River below the Toledo Bend Reservoir. Upon reviewing existing methodology and scientific literature, it was determined that a conceptual definition does exist for defining riparian areas in Texas despite the wide ecosystem variability across the state. A limitation with the selected definition is that it is conceptual, so modification may be necessary based on different scientific disciplines or special circumstances. Ideally a set of definition becoming established would allow researchers and resource managers better manage and understand riparian area issues.

This literature review identifies components obtained from different wetland delineation and functional assessment methodologies which were employed together as a tool in delineating the defined riparian area both in the field and through GIS analysis. By combining definition, concepts, and methodologies, a technique was established for delineation in the field and through GIS modeling which utilized together gain rigor in accuracy which greatly adds to future management goals. The literature review and delineation consists mainly of descriptions and concepts applicable to the Southeastern U.S. with sections discussing west Texas when applicable to highlight differences between east and west Texas riparian areas.

Three GIS based techniques were investigated for delineating the riparian area. The first approach used the parameters of hydric soils, hydrology, vegetation, and site potential vegetation height. The total riparian area is the summation of all areas delineated by the parameters plus site potential vegetation height. The objective of the delineation was to encompass the aquatic

features (stream channel and bank), the floodplain (areas of movement of animals and dispersal of plants and sediment, etc.), and a section of the adjacent upland areas (interact subsurface water flow, bank stabilization, and allochthonous inputs, etc.). The second approach obtained satellite images acquired near the date of a flooding event and related this image with USGS gage station data. The advantage of this method is it details exactly where the water is during a flooding event. Because flooding is a dangerous event a third approach was used in conjunction with the first two techniques to establish necessary action to prevent harm to people and property. This was completed by combining LIDAR with the NOAA advanced hydrologic prediction service gage station stage events. Remote Sensing and GIS modeling showed great potential in the delineation of riparian areas of the Sabine River below Toledo Bend Reservoir. As software capabilities continue to increase and more knowledge of riparian function is gained so should the potential to develop even more accurate Remote Sensing and GIS models depicting riparian areas. The ability to model such areas is important as it is an economically feasible and practical means of identifying the riparian area over a large area of land.

Because the hydrologic regime develops and maintains the riparian area historical and recent flow regimes were reviewed to assess if the current flows mimicked the pre-dam flows during the period of record. There was no evidence found that suggested that the flow regime variability has been altered to the extent that the riparian community has been adversely impacted following the construction of Toledo Bend Reservoir. As long as the flow regime continues to mimic pre-dam flows the riparian community should continue to effectively function as the riparian area.

INTRODUCTION

Riparian Areas

Riparian areas are found throughout the United States, as strips or belts of vegetation adjacent to inland aquatic systems that are affected by the presence of water (Fisher et al. 2001). Riparian areas are more dynamic than adjacent uplands in that they can and do change dramatically by the frequency and duration of flooding events (Lewis et al. 2003). These flooding events can be the commonly occurring temporary overbank flood event or long-term flood resulting from beaver dams. The large diversity of plant and animal species that make up this area are a reflection of a dynamic system. These belts of vegetation between aquatic and upland systems perform a wide array of unique functions (Brown et al. 1978, Tabacchi et al. 1990, Gregory et al. 1991, Lewis et al. 2003). Riverine riparian areas have been found to improve water quality by removing pollutants from storm water, optimizing light and temperature by shading the stream, and storing runoff and recharging aquifers while supporting high levels of biological diversity (Naiman and Decamps 1997, Lewis et al. 2003). Current estimates have found that >80% of the riparian corridor in North America and Europe has been lost in the last two-hundred years (Naiman et al. 1993). One general understanding is there is value in protecting the riparian area. In order to understand, protect and manage this unique area, the riparian area must be defined and delineated.

The riparian area is created and maintained by water near the soil surface at a frequency and duration that is greater than the adjacent land to an extent that vegetation with morphological and physiological adaptations to this condition dominate. The riparian community may be composed of species peculiar to the riparian association, as well as an extension of an upland association fingering downward into the drainage way termed pseudo-riparian (Campbell and Green 1968). This includes vegetation outside of the zone which is not directly influenced by the hydrologic conditions, but that contributes organic matter to the floodplain, or influences the physical regime by shading, and could be considered part of the riparian area (Gregory et al. 1991). So conceptually, the riparian area is not an ecosystem but a collection of ecosystems.

Policy in Managed Flooding Disturbances

The Federal Clean Water Act is quite possibly the most important law regarding water resources, particularly in relation to wetlands. Section 404 of the Clean Water Act is the principal regulatory protection for wetland areas. Section 404 established in 1972 (last amended in 1977) recognized the important ecological services wetlands provide along with the need to protect these areas. However Section 404 does not include or deal with the role flooding plays on the maintenance of riparian areas (Haeuber and Michener 1998).

According to Postel and Carpenter (1997) floods are critical for maintaining the important ecological services provided by riparian areas, in addition to the social and economic benefits humans derive from these services. When it comes to flooding, Haeuber and Michener (1998) find a paradox reflected by society’s fear of, and dependence on flooding. Floods can be extremely dangerous events, leading to loss of property and at times loss of life. Despite the potentially devastating (mainly depending on location and size of event) economic and social impacts, floods are essential for resetting succession, and maintaining a healthy riparian ecosystem (Baily 1991; Michener et al. 1998; Sparks et al. 1998; Swanson et al. 1998; and Yarie et al. 1998). In areas where dams have altered the natural flooding regime, the ultimate goal of riparian area management should focus on managing water flow in a manner that restores the hydrologic regime to their "natural" conditions (Haeuber and Michener 1998).

The difficulty presented here is the need for policy to reconcile the contradictory needs of controlling flooding to safeguard private property and human life and maintaining a flooding regime to support a healthy riparian area. In East Texas where the majority of the water in Texas is located, there are many reservoirs and potentially more being constructed in the near future to meet the water needs of increasing population. So in addition to the dangers presented with flooding events, the need in restoring "natural" or pre dam flow regimes must be balanced with the social and cultural benefits derived from these structures.

By linking current and emerging knowledge and directing future research activities toward key aspects of policy and management, scientists can contribute to the development of water resource management techniques and policies that integrate human needs with important water management plans (Haeuber and Michener 1998). Lubchenco (1995) urges a need to reduce the discrepancy between policy and scientific knowledge by scientist presenting the best possible information in a user friendly, policy relevant format. This research paper seeks first to define and delineate the riparian area using ecological concepts which then can applicable to policy decisions. In this paper we do not give specific recommendations for flows, we provide techniques that allow one the ability to determine flow requirements for riparian maintenance.

The Difficulty in Defining

The riparian area has been defined several different ways, from the oversimplified to the scientific detailed description of a specific region (Anderson 1987). As Verry et al. (2004) states, writing a definition for the riparian area is the easy part; identifying the riparian area on the ground in a wide variety of landscapes is the difficult part. Simply put, riparian areas are individually unique across the United States, to a point that no one definition can account for all of that variability (Fisher et al. 2001). This is no different for the State of Texas where Gould et al. (1960) has divided Texas into eleven natural ecoregions (Figure 1).

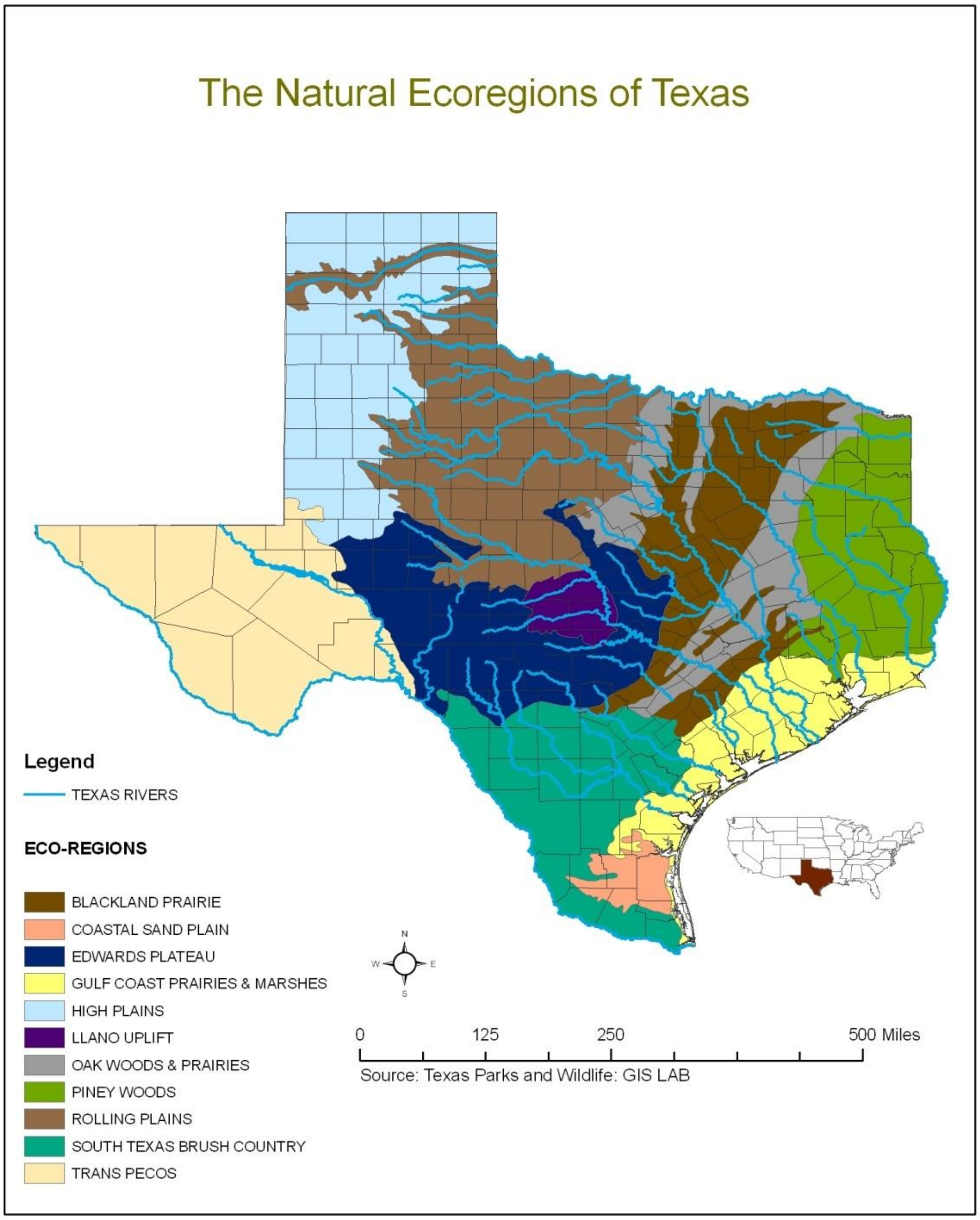

Figure 1. The natural ecoregions of Texas. *Source: Gould et al. 1960.*

Substantial effort and resources have been used in order to classify, inventory, enhance, restore and protect riparian areas, but these efforts have lacked consistency (Prichard et al. 1998). Currently there is no universally accepted definition or regional definitions for what makes up the riparian area. Also, a variety of disciplines study riparian areas and in doing so have developed terminology such as riparian floodplains, alluvial swamp forest, streamside management zones, desert wash, and so on. Consistency in the terminology will allow researchers of differing disciplines and from different regions to effectively communicate with one another by knowing exactly what the riparian areas encompass. Additional problems in defining the riparian area occur when considered in the context of wetlands protection under Section 404 of the Clean Water Act. Jurisdictional wetlands are defined as:

"Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" (Environmental Laboratory 1987).

The riparian area will extend beyond to include non-jurisdictional areas that provide available water to the root zone at a level to establish and maintain wetland soils and vegetation (Lewis et al. 2003), as well as portions of the adjacent upland which have direct influence over the riparian area (Verry 2004).

Defining the riparian area based on its ecological properties is important from the managerial point of view, for those who are protecting or developing within or near this zone (Naiman and Decamps 1997). A common management tool is the use of riparian buffer zones which define a distance from a stream where certain land use activities are prohibited (Texas Forest Service, Bren 1995). The buffer zone technique is rapid, easy to understand, practical, and effective in its objectives. The potential shortfall of this system is that it does not account for all of the variability found within riparian areas, the vast geographic differences (e.g. East Texas vs. West Texas), and differences in valley shape and geomorphic setting on the landscape.

RIPARIAN AREA DEFINITIONS

Choosing a Definition

The meaning of the Latin word 'Riparius' is "of or belonging to the bank of a river" (Webster's New Universal Unabridged Dictionary 1976). The anglicized term 'riparian' refers to the living communities adjacent to lakes and streams (Naiman and Decamps 1997). Historically, the riparian area defined has had profoundly different meanings depending on profession, agency, research area, and geographic location (east vs. west). These definitions, in association with mapping protocols, begin with vegetation community and then invoke a vague but real zone of functional influence (such as hydric soils, large woody debris, shading, etc.) (Verry et al. 2004). The definitions are created by these different entities to describe the specific area or resource they are interested in managing. In order to define a complex area of interest the components that make up the area have to all be included. Because the riparian area operates on an ecosystem level, a functional definition is required to include all the interacting parts. Verry et al. (2000) states there is agreement from the ecological perspective that riparian areas will include water and those features that contain and transport water, an area of interaction between the aquatic and terrestrial ecosystem and occurs at variable widths along the coarse of a water body.

A literature review was conducted to identify a definition among the most common definitions used in governmental agencies, academic institutions, and journal and books written that focus on defining the riparian area. A complete list of all definitions reviewed can found in Appendix A2.

Many federal and state agencies have developed definitions that are generally very narrow in application. This is most likely due to those agencies targeting a particular application that reflects their target goals. These definitions may be very useful in target application but in each case reveal a lack of detail necessary to define the complex riparian area. A list of Federal Agency definitions can be found in Appendix A2.

Elon Verry, James Hormbeck, and C. Andrew Dolloff have written peer-reviewed journal articles and chapters of books devoted to defining the riparian area. The following definition is what these researchers developed in their 2000 book "Riparian Management in Forest of the Continental Eastern United States."

> **Riparian ecotones are a three-dimensional space of interaction that include terrestrial and aquatic ecosystems that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at a variable width.**
>
> **Verry et al. 2000**

This definition incorporates scale and the interactions that occur at each scale. Swanson et al. (1998) described this scale and the interactions within critical for natural resource managers because it illustrates riparian area by ecological function. Addressing the ecological functions of riparian areas is critical to the management aspect of maintaining healthy riparian areas (Verry 2000).

The National Research Council is consistent with the previous definition, but more clearly outlines all the components that comprise the complex riparian area.

> **Riparian areas are transitional between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect water bodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems (i.e., a zone of influence). Riparian areas are adjacent to perennial, intermittent, and ephemeral streams, lakes, and estuarine-marine shorelines.**
>
> **National Research Council 2002**

Applicable Definition

Based on the literature review conducted on riparian area definition, the definition that is most applicable to Texas riparian areas is the National Research Council's 2002 definition of riparian areas. For further use in this study this definition will be used as a guide in delineating the riparian area for the Sabine River Basin.

RIPARIAN AREAS OF THE SOUTHEAST AND SOUTHWEST U.S.

A stark difference exists between the amount of published information covering the riparian areas in pacific, mountain and southwest regions and the southeast region. Over 70% of published literature covering riparian areas focuses on the pacific, mountain and southwest region while only 5% cover the southeast region (National Research Council 2002).

A distinct difference between riparian areas of the Southeastern U.S. and Southwestern U.S. is the sharpness of the vegetation zones between wetland vegetation and adjacent upland vegetation. The vegetation zones of the southeast U.S. are generally much broader, and the humid climate allows for a much wider riparian area encompassing a larger portion of the upland. Conversely the vegetation zones of the Southwestern U.S. exhibit a distinct vegetation gradient with the adjacent upland or xerophytic ecosystem (Brown 1978).

Pase and Layser (1977) describe the riparian areas in the Southwest U.S. as the streamside communities stretching from high elevation forest to the low desert. These communities sustain a wide range of plant and animal communities. The various plant communities forming a riparian community may be represented as forest, woodland, marshland, and grassland/shrub community types (Brown et al. 1977).

In drier climates streams can lose discharge volume downstream. These losing streams may be composed of the typical riparian plant community along sections of the stream where water is more available, and transition into a plant community of facultative and upland species as the stream becomes low flow to a dry creek bed. In wetter climates streams may gain discharge volume downstream as more tributaries enter the stream (Lewis et al. 2003). As a result, broad floodplains with shallow water tables are maintained throughout the watershed. Figure 2 illustrates that the hydrology of streams in a wetter climate develop a broad floodplain that gradually rises into the upland. In contrast, streams in the drier climate of the Southwest U.S. create very narrow floodplains with distinct transitions into the upland.

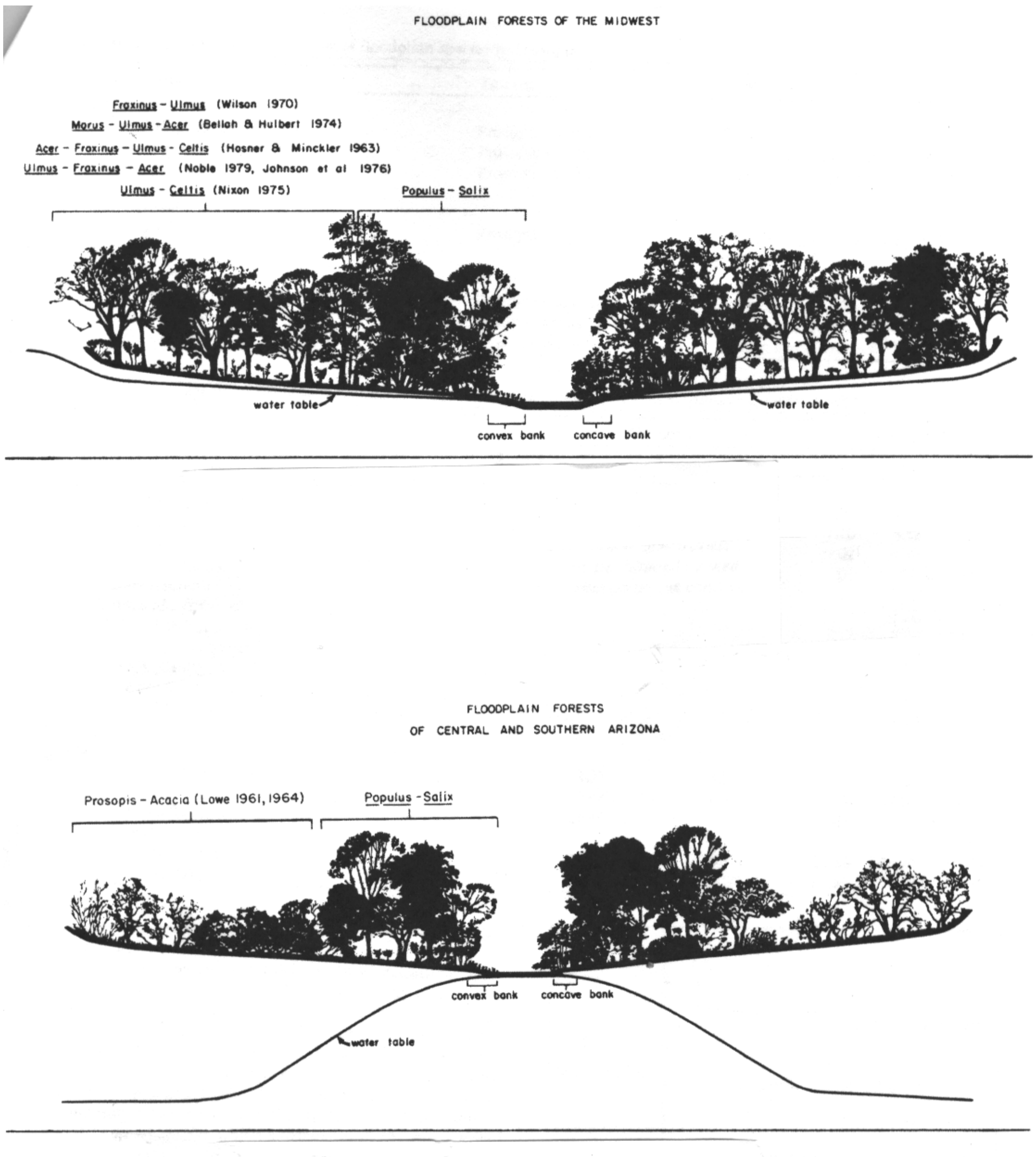

Figure 2. An illustration displaying the distinct difference between the water table of floodplains in moist and dry climates. *Source: adapted from Brown and Lowe (1974)*

Based on these distinct differences, no definition listed here is comprehensive enough to detail the different hydrologic regimes driving these unique areas. At what geographic extent can a definition be used is not clear but a safe assumption is that southeast and southwest riparian areas may require separate definitions. It should be kept in mind that the definitions listed here were all authored by individuals attempting to describe the same area, so none of them are technically wrong. Only from the standpoint of delineating an area as complex and dynamic as the riparian area should the definition be clear, concise, and detailed to the extent that an academic researcher, agency employee or land manager could understand and apply it within their respective disciplines. Using the term riparian ecotone avoids the common zone or area terms that regionally infer a particular landscapes setting (Illhardt et al. 2000). This term will also be equally applicable to lakes, wetlands, streams, rivers, estuaries, and ponds (Verry et al. 2004).

The definition that will encompass the ecotone concept which extends into the upland for the purpose of linking the interactions of the aquatic ecosystem, the wetland ecosystem and the upland ecosystem is most applicable to riparian areas in the southeast.

> "Riparian ecotones are a three-dimensional space of interaction that include terrestrial and aquatic ecosystems that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at a variable width" (Verry et al. 2004).

This is the definition the delineation effort will be directed at encompassing on the Sabine River floodplain below Toledo Bend Reservoir.

FUNCTIONS AND VALUES OF RIPARIAN AREAS

The components of the riparian area provide numerous ecological benefits to aquatic ecosystems. These areas function to protect streams, rivers, and lakes, while providing unique habitats which support a diverse group of plant and animal species. In fact, riparian areas are some of the most diverse areas on the terrestrial segment of Earth (Naiman et al. 1993; Naiman and Decamps 1997).

Delineation by Function

One concept that can be used to delineate the riparian area is to use riparian function or the movement of materials and energy between the land and the water. This avoids basing the riparian area on an arbitrary distance or solely on vegetation, or soils, or flood return intervals. By delineating the riparian area by function it will include an area greater than the area generally associated directly with the floodplain or those areas with wetland indicators. Since the purpose of riparian area management is to manage the riparian area to maintain the functioning capacity, ideally this would be the most beneficial method of delineation. Unfortunately on the ground assessments of riparian area width by function would be complex, expensive, and potentially impossible for certain functions. Also the function being considered will vary and certain functions will be difficult to determine accurately (Verry et al 2000). The benefit of the functional delineation is based on an area by its static state variables such as the flow of energy and materials as opposed to a fixed map unit (Verry et al. 2000). Although function alone may not be able to be used as the sole delineating variable, the riparian area functions should be an integral component when it can be applied.

Important Riparian Area Functions

Riparian areas are effective at removing pollutants from storm water runoff. Riparian riverine areas may serve a dual role of removing both sediment and chemicals from the water. The stream's ability to carry sediment is largely dependent on the velocity of the stream. A wetland's effective ability to raise water quality parameters is dependent on the hydrological characteristics of the area. The suspended solids in the stream are inorganic and organic materials. Most of the suspended solids are inorganic particles of sand, silt, and clay. The suspended inorganic particles of sand, silt, and clay are chemically inert themselves, but they do have very large surface area, whereby dissolved chemicals can be absorbed to them and removed from the water column by sedimentation (Kibby 1978). Pionke and Chesters (1973) determined the organic rich sediments of riverine wetlands may immobilize and retain heavy metals and pesticides for a period long enough to be detoxified. The riparian soil also function to capture and store water from adjacent land, act as a medium for plant and microorganism nutrient cycling, nutrient storage, and aquifer recharge (Lewis et al. 2003). Riparian areas provide an important role in the uptake and long-term storage of nutrients.

The cycling of nutrients refers to the riparian area's capacity to convert nutrients from an organic form to an inorganic form, which includes processes such as microbial decomposition and photosynthesis. Included is the capacity of the riparian area to remove compounds that are brought to riparian wetlands, most likely by floodwaters (Klimas et. al, 2005). Denitrification is a well-studied function of riparian wetlands because it is a process for nitrogen removal in polluted waters (Hunter et al., 2008). The removal of nutrients or compounds aids in the prevention of eutrophication in riparian areas (Dennison and Berry, 1993). The nutrient cycle takes place with the soil, dead organic matter, primary producers, and consumers (Klimas et al., 2005). The withholding of dissolved substances leads to the reduced transport of nutrients downstream (National Research Council 2002). In a Louisiana Basin, the retention function is understood to be very important as the stored sediment has the chance to undergo biogeochemical transformations which reduce the nutrient, contaminant, and carbon inputs into the Gulf of Mexico (Hupp et al., 2008).

Naturally vegetated areas serve the function of flood control. A vegetated undeveloped floodplain will reduce the height, force and volume of floodwater by spreading the water horizontally across the floodplain. The water that has entered the floodplain during a flood event will reenter the river channel slowly. This slow reentry is due in part to the soils, dead/decaying vegetation soaking up water, and the uptake and transpiration of water by living vegetation. In addition, the living and dead/decaying vegetation create a barrier against moving water. These properties of riparian areas effectively slow down the total delivery of water over time. In addition, riparian areas intercept and detain runoff from the adjacent upland areas. The riparian corridor is disturbed frequently by floods and debris flows, which create an ever shifting mosaic of landforms and plant communities (Naiman et al. 1993). Flooding creates heterogeneity within the riparian area (Naiman and Decamps 1997). As a result of the large variety of microsites, ridge/swale complexes, and high frequency disturbance regimes, the riparian zones are composed of greater species diversity when compared to the upslope habitats (Gregory et al. 1991).

The riparian area is recognized as a corridor for the movement of animals and dispersal of plants. This zone or corridor possesses a very diverse array of species, and provides unique environmental processes (Naiman et al. 1993). Less than one percent of the Western North

America landscape is dominated with riparian vegetation, yet more species of birds utilize this vegetation type for habitat than all other vegetation types combined (Knopf et al. 1988).

The inter-connection of the river channel and the floodplain is critical for maintaining riparian function (Middleton 2002). The actions of developing or degrading by bypassing the riparian area may degrade the overall stream health by increasing the pollutant load to the stream, the potential for stream bank erosion, and sedimentation of the stream. Because of the functional value of these areas, protection and proper management must be employed to maintain these functions. In order to properly protect and manage these areas, the riparian area must be defined and delineated for the area in question.

RIPARIAN SOILS OF THE EAST TEXAS RIVER BASINS

Because of the frequency and duration of water near the soil surface, riparian areas have soil properties that differ from upland soils. Soils of the riparian area will largely be composed of hydric soils. Hydric soils are those soils that developed under saturated, flooded or ponded anaerobic conditions (Environmental Laboratory 1987). Just as hydrology has an effect on soils and vegetation in the riparian area, the soils have an effect on the hydrology and vegetation in the riparian area. These soils may act as a sponge retaining flood and rain water slowly releasing the water to the surface water and recharging the aquifers. The soils may also restrict water permeation by hardpans or clayey soils which will stand water for a longer period of time. The soil texture and hydrologic regime will directly influence the vegetation composition within the riparian area by the levels oxygen and moisture in soil profile where roots are present. Lewis et al. (2003) describes the soils along the riparian area as being the foundation of the watershed.

The soils of riparian areas have characteristics that depend on the hydrological regime along with the rates of supply of material that are delivered from the upstream source and within the floodplain itself (Brown et al. 1977). As the rivers move farther into the forested areas of East Texas, the soil color changes from dark to light. The soils along the Sabine follow this trend as they move downstream. More examples of this pattern can be found in river systems throughout the State of Texas. The soils of the forested region of East Texas that formed on flood plains and terraces of streams of the Angelina, Neches, Sabine, Cypress, White-Oak, and Attoyac Rivers characteristically consist of light gray and light gray-brown soils of the Bibb and Iuka series. The soils on flood plains of the Trinity, Sulphur, and upper Sabine flowing through the Blacklands consist typically of dark-colored soils of the Kaufman, Trinity, and Navasota series. The lighter colored soils of the Ochlocknee series are also found along the lower part of the Trinity. Soils next to the Navasota River (Navasota series) are dark colored mainly due to dark sediments derived from small isolated blackland prairies in the southwest Post Oak Savannah Region. Soils developed on flood plains and terraces of the Brazos River (Miller and Norwood series) and Red River (Portland, Miller, and Yahola series) are largely red and brown resulting from drainage of the north-central Texas Redlands. Locally red soils are developed along streams draining the East Texas Redlands, but these have small distributions (Fisher 1965).

The most common soil orders in East Texas bottomlands are Inceptisols, Alfisols, and Entisols (Table 1 and Table 2). Most bottomlands in East Texas are composed of loamy textured soils beside small streams, and more clayey textured soils adjacent to large streams. The dominant clays in East Texas are kaolinite and montmorillonite (Dozel 1986). Kaolinte clays are low in bases with a low pH of <5.5. In contrast, the montmorillonite clays are high in bases with high pH and exhibit shrink-swell characteristics (Fisher 1965). Dozel (1986) found the primary species composition of wet East Texas bottoms with kaolinitic clays to be water oak (*Quercus nigra*) – willow oak (*Quercus phellos*), ash (*Fraxinus spp.),* sweetgum (*Liquidambar styraciflua*) and pine (*Pinus spp*.) making up smaller amounts. However, sites where high base montmorillonite clays compose a considerable amount of the clay sized particles, overcup oak (*Quercus lyrata*), pecan (*Carya illinoinensis*), locust (*Gleditsia spp.)*, and elm (*Ulmus spp.)* tend to dominate the tree community. Both of these clays are present in the Sabine River Basin and within the study site below Toledo Bend Reservoir. Although this is beyond the scope of delineating the riparian area, Dozel gives interesting insight into the influence hydric soils have on wetland plant community composition.

Table 1. Soil associations of riparian areas within East Texas.

River Basin	**Map Unit**	**Orders**	**Characteristics**	**Principal Landscape Setting**
Sulphur River Basin	Texark-Kaufman-Gladewater	Vertisol	Very deep, somewhat poorly drained, very slowly permeable clay soils that formed in clayey alluvium.	On the floodplains of streams draining the Blackland Prairies.
	Woodtell-Freestone	Alfisol	Deep, well to moderately well drained, slowly to very slowly permeable soils.	On Pleistocene terraces and remnants of terraces on upland positions.
	Woodtell-Sawyer-Sacul-Eylau	Alfisol Ultisol	Deep to very deep moderately well drained, slowly permeable soils.	On Pleistocene terraces and remnants of terraces on broad ridges and upland positions.
Cypress Creek River Basin	Socagee-Mooreville-Mantachie-Iuka-Guyton	Inceptisol Alfisol Entisol	Deep to very deep, poorly to moderately well drained soils	On the bottomlands of floodplain.
	Mollville-Latch-Bienville	Alfisol	Very deep, moderately to somewhat excessively drained, slowly to moderately permeable soils.	On gently sloping and nearly level or depressional positions on stream terraces.
Neches River Basin	Pophers-Ozias-Koury	Inceptisol Vertisol	Very deep, somewhat poorly drained slowly permeable soils.	On nearly level floodplains.
	Mantachie-Estes	Inceptisol Vertisol	Very deep, somewhat poorly drained, moderately permeable, loamy and clayey soils.	On nearly level floodplains.
	Tuscosso-Marietta-Mantachie-Iuka-Hannahatchee	Inceptisol Entisol	Very deep, moderately well to somewhat poorly drained, moderately permeable soils.	On nearly level soils along streams and bottom lands in the flood plain

Table 2. Soil associations of riparian areas within East Texas continued.

Sabine River Basin	Texark-Kaufman-Gladewater	Vertisol	Very deep, somewhat poorly drained, very slowly permeable clay soils that formed in clayey alluvium.	These soils are found on the floodplain
	Nahatche	Entisol	Very deep, somewhat poorly drained, moderately permeable soils.	On flood plains of streams draining soils of the Southern Coastal Plain.
	Mantachie-Estes	Inceptisol Vertisol	Very deep, somewhat poorly drained, moderately permeable, loamy and clayey soils.	On nearly level floodplains.
	Mollville-Latch-Bienville	Alfisol	Very deep, moderately to somewhat excessively drained, slowly to moderately permeable soils.	On gently sloping and nearly level or depressional positions on stream terraces.
	Guyton-Estes-Deweyville-Arat	Alfisol Vertisol Histisol Entisol	Very deep, poorly and very poorly drained, slowly and moderately rapid permeable	On stream floodplains and in depressional areas on late Peistocene age terraces. Deweyville is also in swamps and poorly defined drainageways.
	Mollville-Mantachie-Bienville-Besner	Alfisol Inceptisol	Very deep, poorly drained to somewhat excessively drained, moderately to slowly permeable soils.	On Pleistocene terraces. Typically first level terraces, but is also on third and fourth level on larger river systems. Mantachie series is also found on the floodplain.
Trinity River Basin	Kaman-Hatliff-Fausse	Inceptisol Vertisol Entisol	Very deep, poorly to moderately well-drained, very slowly to moderately rapid permeability.	On nearly level floodplains. Fausse series is found in ponded backswamp areas.
	Tinn-Kaufman-Gladewater	Vertisol	Very deep, moderately well drained to somewhat poorly drained very slowly permeable clayey soils.	On nearly level floodplains.

RIPARIAN VEGETATION WITH SPECIAL ATTENTION TO TEXAS

Riparian ecosystems in the Southeastern United States are often situated in broad zones. In contrast, the riparian areas of the Southwestern United States are often prominent narrow belts of vegetation following along streams and rivers (Knopf et al. 1988). The vegetation communities associated with riparian areas can tolerate anaerobic conditions to the extent that species common to upland areas are restricted (Lewis 2003). Plant species within the riparian area have physiological and/or morphological adaptations which enable these species to grow, survive, and reproduce in this dynamic landscape (Perry 1994, Zimmermann and Brown 1971, Naiman and Decamps 1997). Some morphological adaptations are aerenchyma tissue (enable the plant to diffuse oxygen absorbed from aerial tissues down into the root system) (Marschner 1986), lenticels (pores on the surface of normally thick bark that allow the passage of gas to and from the interior tissue) (Kozlowski et al. 1991), and specialized roots (roots protrude up through the anaerobic zone to allow for gas exchange) (Kurz and Demaree 1934). Floodplains in the southeast generally lack complex topographic features and thereby slope gently from the river to the uplands. As a result, flooding frequency and depth are inversely proportional to the elevation of the floodplain (Brinson 1990). However, vegetation does not respond simply to this elevation change due to the variable of soil texture, aeration of the soil, and the soil's capacity to drain water (Robertson et al. 1978). Lewis et al. (2003) grouped plants adapted to riparian environments into three categories: xeroriparian, mesoriparian, and hydroriparian. The **xeroriparian** plants are those found in upland to wetland intergrades where soils generally do not become saturated. Here, upland plants may take advantage of greater moisture availability. In some situations, species from drier riparian environments that are unable to tolerate the saturated soil conditions take advantage of comparatively lower moisture levels. The USDI Fish and Wildlife Service refer to these as obligate upland plants. The **mesoriparian** plants are found along streams and on commonly inundated floodplains with shallow water tables. These areas experience seasonal saturation to the soil surface. The USDI Fish and Wildlife Service refer to these as facultative and facultative upland plants. The **hydroriparian** plants are true aquatic plants that require continual surface wetness. The USDI Fish and Wildlife Service refer to these as obligate wetland and facultative wetland plants. These categories illustrate how the hydrologic regime of the riparian area creates this diverse area. A plant's indicator status, the vegetation communities on site give evidence to the presence of riparian wetland hydrology.

Vegetation communities making up the riparian area are common to each river basin. These communities may change in composition as they move through different eco-regions (Figure 1). Vegetation work in riparian areas involves the description and analysis of the floodplain, banks, terraces, channel, water source, and associated habitat (Gebhardt et al. 2005).

The riparian plant community is the community of plant species that are affected by the presence and duration of water near the soil surface. In order for water to influence species composition, the water table must be within the plant's zone of influence, which is generally understood to be the upper twelve inches of the soil profile during a certain percent of the growing season (Environmental Laboratory 1987). Floodplains of the Southeast U.S. are generally broad while those of the Southwest U.S. are generally narrow and distinct. The presence or absence of certain plant species making up a plant community is an indicator of whether or not wetland hydrology exists at a particular site. Aerial photos and satellite imagery observe the land cover. Using high resolution imagery tree species can be differentiated and identified down to the genus and in some instances the species. Aksheh et al. (2008) used aerial photography to delineate areas dominated with plant communities common to the riparian area. This is an easy way to obtain a rough estimate of the extent of the wetland or even the riparian area. The plant community can then be used to delineate large areas of land potentially under the influence of riparian wetland hydrology.

Below is a brief review of descriptions to highlight plant community assemblages in riparian areas of some river basins across the State of Texas. This is not a complete review, and for a more detailed review of plant communities in East Texas see: Diggs et al. 2006 "Illustrated Flora of East Texas". The difference between riparian plant communities of East and West Texas is great, while more minute differences exist between neighboring river basins in East Texas. The differences that exist within each basin may correspond with the river moving into different ecoregions. The natural variation of the riparian area is an important consideration to conduct effective management practices in these areas (Lewis et al. 2003).

Sabine River Basin Vegetation

A large section of the Sabine River flows through the Pineywoods Ecoregion. Within this area, trees in connected depressions, disconnected channels, and next to the river bank are in commonly composed of water hickory (*Carya aquatica*), baldcypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica*) overcup oak, blackgum (*Nyssa sylvatica*), and black willow (*Salix nigra*). On terraces the overstory plant community is commonly composed of sweetgum (*Liquidambar stryaciflua*), water oak, cherrybark oak (*Quercus falcata*), green ash (*Fraxinus pennsylvanica*) and elms. The understory is commonly composed of red maple (*Acer rubrum*), American hornbeam (*Carpinus caroliniana*), boxelder (*Acer negundo*), and deciduous holly (*Ilex decidua*). The area transitioning into the upland area is commonly composed of loblolly pine

(*Pinus taeda*), southern magnolia (*Magnolia grandiflora*), sweetgum, hickories (*Carya spp*.), American beech (*Fagus grandifolia*) and shortleaf pine (*Pinus echinata*) in the overstory. The understory is commonly composed of flowering dogwood (*Cornus florida*), American holly (*Ilex opaca*) and eastern hophornbeam (*Ostrya virginiana*).

Neches River Basin Vegetation

The Neches River Basin contains the Neches and Angelina Rivers and is completely located within the Pineywoods Ecoregion. Nixon et al. (1977) found the principal woody species in the Neches River bottom near Jasper County, Texas, to be American hornbeam, Carolina ash (*Fraxinus caroliniana)*, water oak, red maple, possumhaw (*Ilex decidua*) and silver bells (*Styrax americana*). Other species identified were blackgum, sweetgum, baldcypress, and laurel oak (*Quercus laurifolia*). The mid-story is composed of common persimmon (*Diospyros virginiana*), American hornbeam, Carolina ash, red maple, and possumhaw. The understory is made up mainly of silver bells, Sebastian bush (*Sebastiania fruticosa*), bush palmetto (*Sabal minor*), and southern arrow-wood (*Viburnum dentatum*).

Marks and Harcombe (1981) divided floodplain communities around the Big Thicket into four groupings: floodplain hardwood-pine forest (narrow floodplains of streams), floodplain hardwood forest (broad, well defined stream and river floodplains), wetland baygall shrub thicket (slope bases and poorly drained depressions), and swamp cypress-tupelo forest (perennially flooded sloughs). The floodplain hardwood forest found along major rivers is dominated with sweetgum and water oak in the overstory. The plain hardwood-pine forest found along smaller streams is composed of American beech, loblolly pine, with American hornbeam in the understory. The swamp cypress-tupelo forest located in deep sloughs and oxbow lakes are dominated with baldcypress and water tupelo. The wetland baygall shrub thicket is composed of blackgum, laurel oak, red maple, and sweetbay *(Magnolia virginiana)*.

Trinity River Basin Vegetation

The flatlands on the low elevation terraces of the Trinity River are composed of swamp chestnut oak (*Quercus michauxii*), willow oak, laurel oak, loblolly pine, and green ash (Nixon and Willett 1974). Nixon et al. (1990) found that the ten most dominant plants in the Trinity River Floodplain were cedar elm (*Ulmus crassifolia*), Texas sugarberry (*Celtis laevigata*), green ash, tupelo, deciduous holly (*Ilex decidua*), baldcypress, hawthorn (*Crataegus spp.*), swamp privet (*Forestiera acuminata*), water elm (*Planera aquatica*), and roughleaf dogwood (*Cornus drummondii)*. Other prevalent species included water hickory, pecan, sweetgum, overcup oak, black willow, and American elm (*Ulmus americana*).

Sulphur River Basin Vegetation

East Texas State University (1971) divided the Sulphur River basin by the three major ecoregions through which the Sulphur River runs. The dominant higher plant community of the Blackland Prairies region of the Sulphur River is composed of boxelder (*Acer negundo*), bumelia (*Bumelia langinosa*), sugarberry (*Celtis laevigata*), eastern redbud (*Cercis canadensis*), white ash (*Fraxinus americana*) possum haw, water oak, willow oak, black oak (*Quercus velutina*), cedar elm, slippery elm (*Ulmus rubra*).

The dominant higher plant community of the Post Oak Ecoregion of the Sulphur River is composed of boxelder, giant cane (*Arundinaria gigantea*), pecan, sugarberry, rough leaf dogwood, common persimmon, white ash, possum haw, sweetgum, American sycamore

(*Platanus occidentalis*), bur oak (*Quercus macrocarpa*), water oak, willow oak, dwarf palmetto (*Sabal minor*), and cedar elm. The dominant higher plant community of the Pineywoods Ecoregion of the Sulphur River is composed of American hornbeam, hickory species, buttonbush (*Cephalanthus occidentalis*), eastern redbud, English dogwood (*Cornus stricta*), common persimmon, swamp privet (*Forestiera acuminata*), sweetgum, overcup oak, water oak, willow oak, black willow, and baldcypress.

Nueces River Basin Vegetation

The Nueces River Basin is divided by the Edwards Plateau and the South Texas Plains Ecoregions. Wood and Wood (1988) divided the Frio River into four community types based on species composition. The lower section of the Frio River along the river bank is composed of Mexican ash (*Fraxinus berlandieriana*) and black willow, while the terrace consisted of cedar elm, live oak (*Quercus virginiana*), sugarberry in the overstory and Texas persimmon (*Diospyros texana*) and chittamwood (*Bumelia lanuginosa*) in the understory. The second section was characterized by a pecan-castor bean (*Ricinus communis*) honey mesquite (*Prosopis glandulosa*) community along the bank, while the terrace consisted of larger pecan, net leaf hackberry, and live oak in the overstory, and Texas persimmon in the understory. The third community is described as a dry portion of the Sabinal River crossing over the Balcones Fault zone of the Edwards Aquifer. Here the riparian area is narrow and nearly absent due to cultivation and range lands bordering almost to the edge of the river. Here the river's edge is composed of cedar elm and little black walnut (*Juglans microcarpa*), while the terrace is composed of net leaf hackberry (*Celtis reticulata*) in the overstory, and desert sumac (*Rhus microphylla*) and Brazilian bluewood (*Condalia hookeri*) in the understory. The upper portion of the Frio River commonly has flowing water except during drought years. This section of the Frio River is typically bordered by high limestone canyon walls. The river's edge on the east branch consists of bald cypress and sycamore while the west branch is void of baldcypress and is dominated with little black walnut. The terrace on the east branch is characterized by Ashe juniper (*Juniperus ashei*), little black walnut, and Texas persimmon, while the west branch terrace is composed of Texas persimmon and chinkapin oak (*Quercus muehlenbergii*) (Wood and Wood 1988).

Leona River Riparian Vegetation

The Leona River riparian area overstory is composed of live oak, net leaf hackberry, and cedar elm, and the understory is composed of Texas persimmon, Texas mountain laurel (*Sophora secundiflora*), and chittamwood. The upper portion of the Leona River is dominated by live oak, while at the middle and lower portions pecan and Mexican ash are present, and live oak densities decrease (Wood and Wood 1989).

Sabinal River Riparian Vegetation

The vegetation community of the Sabinal River was divided in to four communities by (Wood and Wood 1989). The lower Sabinal River is composed of baldcypress along the river's edge, with the terrace consisting of live oak, net leaf hackberry, and pecan in the overstory and Texas persimmon and soapberry (*Sapindus drummondii*) in the understory. The second community is described as a dry portion of the Sabinal River crossing over the Balcones Fault zone of the Edwards Aquifer. Here the riparian area is narrow and nearly absent due to cultivation and range lands bordering almost to the edge of the river. Here the river's edge is composed of cedar elm, baldcypress, sycamore, and live oak. The terraces consist of live oak and cedar elm in the overstory and Texas persimmon and Texas mountain laurel in the understory. The third community above the Balcones fault zone is dominated by baldcypress and sycamore near the bank, whereas the terrace overstory is composed of pecan, net leaf hackberry, live oak, and little black walnut and the understory is composed of Texas persimmon and chinaberry (*Melia azedarach*). The fourth community is located within the upper portion of the Sabinal River where, unlike the Frio River (Wood and Wood 1988), water flow is minimal forming small pools that flow during wet periods of the year. This section of the river is narrow and often bordered by the limestone canyon walls. This section of the river's edge consists of sycamore, little black walnut, and common button bush. The terrace is characterized by ashe juniper, Texas oak, bigtooth maple (*Acer grandidentatum*), and white shin oak (*Quercus sinuate*) in the overstory with Texas persimmon in the understory (Wood and Wood 1989).

Guadalupe River Riparian Vegetation

The riparian area of the Guadalupe River on the Edwards Plateau is dominated with pecan, with sub-dominants composed of Texas sugarberry, baldcypress, cedar elm, Texas persimmon, red mulberry (*Morus rubra*), boxelder, black walnut, American elm, soapberry, Virginia creeper (*Parthenocissus quinquefolia*) and possum-haw (Ford and Van Auken 1982). In addition, species that were present in a lower density included: rough-leaf dogwood, hill country live oak (*Quercus fusiformis*), white ash, sycamore, gum bumelia, Osage-orange (*Maclura pomifera*), Mexican juniper (*Juniperus ashei*), buttonbush, tree-of-heaven (*Ailanthus altissima*), bastard indigo (*Amorpha fruticosa*), hop tree (*Ptelea trifoliate*), poison ivy (*Toxicodendron radicans*), honey mesquite (*Prosopis glandulosa*), black willow, and common elderberry (*Sambucus canadensis)* were present in fewer numbers.

San Antonio River Riparian Vegetation

Bush and Van Auken (1984) cross-sectioned the San Antonio River into three physically defined regions: the inner bank, the floodplain, and the outer bank. Few differences existed within the plant community across the floodplain, excluding cottonwood (*Populus deltoids*) and black willow, whose distribution is almost completely limited to the inner bank of the river, while gum bumelia was almost exclusively on the outer edge of the terrace. The species composition of the floodplain terrace included sugarberry, boxelder, cedar elm, pecan, and American elm. The sapling layer is composed of boxelder, Texas sugarberry, red mulberry, cedar elm, chinaberry, ash, black willow, cottonwood, pecan, buttonbush, American elm, and soapberry, with the density of the sapling layer being dominated with boxelder and Texas sugarberry (Van Auken and Bush 1988). Bush et al. (2006) found the early (15-25 yrs) successional plant community on the terrace were composed mainly of huisache (*Acacia farnesiana*), Roosevelt weed (*Baccharis neglecta*), and honey mesquite (*Prosopis glandulosa*). As the stand ages (27-47 yrs) the plant community becomes composed of sugarberry, desert hackberry (*Celtis pallida*), waxyleaf privet (*Ligustrum quihoui*), and chinaberry.

Middle Rio Grande River Riparian Area

Akasheh et al. (2008) found that the composition of plant species along the riparian corridor of the Middle Rio Grande Basin consisted of cottonwood (*Populus deltoids)*, tamarisk (*Tamarix ramosissima*), Russian Olives (*Elaeagnus angustifolia*), and coyote willow (*Salix exigua*). Schmidly and Ditton (1978) described the bottomlands of the Rio Grande as dominated by salt cedar (*Tamarix gallica*), mesquite (*Prosopis sp*.), and willows (*Salix sp*.), with the occasional cottonwood (*Populus sp*.). Lonard and Judd (1993) described are mesic plants that commonly grow in riparian habitats include seepwillow (*Baccharis glutinosa*), honey mesquite, desertwillow (*Chilopis linearis*), tree tobacco (*Nicotiana glauca*), and screwbean (*Prosopis pubescens*).

Nixon et al. (1991) found that the overstory vegetation of a creek side stand in central Texas and found it consisted of shumard oak (*Quercus shumardii),* ash species, black walnut, bur oak, sugarberry, elm species, water hickory and chinquapin oak.

These surveys indicate that the vegetation composition of the riparian area within river basins and across the state of Texas differs. Plant community composition is different between river basins, as well as within the river basin as it meanders through different eco-regions. There are many plant species common to the riparian area across adjacent river basins, but due to differences described here, specific knowledge of the local riparian community is required to accurately delineate the riparian vegetation on a section of a river basin.

THE HYDROLOGY OF RIPARIAN AREAS

Hydrologic Regime

For proper management of riparian areas, information on the "natural" hydrologic regime is required. This natural hydrologic environment includes timing, depth, and duration of inundation, hydraulic head, the quality of the water, ecology of the site, and the mechanism by which the water reaches and leaves the area. This information will aid in ensuring that adequate water will penetrate into the adjacent blocks of forest (Bren 1993). The riparian area may also encompass older stream channels and oxbow lakes which, at best, have an intermittent connection to the main stream during flood events. These topographic features may also impound rain water (Brinson 1990). Boon (1990) implied these cut-off areas play an important role in maintaining biotic diversity of stream systems. In order to maintain diversity of stream systems, a natural flow regime that allows periodic connection to the main channel must be preserved for the health of both systems. The disturbance caused by floods is required to create river-edge light-gaps and accretion bars. Van Auken and Bush (1988) found that flood caused disturbances are necessary for black willow and cottonwood to remain as community members of Southern and Central Texas riparian areas.

The hydrologic regime must be understood so as to properly understand the frequency and duration of flooding and how this affects physiological changes in plant species (Kozlowski 2002). Bilan (1986) described species in the Neches River basin that were flood intolerant, indicating that dogwood, red cedar, black walnut, longleaf pine (*Pinus palustris*), and post oak (*Quercus stellata*) will die after frequent or prolonged flooding. Flood tolerant species such as baldcypress, red maple, American sycamore, American elm, sweetgum, green ash, willow oak, and water oak can survive, grow, and reproduce in a flooding environment to an extent. Baldcypress can survive long periods of flooding in stagnant water while exhibiting reduced growth (Shanklin and Kozlowski 1985), but the remaining flood tolerant species listed may increase growth during the first year of continuous flooding, decrease growth during the second year, and greatly increase mortality at year three of continuous flooding (McDermott 1954, Hosner 1960, Tang and Kozlowski 1982, Broadfood and Williston 1973). A potential method would be to determine flooding pulses by looking at historic hydrographs and maintaining frequency and duration of past flooding events.

The ecosystems of streams and rivers will differ both locally and regionally, including characteristics such as frequency of flooding, the width and depth of streams, and hydrogeomorphic features. These differences are evident when comparing eastern and western regions of the United States (Fisher et al. 2001). There is considerable variation from stream to stream and within sections of a single stream (Brinson 1990). For the purpose of delineating the riparian area, local climatic conditions and geomorphic settings should be established to determine the extent on the landscape with which the water influences vegetation composition.

Hydrographic peaks are sharp and frequent, predominantly near the end of the winter and into spring, when evapotransporation is low and soil water storage is high (Brinson 1990). The Pineywoods region of East Texas in most years will have higher rainfall during the winter and fall months, with less rain fall during the summer and fall months (Chang et al 1980). This rainfall influences the hydrologic regime where flow discharge (though variable) increases during winter and spring months and decreases during summer and fall months. The hydrologic regime is the vital component sustaining the riparian area. Figure 4 adapted from (Bayley 1991) illustrate the flux in water level.

Seed Dispersal in Riparian Areas

The riparian area is commonly associated as a corridor for the movement of animals, but they are also important in the dispersal of plants (Gregory et al. 1991). Plants adapted to the fluvial riparian areas have unique strategies for seedling establishment (Naiman and Decamps 1997). The riparian area is typically associated with relatively short duration flood events generated by a large rain event. Seeds from vegetation in the riparian area are dispersed as floodwaters rise (Figure 4) and spread across the across the riparian area (Lewis et al. 2003). A plethora of studies have been conducted at seed germination response to submersion, inundation and saturated soils, as well as survivability of planted seedlings and saplings. These types of studies indicate the field distributions of species directly relate to their level of flood tolerance along a flood frequency gradient (Franz and Bazzaz 1976). Gill (1970) concludes the best indication of relative flood tolerance among species is their relative distribution along the flood frequency gradient. In Tables 3-22, the requirements for establishment of species common to East Texas riparian areas are listed. References supporting the information in these tables can be found in the Appendix A1.

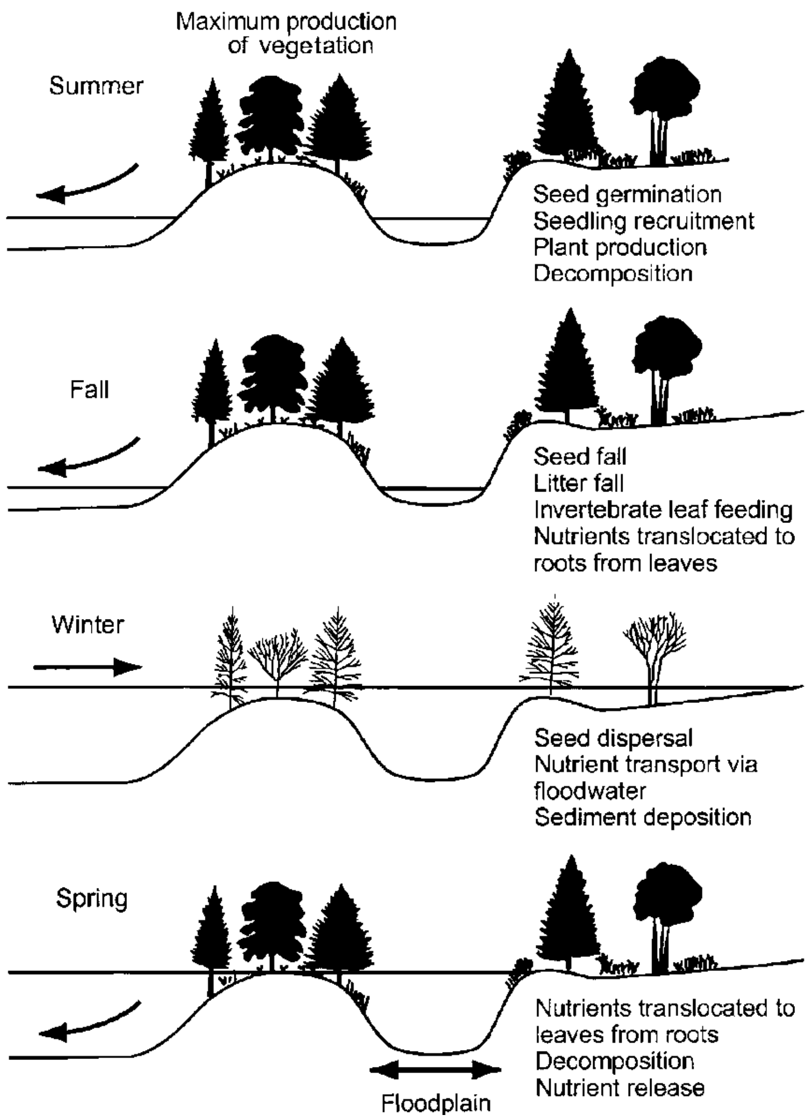

Figure 3. The typical hydrologic regime through the different seasons for floodplains of the Southeastern U.S. *Source: Adapted from Bayley 1991, in Middleton 2000.*

Table 3. Seedling characteristics of dominant native trees in East Texas riparian areas.

Scientific Name	Common Name	Max Height/Diameter	General Habitat Requirements	Shade Tolerance
<u>Trees</u>				
Acer negundo	boxelder	75 feet/ 4 feet	Wide-reaching species grows on southern coastal United States all the way into Canada. Grows best on deep alluvial soils near streams but is found on almost any type of soil.	tolerant
Acer rubrum	red maple	120 feet/ 5 feet	moderately well-drained moist sites at low elevations, slow-draining flats and depressions, swampy areas	tolerant
Betula nigra	river birch	100 feet/ 5 feet	Grows in a wide range of climates, 50 inches of rain, grows best on alluvial soils of streambanks	intermediate
Carpinus caroliniana	American hornbeam	35 feet/ 10 inches	60 deg F winter avg, 84 deg F summer avg, 50-60 inches of rain, prefers alluvial or colluvial sites between mesic and wet areas, well-drained terraces near rivers, and areas near lakes and streams.	very tolerant
Carya aquatica	water hickory	110 ft/ 3 feet	35-65 deg F winter avg, 80 deg F summer avg, 40-60 inches of rain, prefers well-drained loamy or silty soils, clay flats, sloughs, backwater areas.	intermediate
Carya cordiformis	bitter-nut hickory	100 feet/ 3 feet	40-55 deg F, 25-50 inches of rain, overflow bottoms and rich bottoms	intolerant
Carya myristiciformis	nutmeg hickory	100 feet/ 2 feet	45-80 deg. F,45-55 inches of rain, second bottom flats	intolerant
Carya ovata	shagbark hickory	140 feet/ 30 inches	40-65 deg. F, 30-50 inches of rain, deep, moist alluvial soils	intermediate

References in Appendix A1.

Table 4. Seedling characteristics of dominant native trees in East Texas riparian areas continued.

Scientific Name	Flood Tolerance	Fruit Type	Fruiting Period	Germination Requirement	Chilling Requirement (stratification only)	Photoperiod Requirement	Germination Period
<u>Trees</u>							
Acer negundo	tolerant	samara	August-October	stratification	41 deg F for 60-90 days	none	spring
Acer rubrum	moderately tolerant	samara	April-June	none	none	none	spring
Betula nigra	moderately tolerant	catkin	May-June	stratification	30-60 days	yes	spring
Carpinus caroliniana	weakly tolerant	nutlet	August-October	stratification	41 deg for 60 days	none	spring
Carya aquatica	highly tolerant	nut	September-November	stratification	33-40 deg for 30-150 days	yes	spring
Carya cordiformis	intermediate	nut	September-October	stratification	33-40 deg for 30-150 days	yes	spring
Carya myristiciformis	tolerant	nut	September-October	stratification	33-40 deg for 30-150 days	yes	spring
Carya ovata	intolerant	nut	September-October	stratification	33-40 deg for 30-150 days	none	spring

Table 5. Seedling characteristics of dominant native trees in East Texas riparian areas.

Scientific Name	Common Name	Max Height/Diameter	General Habitat Requirements	Shade Tolerance
Cornus florida	flowering dogwood	40 feet/ 18 inches	70 deg F avg, 30-80 inches of rain, deep, moist soils along streambanks to well-drained, light upland soils. Best with pH 6-7.	very tolerant
Cornus foemina	stiff dogwood	15 feet tall	swamps and floodplain forests	intermediate
Diospyros virginiana	common persimmon	70 feet/ 24 inches	95 deg F avg max temperature, 10 deg F avg min temperature, 48 inches of rain, grows best on alluvial sites with clay and heavy loams, river terraces, and first bottoms.	tolerant
Fagus grandifolia	American beech	120 feet/ 5 feet	40-70 deg F, 30-50 inches of rain, loamy soils and soils with high humus content, low elevations up to 6,000 feet.	very tolerant
Fraxinus pennsylvanica	green ash	120 feet/ 30 inches	55 deg F winter avg, 80 deg F summer avg, 15-60 inches of rain, grows best on fertile, moist, well-drained soils.	intermediate
Gleditsia aquatica	water locust	80 feet/ 3 feet	65 deg F winter avg, 90 deg F summer avg, 50-70 inches of rain, river swamps, floodplains, swamps	intermediate
Liquidambar styraciflua	sweetgum	150 feet/ 5 feet	50 deg. Avg. Min, 100 deg max F, 40-60 inches of rain, very tolerant of different soils but best on rich moist alluvial clay and loam soils of river bottoms	intolerant
Magnolia grandiflora	southern magnolia	60-80 feet/2-3 feet	warm-temperate/semi-tropical, 50s avg min, 80-100max, 50-60 inches of rain, best in moist well-drained soils along streams or near swamps.	tolerant
Nyssa aquatica	water tupelo	110 feet/3-4 feet	45 deg. F Winter avg, 81 deg F summer avg, 52 inches of rain avg, grows in low, wet flats or sloughs and deep swamps in floodplains of alluvial streams	intolerant

Table 6. Seedling characteristics of dominant native trees in East Texas riparian areas continued.

Scientific Name	Flood Tolerance	Fruit Type	Fruiting Period	Germination Requirement	Chilling Requirement (stratification only)	Photoperiod Requirement	Germination Period
Cornus florida	very intolerant	drupe	October	stratification	41 deg for 120 days	yes	spring
Cornus foemina	tolerant	drupe	June-August	stratification	41 deg for 60 days	yes	spring
Diospyros virginiana	intermediate	berry	September-November	stratification	37-50 deg for 60-90 days	none	spring
Fagus grandifolia	least tolerant	nut	September-November	stratification	37-41deg for 90 days	none	spring
Fraxinus pennsylvanica	generally tolerant	samara	September-October	stratification	32-41 deg for 210 days	none	spring
Gleditsia aquatica	highly tolerant	raceme	September-December	scarification	1-2 hours in sulfuric acid	yes	spring
Liquidambar styraciflua	moderately tolerant	capsule	September-November	none		none	spring
Magnolia grandiflora	weakly tolerant	follicle	August-November	stratification	32 to 41 deg for 90 to 180 days	none	spring
Nyssa aquatica	most tolerant	drupe	September-October	stratification	35-40 deg for 30 days	yes	spring

Table 7. Seedling characteristics of dominant native trees in East Texas riparian areas.

Scientific Name	Common Name	Max Height/Diameter	General Habitat Requirements	Shade Tolerance
Nyssa sylvatica	black tupelo	120 feet/ 4 feet	38 deg F winter avg, 74 deg F summer avg, 49 inches of rain avg, grows on well-drained light textured soils on second bottoms and high flats of silty aluminum	tolerant
Ostrya virginiana	eastern hophornbeam	50-60 feet/ 12 inches	56 deg F winter avg, 84 deg F summer avg, 64 inches of rain, found on minor stream terraces, outwashes in major bottoms, and in uplands. Loamy poor- to well-drained soils are preferred.	very tolerant
Pinus taeda	loblolly pine	150 feet/50-60 inches	36-63 deg F winter avg, 75-100 deg F summer avg, 40-60 inches of rain, grows on wide variety of soils but is best where there is poor surface drainage, a deep surface layer, and a firm subsoil	intolerant
Planera aquatica	water elm	50 feet	Swamps, streams, lakes, alluvial flood plains	tolerant
Quercus falcata	cherrybark oak	130 feet/ 5 feet	65-70 deg F yearly avg, 50-60 inches of rain, found on first bottoms, well-drained terraces, colluvial sites	intermediate
Quercus lyrata	overcup oak	100 feet/ 3 feet	30 deg F winter avg, 95 deg summer avg, 45-60 inches of rain, found in the lower, poorly drained parts of first bottoms and terraces	intermediate
Quercus michauxii Nutt.	swamp chestnut oak	120 feet/ 7 feet	Avg. annual temperature of 60-70 deg. F, 50-60 inches of rain, prefers well-drained loamy first bottom ridges and silty clay, loamy terraces, and colluvial sites in bottomlands.	intolerant

Table 8. Seedling characteristics of dominant native trees in East Texas riparian areas continued.

Scientific Name	Flood Tolerance	Fruit Type	Fruiting Period	Germination Requirement	Chilling Requirement (stratification only)	Photoperiod Requirement	Germination Period
Nyssa sylvatica	weakly tolerant	drupe	September-October	stratification	35-40 deg for 30 days	yes	spring
Ostrya virginiana	least tolerant	nut	August-November	stratification	68-86 deg for 60 days, then 40 deg for 140 days, then 50-77 deg for 30-40 days	yes	spring
Pinus taeda	moderately tolerant	cone	September-October	stratification	37-41 deg for 30-90 days	yes	spring
Planera aquatica	most tolerant	achene	April-May	none		none	spring
Quercus falcata	weakly tolerant	nut	August-December	stratification	32-41 deg for 60-120 days	yes	spring
Quercus lyrata	highly tolerant	nut	August-December	none		yes	spring
Quercus michauxii Nutt.	weakly tolerant	nut	August-December	none		yes	spring

Table 9. Seedling characteristics of dominant trees in East Texas riparian areas.

Scientific Name	Common Name	Max Height/Diameter	General Habitat Requirements	Shade Tolerance
Quercus nuttallii	nuttall oak	120 feet/ 3 feet	45 deg. F Winter avg, 80 deg F. Summer avg, 50-65 inches of rain, grows well on heavy, poorly drained alluvial clay soils on first bottoms, and clay ridges	intolerant
Quercus phellos	willow oak	120 feet/ 3 feet	35-55 deg F winter avg, 75-80 deg F summer avg, 40-60 inches of rain, grows best on alluvial soils	intolerant
Rhamnus caroliniana	Carolina buckthorn	30 feet/ 6 inches	Bottomlands, ravines, stream banks, and stream bottoms.	tolerant
Salix nigra	black willow	140 feet/ 4 feet	60 deg F winter avg, 93 deg F summer avg, 51 inches of rain, prefers river margins, swamps, sloughs, swales, and banks of bayous, gullies, and drainage ditches.	very intolerant
Sassafras albidum	sassafrass	100 feet/ 6 feet	55 deg F winter avg, 80 deg F summer avg, 30-55 inches of rain, prefers first bottom ridges	intolerant
Taxodium distichum	baldcypress	120 feet/ 5 feet	Avg. minimum temperature 40 deg F in the south, 30-64 inches of rain per year, usually found on very wet soils made of muck, clay, or fine sand, but grows best on deep, fine sandy loams with moderate drainage	intermediate
Ulmus americana	American elm	120 feet/ 5 feet	60 deg F avg winter temperature, 80 deg F avg summer temperature, 35-60 inches of rain, is most common on silty-clay loams on first bottoms or terraces.	intermediate

Table 10. Seedling characteristics of dominant native trees in East Texas riparian areas continued.

Scientific Name	Flood Tolerance	Fruit Type	Fruiting Period	Germination Requirement	Chilling Requirement (stratification only)	Photoperiod Requirement	Germination Period
Quercus nuttallii	moderately tolerant	nut	August-December	stratification	32-41deg for 60-90 days	yes	spring
Quercus phellos	moderately tolerant	nut	August-December	stratification	32-41 deg for 30-90 days	yes	spring
Rhamnus caroliniana	Tolerant	drupe	August-October	none		none	spring
Salix nigra	most tolerant	capsule	June-July	none		yes	spring
Sassafras albidum	least tolerant	raceme	August-September	stratification	41 deg for 120 days	none	spring
Taxodium distichum	most tolerant	cone	October-December	scarification and stratification	41 deg for 90 days	yes	spring
Ulmus americana	moderately tolerant	samara	February-June	stratification	41 deg for 60-90 days	yes	spring

Table 11. Seeding characteristics of dominant native shrubs in East Texas riparian areas.

Scientific Name	Common Name	Max Height/Diameter	General Habitat Requirements	Shade Tolerance
<u>Shrubs</u>				
Amorpha fruticosa	indigobush		Stream and pond edges, gravel bars, open woods	intolerant
Asimina parviflora	dwarf pawpaw		Sands, sandy loams, or sandy alluvium of rich woods, alluvial terraces, and upland dry woods	tolerant
Baccharis halimifolia	eastern baccharis		occurs in right-of-ways, open forests, new plantations, shore hammocks, sea beaches, salt marshes, and low grounds inland.	intermediate
Callicarpa americana	American beautyberry		grows best in moist sites under pine canopies	intermediate
Cephalanthus occidentalis	buttonbush		Found in margins of streams, rivers, ponds, and marshes, as well as wet meadows, ditches, and freshwater swamps.	tolerant
Crataegus marshallii	parsley hawthorn		Found along swamps and streams and in open moist forests	tolerant
Euonymus americana	strawberry bush		moist forests, deciduous woods, sandy thickets, swamps, woodlands, shady edges, ravines, stream sides	tolerant
Halesia diptera	two-wing silver-bell		rich woods; swamp margins, partial shade, acid-based soils	intermediate
Hamamelis virginiana	witch-hazel		found along forest margins and streams, open or shady habitat	intermediate

Table 12. Seedling characteristics of dominant native shrubs in East Texas riparian areas continued.

Scientific Name	Flood Tolerance	Fruit Type	Fruiting Period	Germination Requirement	Chilling Requirement (stratification only)	Photoperiod Requirement	Germination Period
<u>Shrubs</u>							
Amorpha fruticosa	Tolerant	pod	August	none		yes	spring
Asimina parviflora	Tolerant	berry	August-September	stratification	41 deg for 60 days	none	spring
Baccharis halimifolia	very tolerant	achene	September-November	none		yes	spring
Callicarpa americana	occasionally tolerant	drupe	August-January	none		yes	spring
Cephalanthus occidentalis	most tolerant	nutlets on fruiting head	August-January	none		yes	spring
Crataegus marshallii	moderately tolerant	pome	September-October	scarification and stratification	acid scarification followed by stratification at 39 deg F for 5 months	yes	spring
Euonymus americana	occasionally tolerant	capsule	September-December	stratification	41 deg. F. for 139 days	none	spring
Halesia diptera	Tolerant	drupe	September-December	stratification	moist at 56-86 deg for 60-120 days, then cold at 33 to 41 deg for 60-90 days	none	spring
Hamamelis virginiana	intolerant	capsule	October-November	stratification	2 months of warm, 2 months of cold, then 2 months of warm and 4 months of cold.	yes	spring

Table 13. Seeding characteristics of dominant native shrubs in East Texas riparian areas.

Scientific Name	Common Name	Max Height/Diameter	General Habitat Requirements	Shade Tolerance
Ilex glabra	gallberry		prefers acid soils in flatwood forests	intolerant
Ilex opaca	American holly		bottomland forests and swamp edges	tolerant
Ilex vomitoria	yaupon		grows in well-drained sandy soils as well as nontidal forested wetlands, salt and brackish marsh edges, and sandy hammocks	intermediate
Ligustrum spp.	privet		grows best in mesic soil and abundant soil	tolerant
Lindera benzoin	common spicebush		low woods, swamp margins, streamsides	intermediate
Magnolia virginiana	sweetbay		Swamps, bays, low wet woods, savannahs	intermediate
Morus rubra	red mulberry		well-drained, moist soils along streams, 40-80 inches of rain per year	tolerant
Myrica cerifera	waxmyrtle		dunes, bog margins, right-of-ways, open or shady habitats	intolerant
Myrica heterophylla	bayberry		Bogs, stream, pond and lake margins, moist regions of mixed deciduous forests, pine flatlands near pitcher-plant bogs, swamps	tolerant

Table 14. Seeding characteristics of dominant native shrubs in East Texas riparian areas continued.

Scientific Name	Flood Tolerance	Fruit Type	Fruiting Period	Germination Requirement	Chilling Requirement (stratification only)	Photoperiod Requirement	Germination Period
Ilex glabra	very tolerant	drupe	September-February	stratification	68-86 deg for 60 days, then 41 deg for 60 days	yes	spring
Ilex opaca	weakly tolerant	drupe	September-April	stratification	68-86 deg for 60 days, then 41 deg for 60 days	yes	spring
Ilex vomitoria	Tolerant	drupe	October-November	stratification	68-86 deg for 60 days, then 41 deg for 60 days	yes	spring
Ligustrum spp.	weakly tolerant	drupe	October-February	none		none	spring
Lindera benzoin	intermediate	berry	August-October	stratification	41 deg for 105 days	none	spring
Magnolia virginiana	very tolerant	follicle	June-October	stratification	32-41 deg for 90-180 days	none	spring
Morus rubra	weakly tolerant	drupe	June-August	stratification	33-41 for 30-90 days	yes	spring
Myrica cerifera	Tolerant	drupe	August-October	stratification	34-40 deg for 60-90 days	yes	spring
Myrica heterophylla	Tolerant	drupe	June-October	stratification	34-40 deg for 60-90 days	yes	spring

Table 15. Seeding characteristics of dominant native shrubs and herbaceous plants in East Texas riparian areas.

Scientific Name	**Common Name**	**Max Height/Diameter**	**General Habitat Requirements**	**Shade Tolerance**
Rhododendron canescens	wild azalea		acid bogs	tolerant
Rhododendron oblongifolium	Texas azalea		sandy woods, stream banks, and bog margins	tolerant
Sabal minor	dwarf palmetto		lowlands, swamps, river terraces, floodplains	tolerant
Sambucus canadensis	elderberry		alluvial forests, bogs, ditches, old fields, edges of riparian thickets	intolerant
Styrax americana	American snowbell		moist woods, wooded stream banks, swamps	tolerant
Toxicodendron vernix	poison-sumac		wet soils in swamps, bogs, seepage slopes, and frequently flooded areas	tolerant
Vaccinium arkansanum	Arkansas blueberry		Swamps and pine barrens, wet woods and the edges of lakes	intermediate
Viburnum nudum	possumhaw		savannas, low wet woods, and bogs	intermediate
Herbaceous				
Arundinaria gigantea	switchcane		open river and stream banks, shrub bogs, sloughs, and bayous	intolerant
Chasmanthium latifolium	inland seaoats		along streams, wet forests, and bluffs in sun and shade	generally tolerant

Table 16. Seeding characteristics of dominant shrubs and herbaceous plants in East Texas riparian areas continued.

Scientific Name	Flood Tolerance	Fruit Type	Fruiting Period	Germination Requirement	Chilling Requirement (stratification only)	Photoperiod Requirement	Germination Period
Rhododendron canescens	moderately tolerant	capsule	May-August	none		yes	spring
Rhododendron oblongifolium	moderately tolerant	capsule	May-August	none		yes	spring
Sabal minor	very tolerant	berry	September-January	none		yes	spring
Sambucus canadensis	very tolerant	drupe	July-September	stratification	68-86 deg for 60 days, then 41 deg for 90-150 days	yes	spring
Styrax americana	occasionally tolerant	berry	September-October	stratification	3 months of cold stratification	none	spring
Toxicodendron vernix	very tolerant	drupe	August-January	none		yes	
Vaccinium arkansanum	Tolerant	berry	July-August	none		yes	spring
Viburnum nudum	generally tolerant	drupe	August-December	none		none	spring
Herbaceous							
Arundinaria gigantea	generally tolerant	grain	June-August	none		none	spring
Chasmanthium latifolium	occasionally tolerant	grain	June-October	stratification	35 deg F for 21 days	yes	spring

Table 17. Seeding characteristics of dominant native herbaceous plants in East Texas riparian areas.

Scientific Name	Common Name	Max Height/Diameter	General Habitat Requirements	Shade Tolerance
Eupatorium serotinum	late boneset		most common in bottomlands, often found on dry to wet and open to partially to shady habitats	generally tolerant
Juncus effusus	soft rush		wet, open-to-semi shady ground	intolerant
Leersia oryzoides	rice cutgrass		marshes, wet wooded areas	intolerant
Onoclea sensibilis	sensitive fern		swamps, low woods, wet areas	generally tolerant
Osmunda cinnamomea	cinnamon fern		wet areas	very tolerant
Panicum dichotomiflorum	fall panicgrass		moist, disturbed soils	intolerant
Panicum virgatum	switchgrass		low moist areas	intolerant
Paspalum urvillei	vaseygrass		low disturbed areas	intolerant
Sesbania macrocarpa	coffee bean		wet roadside ditches, fields, sand marshes, river sand bars	tolerant
Tripsacum dactyloides	eastern gamagrass		prairies, depressions, low areas	intolerant
Zizaniopsis miliacea	southern wildrice		marshes, creekbottoms, lakeshores, forms beds in wet ground or shallow water	intolerant

Table 18. Seeding characteristics of dominant native herbaceous plants in East Texas riparian areas continued.

Scientific Name	Flood Tolerance	Fruit Type	Fruiting Period	Germination Requirement	Chilling Requirement (stratification only)	Photoperiod Requirement	Germination Period
Eupatorium serotinum	generally tolerant	achene	December-February	stratification	3 weeks at 40 deg F and 35% humidity	yes	spring
Juncus effusus	generally tolerant	capsule	May-December	stratification	39-46 deg F for 270 days	yes	spring
Leersia oryzoides	always tolerant	grain	April-November	stratification	180-270 days of cool moist stratification	yes	spring
Onoclea sensibilis	generally tolerant	spore	May-October	none		yes	spring
Osmunda cinnamomea	generally tolerant	spore	May-October	none		yes	spring
Panicum dichotomiflorum	very tolerant	grain	August-September	none		yes	spring
Panicum virgatum	generally tolerant	grain	August-November	none		yes	spring
Paspalum urvillei	very tolerant	grain	July-February	none		yes	spring
Sesbania macrocarpa	tolerant	legume	November-January	scarification	45-60 minutes of acid treatment	none	spring
Tripsacum dactyloides	mild tolerance	grain	June-November	stratification	42 to 56 days at 30 deg C in the day and 20 deg C at night	yes	spring
Zizaniopsis miliacea	always tolerant	grain	April-July	none		yes	spring

Table **19**. Seeding characteristics of dominant native herbaceous plants in East Texas riparian areas.

Scientific Name	Common Name	Max Height/Diameter	General Habitat Requirements	Shade Tolerance
Vines				
Ampelopsis arborea	peppervine		wet to moist bottomland forests, along streams and rivers, and moist forest plantations	tolerant
Berchemia scandens	Alabama supplejack		swamps and wet forests, forest plantations, upland mixed forests and fencerows	tolerant
Bignonia capreolata	crossvine		canopy of bottomland forests, lowland forest plantations,upland mixed forests	high
Bignonia sempervirens	Carolina jessamine		dry to wet thickets, woods, fence rows, hammocks	tolerant
Brunnichia cirrhosa	redvine		Riverbanks, margins of lakes, edges of wet woods and thickets	tolerant
Campsis radicans	trumpet creeper		occurs on fencerows, right-of-ways, fields, and forest plantations	intolerant
Lonicera japonica	Japanese honeysuckle		invasive exotic which is extremely common on bottomland forests	tolerant
Parthenocissus quinquefolia	Virginia creeper		occurs most frequently in open mixed upland forests, but also colonizes moist sites	intermediate
Smilax glauca	cat greenbrier		forest plantations to open mature forests, dry to seasonally wet habiats	tolerant
Smilax laurifolia	laurel greenbriar		shaded woods, swamps	tolerant

Table 20. Seeding characteristics of dominant native herbaceous plants in East Texas riparian areas continued.

Scientific Name	Flood Tolerance	Fruit Type	Fruiting Period	Germination Requirement	Chilling Requirement (stratification only)	Photoperiod Requirement	Germination Period
Vines							
Ampelopsis arborea	Tolerant	berry	September-December	none		none	spring
Berchemia scandens	Tolerant	drupe	August-November	none		none	spring
Bignonia capreolata	Tolerant	capsule	June-September	none		yes	spring
Bignonia sempervirens	Tolerant	capsule	October-June	none		yes	spring
Brunnichia cirrhosa	Tolerant	achene	summer to fall	none		none	spring
Campsis radicans	Tolerant	capsule	October-February	stratification	60 days in sand at 40 deg F, 30% R.H., must use a fungicide to prevent mildew	yes	spring
Lonicera japonica	Tolerant	berry	August-March	stratification	60 days at 43 to 46 deg F	yes	spring
Parthenocissus quinquefolia	occasionally tolerant	drupe	October-February	stratification	60 days in moist sand at 40 deg F, 35% R.H., must use fungicide	none	spring
Smilax glauca	Tolerant	berry	September-October	stratification	Up to 210 days at 39 deg F	yes	spring
Smilax laurifolia	Tolerant	berry	August-October	stratification	Up to 210 days at 39 deg F	yes	spring

Table 21. Seedings characteristics of dominant native herbaceous plants in East Texas riparian areas.

Scientific Name	Common Name	Max Height/Diameter	General Habitat Requirements	Shade Tolerance
Smilax rotundifolia	common greenbrier		forest plantations to open mature forests, dry to seasonally wet habiats	intolerant
Toxicodendron radicans	poison-ivy		occurs in many habitats moist or dry, open or shady	high
Vitis aestivalis	summer grape		forest margins, occasionally on stream or river banks, young or mature forest	tolerant
Vitis rotundifolia	muscadine grape		upland and bottomland forests, young and mature forests	intermediate

Table 22. Seedings characteristics of dominant native herbaceous plants in East Texas riparian areas continued.

Scientific Name	Flood Tolerance	Fruit Type	Fruiting Period	Germination Requirement	Chilling Requirement (stratification only)	Photoperiod Requirement	Germination Period
Smilax rotundifolia	Tolerant	berry	August-September	stratification	Up to 210 days at 39 deg F	yes	spring
Toxicodendron radicans	Tolerant	drupe	August-February	scarification	30 minutes in sulfuric acid treatment	yes	spring
Vitis aestivalis	infrequently tolerant	berry	June-October	stratification	6 weeks cold stratification	none	spring
Vitis rotundifolia	Tolerant	berry	July-September	stratification	6 weeks cold stratification	none	spring

REVIEW OF RIPARIAN AREA SURVEY METHODS

Currently, on site riparian delineations utilize aerial mapping or sample plots where lines are drawn and estimates are made based on socially derived or arbitrary width criteria (Verry et al. 2004). Common associations used in Texas are BMP (best management practice), RMZ (riparian management zone), and SMZ (streamside management zone).

Based on the accepted definition of riparian area (National Research Council 2002) a classification scheme can be developed to identify and delineate the area this definition encompasses. Many of the classification, functional assessment, and delineation guidebooks that can be used for riparian areas were designed in a regulatory context specifically for wetlands. Consequently, the term "wetland" will be seen throughout the following review of survey methodologies.

Classification Techniques

There are classification guidebooks that employ a hierarchical classification system to define what an area is on the ground. These include "Classification of Wetlands and Deepwater Habitats of the United States," (Cowardin et al. 1979) "Riparian Area Management: Procedures for Ecological Inventory-With Special Reference to Riparian-Wetland Sites", (Leonard et al. 1992), "Southwestern Riparian Communities: Their Biotic Importance and Management in Arizona,"(Pase and Layser 1977) "Classification and Spatial Mapping of Riparian Habitat with Application Toward Management of Streams Impacted by Nonpoint Source Pollution" (Delong and Brusven 1991), "The Ecosystem Classification Handbook," (Hunter 1990) "SCS-BLM

Standard Ecological Site Description" and "An Energy Theory of Landscape for Classifying Wetlands" (Kangas 1990).

Classification Schemes

One type of classification methodology is one that uses a hierarchical classification system. Some guidebooks look to use a hierarchical classification to describe and inventory areas (Frissell et al. 1986). A common hierarchical classification technique used is the "Classification of Wetlands and Deepwater Habitats of the United States" by Lewis M. Cowardin, Virginia Carter, Francis Golet, and Edward Laroe. The purpose of this classification is to inventory both wetlands and deepwater habitats. The taxa are described and organized into a usable system for resource managers. The classification also looks to provide uniformity in concepts and terms (Cowardin 1979).

The classification provides hierarchical levels from the broadest (marine, estuarine, riverine, lacustrine, palustrine) to the lowest level and dominance type, which is named for the dominant plant or animal form of the area. The uphill limit of a wetland is "the boundary between land composed of predominantly hydrophytic vegetation and land with predominantly mesophytic or xerophytic vegetation." The soil boundary is found between soil which is "predominantly hydric and soil that is predominantly non-hydric." The hydrology boundary is "between land that is flooded or saturated at some time during the growing season each year and land that is not."

The system is easy to apply, particularly when aerial photos are incorporated (Gebhardt 2005**)**. The hierarchical classification units begin with the most basic and end with the most complex. The units include: 5 Systems, 8 Subsystems, 11 Classes, 28 Subclasses, an unspecified number of Dominance Types, and Modifiers. The description of the system is the water source (riverine, estuarine, etc.) The subclass is the basic water persistence feature (lower perennial, upper perennial, etc.). The class is the substrate/ vegetation form (aquatic bed, emergent wetland, rock bottom, forested wetland, etc.). The subclass is a specific substrate/vegetation type (sand, mud, broad-leaved deciduous, etc.). The dominance type is described by dominant plant/animal species (crayfish, cattail, black willow, caddis fly, etc.). The modifiers are site-specific attributes of soil, regime, water chemistry, and land alteration. Once the classification has been developed at an area of interest an aerial photo may be used to aid in developing an accurate inventory.

A classification similar to Cowardin's scheme is the "Southwestern Riparian Communities: Their Biotic Importance and Management in Arizona" by David E. Brown, Charles H Lowe, and Janet F. Hausler. Brown and Lowe (1974), Brown (1978), Brown, Lowe, and Pase (1977), and Pase and Layser (1977) formed this hierarchical classification for the world's biotic communities. The objectives of this classification are to provide a hierarchical structure for the world's biotic communities based on those factors most important in the evolution of origin, structure, and composition of all ecosystems, both wetland and terrestrial. The system recognizes plant components within an assigned ecological distribution and could lead to the species of wildlife expected to be present.

The digitized hierarchy of the world's natural ecosystems (Brown and Lowe 1974).

A. 1,000: Biogeographic (Continental) Realm
B. 1,100: Vegetation
C. 1,110: Formation-type
D. 1,111: Climatic (Thermal) Zone
E. 1,111.1: Regional Formation (Biome)
F. 1,111.11: Series (Community of generic dominants)

G. 1,111.111: Association (Community of specific dominants)

H. 1,111.1111: Composition-Structure-Phase

A) The value preceding the comma assigns the location to its biogeographic realm (1-Neartic, 2-Palaeartic, 3-Neotropical, 4-Oriental, 5-Ethopian, 6-Australian, 7- Oceanic).

B) The first value following the comma refers to all potential and/or existing vegetation that is presumed to be established naturally under the existing climate and the cessation of anthropogenic influences.

C) The second value following the comma refers to the ecological formation types or biome types. This is based on vegetation responses to integrated environmental factors, most importantly available plant moisture.

D) The third value refers to the world climatic zones (Walter 1973) in which temperature is a major of, and is found within, the zonation and formation-types.

E) The first value following the decimal refers to the sub-continental unit which is the major biotic community.

F) The second value following the decimal refers to the principal plant-animal communities within the biomes. These series are often referred to as cover types. The Society of American Foresters *Forest Land Cover Types* (Society of American Foresters 1980) is an example of this.

G) The third value following the decimal refers to distinctive plant associations based on local or regional distribution. The East Texas bottomland hardwood tree association numbers established by the Society of American Foresters (Eyre 1990) are an example. (See Appendix table B1 (Ortego 1986) to aid in illustrating East Texas cover types on the landscape.)

H) The fourth value following the decimal represents a detailed measurement and assessment quantitative structure, composition, density and other numerical determinations for dominants, understory, and associated species.

Once again, the classification is developed at an area of interest and the use of aerial photography may be an aid in developing an accurate inventory. The major difference between the Brown and Lowe (1974) and Cowardin's classification is Cowardin's focus on wetland areas which differs from Brown and Lowe's method that classify all ecosystems. Ultimately in these two classification techniques in most cases will delineate riparian areas similar to one another.

A hierarchical classification that considers riparian function and its influence on fisheries is the “Classification of Riverine Riparian Habitats for Management of Fisheries Resources” by William S. Platts, Sherman E. Jenson and Frank Smith (Platts et al. 1988). The purpose of this classification system is to recognize the preexisting state, structure, and function, along with the particular physical and biological processes. The classification is hierarchical and mappable. The system will identify the normal condition under the present setting and identify units of similar potential, even though present states are not functionally identical. The state of the direction of the moving system is determined by the time intervals occurring between state changes under known applications of stresses or benefits. The best and worst management practices can be determined. The procedure indicates limiting factors that determine the biotic carrying capacity for each state. Then, an evaluation is made about the influence of natural and artificial geomorphic-physical conditions within the watershed on the fisheries. Attainability determination in accordance with the Water Quality Act of the riverine riparian habitats in a regional perspective will be made. A valid establishment of control and treatment sites for evaluating non-point source impacts to riverine riparian habitats is included, and variables that are sensitive for identifying and assessing non-point source impacts are recognized. Riverine riparian habitats at selected hierarchical levels are described. The regional characteristics of riverine riparian complexes and their inherent capabilities and potentials will be described. A benefit of using this classification is that it is amenable to hypothesis or model testing. This classification was established to be applicable anywhere.

Similar in purpose is a guidebook by Michael D. Delong and Merlyn A. Brusven titled “Classification and Spatial Mapping of Riparian Habitat with Application Toward Management of Streams Impacted by Nonpoint Source Pollution” (Delong and Brusven 1991). They begin by describing how the management of riparian areas has been important in reducing the instream effects produced by agricultural nonpoint source pollution. Well structured riparian habitats serving as a buffer have the potential to reduce nonpoint source pollutants in rivers and lakes by filtering the surface runoff from field to stream. Based on this function of the riparian area, the classification system has been developed to include the key characteristics of riparian habitat, vegetation type, height, width, riparian and shoreline bank slope, and land use, all of which are classified using discrete categorical units. The classification distinguishes seven riparian vegetation types, which are determined by dominant plant type. The riparian and shoreline bank slope, with the riparian width and height, constitute five categories. Classification by discrete units allows for ready digitizing of information for production of spatial maps using GIS. The classification system was simple to use during field applications and provided a good inventory of riparian habitat (Gebhardt et al. 2005). This classification system can integrate the spatial maps of the riparian classification and watershed characteristics to produce a tool used as an aid in making better informed management decisions for mitigating off-site impacts of agricultural nonpoint source pollution.

Ecological Based Guidebooks

There are guidebooks that call for procedures that collect baseline data to determine the current ecological state, and the potential of restoration. This is found in "Riparian Area Management: Procedures for Ecological Inventory-With Special Reference to Riparian-Wetland Sites" (Leonard et al. 1992) by Steve Leonard, George Staidl, Jim Fogg, Karl Gebhardt, Warren Hagenbuck, and Don Prichard. The purpose of this guidebook is to give field procedures for describing ecological site information. The ecological site information consists of the interaction between soils, climate, hydrology, and vegetation for riparian-wetland resources and uplands. This information may be used in BLM's planning process, resource evaluations, and other riparian resource applications. Maintenance and permanence of baseline data is a component of the guidebook. This document "is intended to be used in conjunction with, not as a replacement for, guidance provided in the National Range Handbook Manual H-4410-1, National Range Handbook, National Soils Handbook (U.S. Department of the Interior 1990), Soil Survey Manual and other appropriate technical references." This procedure provides the framework methodology on how to collect, compile, store, and evaluate the data obtained in order to determine current ecological states and the potential for both riparian and upland areas. This technique utilizes an interdisciplinary approach for ecological inventory at the beginning in order to obtain soil, vegetation, hydrology, and biological information about the site for management use on public lands. Documentation and data permanence begin with coordinated resource inventory and the interdisciplinary team, the utilization of the soil survey map unit concept, the development of a soil and ecological site correlation, identification of present vegetation, collection of hydrologic information, and concluding with the ecological site description content. A benefit of this technique is the permanent record of ecological site information. This information can then be used to determine how different management practices are performing toward achieving the set goals. This baseline information also allows for the evaluation of met objectives.

Another resource is the SCS-BLM Standard Ecological Site Description (U.S. Department of the Interior 1990)**.** The objectives in the National Range Handbook (SCS) as supplemented by BLM Manual Handbook J-4410-1 National Range Handbook include procedures for preparing standardized ecological site descriptions. The application of this procedure requires a team of specialist or experienced personnel (Gebhardt et al. 2005). This site description develops an end product that is a very useful document for management purposes (Gebhardt et al. 1990). The guidebook supplies range site descriptions that include unique names, physiographic features, climatic features, vegetation ecology and production, soils, and management interpretations. The description is a universal application to rangeland, woodland, and native pasture.

The "Ecosystem Classification Handbook" by Wendel J. Hann and Mark E. Jensen is a procedure that integrates data inventory and the analysis of terrestrial and riparian habitats into a complete and flexible hierarchical classification system. The procedure is a means for the collection, management, and interpretation of data. The procedure is easy to use, especially when aerial photography is available (Gebhart et al. 1990). This procedure was developed to exhibit applicability throughout the United States, although it could be applicable elsewhere.

The Energy Theory

"An Energy Theory of Landscape for Classifying Wetlands" by Patrick C. Kangas uses the environmental energy sources to determine ecosystem characteristics. Landscapes are classified by the spatial expression of the input of energy. There are four basic types of spatial energy distributions described: energy sheet, energy point, energy front, and energy line. Six basic categories called ecosystem forms (zone, string, island, strip, background, and center) are used to describe the orientation of energy (Table 23). The shapes of land surfaces described here are recognizable on aerial photos and land use maps.

Backgrounds are formed by power sheets.

Centers may develop within backgrounds. This arises from point sources, or the concentration of sheet energy. Elevation is a feature that distinguishes the centers in the background.

Zones form in response to frontal energies. This ecosystem occurs as rocky intertidal shores, beach and barrier island vegetation, coral reefs, salt marshes, and mangroves.

String and **island** are relatively small features within broad zones. They are similar to centers in size but are distinguished by the orientation of the direction of the frontal energy.

Strips are formed by energy lines through the landscape. An example of this would be the river and floodplain system where the energy line is the channel flow of the river, and will overflow during flooding.

Table 23. A Classification of Ecosystem Forms. *Source: adapted from Kangas (1990).*

Form	Shape	Orientation of energy
Generated by frontal energies		
Zone	Rectangular	Perpendicular
String	Linear	Perpendicular
Island	Ovoid, curved, or pointed	Pointed in direction of Energy movement
Strip	Linear	Parallel
Generated by sheet energies		
Background	Undifferentiated	No orientation
Center	Circular to irregular	Centrally located

The advantage of this classification scheme is the focus on the hydrology/geology interaction. Kangas (1990) states the advantage of this classification is that it is based on energy which approaches the level at which ecosystems operate, and the complex interactions between the physical environment and living systems. This reinforces Brinson (1990) who suggests hydrology and the interaction with the local geology are the most important factors in developing and maintaining the dynamic riparian floodplain. In the Southeast U.S. this geomorphology develops ridge-and-swale topography with vegetation patches that alternate from species adapted to long hydro period on topographic low areas and grading into more mesic species on topographic high areas.

This lends great insight into functioning riparian systems, and would be an excellent tool in restoration efforts, but may be too complicated for delineation. What can be gleaned here for the purpose of delineation are the hydrologic regime and the vital role it plays in the development and dynamic maintenance of the riparian area.

Functional Assessments

Verry et al (2004) linked a functional definition to the delineation of the riparian area. They proposed the riparian area be delineated based on the geomorphology of the stream. This would include the width of the floodplain or the flood prone area plus an additional 30 meters (98 feet) to include the important upland functions that strongly interact with the floodplain. This delineation method would establish a line between where wetland hydrology is present and not present and add 30 meters in the upslope direction.

There are many guidebooks that give methodology to assess function. These include "Hydrogeomorphic Functional Assessment" (HGM), Regional HGM guidebooks, "HGM Light", "California Rapid Assessment Method for Wetlands" (CRAM), Texas Parks and Wildlife's, "Wildlife Habitat Appraisal Procedure" (WHAP), "Ohio Rapid Assessment Method for Wetlands" (ORAM) and the "Classification of Riverine Riparian Habitats for Management of Fisheries Resources." There are guidebooks which address wetland function from the standpoint of their hydrogeomorphic (HGM) classification. One guidebook is titled "A Guidebook for Application of Hydrogeomorphic Assessments to Riverine Wetlands" by Mark M. Brinson, Richard D. Rheinhardt, F. Richard Hauer, Lyndon C. Lee, Wade L. Nutter, R. Daniel Smith, and Dennis Whigham. The HGM guidebook presents technical guidelines for applying functional capacity indices at a site specific scale to determine a wetlands function. This guidebook provides the basis for applying the hydrogeomorphic (HGM) approach for wetland functional assessment to riverine wetlands. 'Riverine' refers to a class of wetland that has a floodplain or riparian geomorphic setting (Brinson 1993). The other geomorphic settings are depressional, slope, mineral soil and organic soil flats, and estuarine and lacustrine fringe.

The hydrogeomorphic classification has been used to understand and evaluate wetland ecosystems. The HGM classification system uses three components: water source, geomorphic setting, and hydrodynamics. The water source is described as groundwater, precipitation, or surface water depending on the value each plays toward the function of the wetland. The geomorphic setting is the wetland's position on the landscape and how that position is related to the source of water. The hydrodynamics include the frequency, magnitude, and duration of vertical fluctuations from precipitation and groundwater, unidirectional fluctuations by riverine flooding, and bidirectional fluctuations from tidal waves.

The functions defined in this guidebook are rated on a scale from "0" to"1" where a value of "0" would indicate a complete lack of function and a value of "1" would indicate a function within the range of the wetland standard. The HGM guidebook for the riverine system includes fifteen functions spread within four functional areas.

- **Hydrologic**
  - Dynamic Surface Water Storage
  - Long-Term Surface Water Storage
  - Energy Dissipation
  - Subsurface Storage of Water
  - Moderation of Groundwater Flow or Discharge.

- **Biogeochemical**
  - Nutrient Cycling
  - Removal of Imported Elements and Compounds
  - Retention of Particulates
  - Organic Carbon Export.

- **Plant Habitat**
  - Maintain Characteristic Plant Communities
  - Maintain Characteristic Detritus Biomass.

- **Animal Habitat**
  - Maintain Spatial Structure of Habitat
  - Maintain Interspersion and Connectivity
  - Maintain Distribution and Abundance of Invertebrates
  - Maintain Distribution and Abundance of Vertebrates.

Similar to the “Wetland Delineation Manual,” regional supplement guidebooks have been developed to address regional wetland characteristics. “A Regional Guidebook for Applying the Hydrogeomorphic Approach to the Functional Assessment of Forested Wetlands in Alluvial Valleys of East Texas” (Williams et al. 2010) will be available soon (under review). Currently the most applicable (although not in the reference domain) regional guidebook is “A Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Forested Wetlands in the West Gulf Coastal Plain Region of Arkansas”.

The California Rapid Assessment Method (CRAM) and the Ohio Rapid Assessment Method (ORAM) procedures utilize worksheets that direct an individual in the field to check boxes, select points to be given, or circle yes/no for the most applicable answer based on current site conditions (CRAM 2008, ORAM 2001). Once each question has been answered a quantitative rating is calculated. Based on this rating a wetland can be assigned a function value. These methods were created to be rapid and easy to use. It is debatable whether the HGM procedure or a CRAM/ORAM type procedure will produce a more accurate representation of how a wetland functions.

The Texas Parks and Wildlife’s, Wildlife Habitat Appraisal Procedure (WHAP) was developed to allow a qualitative assessment of wildlife habitat for various land types statewide without imposing significant time requirements in terms of field work and data analysis (Texas Parks and Wildlife Service 1998). The purpose of WHAP is intended to assess impacts on wildlife populations from development related projects, to begin base line data prior to potential changes in habitat conditions, to compare an area of land for proposed land acquisition or mitigation, and to assess current general habitat quality and the potential for wildlife management on areas of land covering a vast geographical expanse.

The first section evaluates key components which contribute to the ecological condition of the area and determines overall suitability for wildlife. Habitat quality values are generated and combined with acreage figures to provide available Habitat Units. This section leads to a methodology for assessing habitat impacts along with the calculation to determine total mitigation requirements. The second section covers the presence or absence of protected flora and fauna. The third section addresses acquisition priority and management strategies. Scores derived from each section may be incorporated into a summary for the area appraised. The WHAP method is based on the following assumptions: "1) that vegetation structure including species composition and physiognomy is itself sufficient to define the habitat suitability for wildlife; 2) that a positive relationship exists between vegetation diversity and wildlife species diversity; 3) that vegetation composition and primary productivity directly influence population densities of wildlife species."

WHAP is generally biased towards higher indices for bottomland hardwood forest. The WHAP does not evaluate habitat quality in relation to specific wildlife species. Such species-oriented evaluations generally require more detailed life history requirements, which may be deficient in describing the overall ecological conditions as well as having a limited geographical range of applicability.

Wetland Delineation

The guidebook that is used to delineate jurisdictional wetlands under Section 404 of the Clean Water Act is the Corps of Engineers 1987 "Wetlands Delineation Manual." In addition, because of regional wetland differences, supplements have been developed to aid in more accurate and efficient delineation. The “Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Atlantic and Gulf Coastal Plain Region” would be applicable to the East Texas Pineywoods Region (US Army Corps of Engineers 2008).

The vital piece of information needed in order to survey the riparian area is the location of the boundary. Cowardin (1979) defines the “upland limit” using three criteria, vegetation, soils, and hydrology. The vegetation criterion is defined as the boundary between land with predominantly hydrophytic cover and land with predominantly nonhydrophytic cover. The hydric soil criterion is defined as the boundary between soil that is predominantly hydric and soil that is predominantly nonhydric. Third, using hydrology, defined as the boundary between land that is flooded or saturated at some time during the growing season each year and land that is not. This guidance for boundary determination is very similar to the 1987 Corps of Engineers “Wetlands Delineation Manual,” which employs virtually the same three parameter approach. The three parameter approach delineates the wetland not the riparian area. The riparian area will continue up the landscape beyond the three parameters used in the “Wetland Delineation Manual.” The riparian area will include a portion of the water body, the extant of the floodplain, and extend into the adjacent hill slope (Illhardt et al. 2000).

The Corps of Engineers 1987 Wetlands Delineation Manual presents technical guidelines for the identification and delineation of jurisdictional wetlands (Environmental Laboratory 1987). The guidebook utilizes a three parameter approach to identify and delineate wetlands. The three parameter approach is used because the interaction of hydrology, soil, and vegetation affect the developmental characteristics unique to wetlands. Wetlands are generally bordered by both aquatic habitats and non-wetlands. Guidelines are presented identifying wetlands, deepwater habitat, and non-wetlands, yet the procedure for the application of technical guidelines for non-wetlands and deepwater habitat were not included in the guidebook. The guidebook defines wetlands as:

> **"those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas."**

Deepwater aquatic habitats are defined as:

> **"areas that are permanently inundated at mean annual water depths >6.6 feet or permanently inundated areas <6.6 feet in depth that do not support rooted-emergent or woody plant species."**

Non-wetlands defined:

> **"uplands and lowland areas that are neither deepwater aquatic habitats, wetlands, nor other special aquatic sites. They are seldom or never inundated, or if frequently inundated, they have saturated soils for only brief periods during the growing season, and, if vegetated, they normally support a prevalence of vegetation typically adapted for life only in aerobic soil conditions".**

An area is a wetland when it has wetland vegetation, wetland hydrology, and hydric soil. Wetland vegetation is termed 'hydrophytic vegetation'. Hydrophytic vegetation is defined as:

> **"the sum total of macrophytic plant life that occurs in areas where the frequency and duration of inundation or soil saturation produce permanently or periodically saturated soils of sufficient duration to exert a controlling influence on the plant species present."**

The term wetland hydrology is defined as the term ‘wetland hydrology’ “encompasses all of the hydrologic characteristics of areas that are periodically inundated or have soils saturated to the surface at some time during the growing season.”

Hydric soils are defined as the result of the

> **“influence of periodic or permanent inundation or soil saturation for sufficient duration to affect anaerobic conditions. Prolonged anaerobic soil conditions lead to a reducing environment, thereby lowering the soil redox potential. This results in chemical reduction of some soil components (e.g., iron and manganese oxides), which leads to development of soil colors and other physical characteristics that usually are indicative of hydric soils.”**

Regional supplement guidebooks have been developed to address regional wetland characteristics and improve the efficiency of the delineation procedures. For the Sabine River Basin the Interim Regional Supplement to the 1987 Corps of Engineers Wetland Delineation Manual: Atlantic and Gulf Coastal Plain Region would be used (U. S. Army Corps of Engineers. 2008). The development of Regional Supplements is part of a nationwide effort to address regional wetland characteristics and improve the accuracy and efficiency of wetland-delineation procedures.

The commonality found with all the mentioned classification and survey methodologies is the hydrologic regime creating and maintaining the riparian area. Interim Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Atlantic and Gulf Coastal Plain Region is a guidebook that gives technical guidance to identify and delineate wetland hydrology. A section of the delineation manual can be used as a tool to identify a starting point where a line can be drawn and extended beyond.

RIPARIAN BOUNDARY DELINEATION

Upon review of the current methodologies, the standard commonality is in the need to understand and delineate the hydrologic regime which creates and maintains the riparian area. Accurate hydrologic information associated with detailed elevation data through LIDAR could identify with some level of accuracy where on the landscape wetland hydrology is present in frequency and duration. This would not be definitive because of the differences in the rate at which water drains through different soil textures and landscape features. Although through advanced modeling soil texture could be included by using soil classification data readily available in soil surveys and GIS shape files (SSURGO Data), which may need some verification in the field to ensure accuracy.

The regional wetland delineation manual requires three parameters be met in order for the site to be a jurisdictional wetland (a Waters of the U.S.). Figure 4 illustrates a simplistic view of where these parameters reach on the upslope in the typical riverine floodplain of the southeastern U.S. The hydric soil parameter is generally the first to drop off when moving upslope, which is generally where the jurisdictional wetland boundary would be located. For the illustration in (Figure 4) the hydric soil boundary would be the jurisdictional wetland boundary. When applying the definition of riparian by (National Research Council 2002) the jurisdictional approach will not encompass the riparian area as defined. It is the hydrologic regime that creates the environmental condition to develop a riparian area (Naiman and Decamps 1997). The hydric soil is a readily observable indication of wetland hydrology. The hydric soil boundary may be used to set a line in which some distance in upslope direction can be included to encompass the components included in riparian area definition. Verry et al. (2004) delineates the riparian area by identifying the flood-prone area and moving 30 meters (98 feet) in the upslope direction.

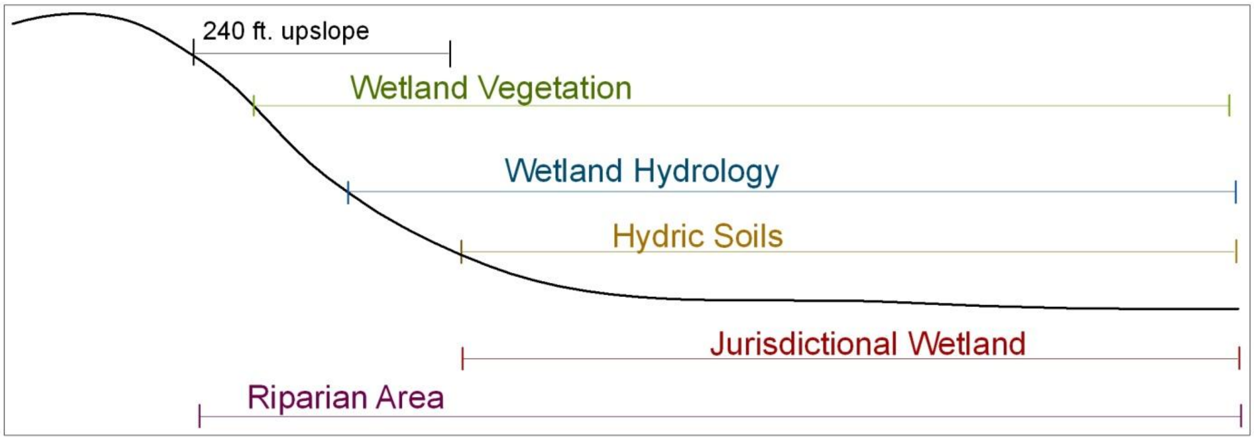

Figure 4. Diagram illustrating the composition of the riparian area in comparison to the jurisdictional wetland based on site potential vegetation height.

A portion of the adjacent upland or terrestrial ecosystem is a component of the riparian area (Gregory et al. 1991). A fundamental aspect of riparian ecology is the inputs of allochthonous material from the upland and floodplain vegetation (Brinson et al. 1984). The vegetation present on the section of land on the upslope side beyond the hydric soil boundary will account for allochthonous inputs of detritus material into the floodplain as well as function in bank stabilization (CRAM 2008). This vegetation composition upslope beyond the hydric soil boundary below the Toledo Bend Reservoir is mainly under forest management practices. As a result the land is dominated with *Pinus spp.* (Loblolly pine, shortleaf pine and longleaf pine) plantations with the occasional mixed *Pinus spp.-Quercus spp* stand. Mature *Pinus spp*. has the potential to grow to 100-120 ft. in height similar to the *Quercus spp.* growing to 100-110 ft. Schopmeyer (1974). The CRAM method distinguishes the riparian area as extending laterally up the upslope a distance equal to twice the Site Potential Vegetation Height. By knowing the dominant vegetation adjacent to the hydric soil boundary, in this case *Pinus spp*., the upslope riparian boundary can be defined. The potential height of the *Pinus spp*. is 120 feet, so by using the CRAM method, 120 feet is multiplied by two to obtain 240 feet width from the edge of hydric soil boundary. This marks the outer boundary of the riparian area (Figure 4). We propose riparian area delineation based on the hydric soil boundary plus two times the Site Potential Vegetation Height. This point on the landscape may be similar to Verry's method of locating the flood-prone boundary and adding to that boundary a width of 98 feet. Because hydric soils data is easily available in surveys and GIS sources, as well as verifiable in the field, it makes more practical sense to use the hydric soil boundary for establishing where to add the upslope width. The "Delineation Manual" can be used as a tool to identify the hydric soil boundary in the field. Once the soil hydric soil boundary has been delineated 240 feet in width is added in the upslope direction. This approach may work for forested riparian areas adjacent to high order streams. The two-times site potential vegetation high beyond the hydric soil boundary may be too large for low order or intermittent streams.

STUDY SITE

Sabine River: Toledo Bend Reservoir

The study area is along the Sabine River directly below the Toledo Bend Reservoir (Figure 5). This section of the Sabine River is located within the Pineywoods Ecoregion (Figure 1). The Pineywoods Ecoregion includes approximately 15,000,000 acres of the eastern portion of the state (Correll and Johnston 1996). The eastern boundary is determined by the Arkansas and Louisiana State lines. The Sabine River represents a major section of the border between Louisiana and Texas. The Pineywoods are situated in West Gulf Coastal Plain Physiographic Province of North America (Bureau of Economic Geology 1996).

Parent material is comprised primarily of unconsolidated sand and mud. The Pineywoods Ecoregion has high humidity, hot summer temperatures and cool winter temperatures indicative of the humid, sub-tropic eco-climatic zone (Bailey 1995). Average daily maximum temperatures range from a high of about 94 degrees F. in August to about 55 degrees F. in January (NRCS 1995). Average daily minimum temperatures range from about 72 degrees F. in July to about 39 degrees F. in January. Average annual rainfall is between 46 to 53 inches. The monthly distribution of rainfall is generally even. Mild droughts occur usually during late summer to early fall (Chang et al. 1980). Slightly greater amounts of rainfall occur during the winter and early spring. Tropical storms periodically enter the Pineywoods from the Gulf of Mexico during the summer and fall resulting in short periods of heavy rain and high winds.

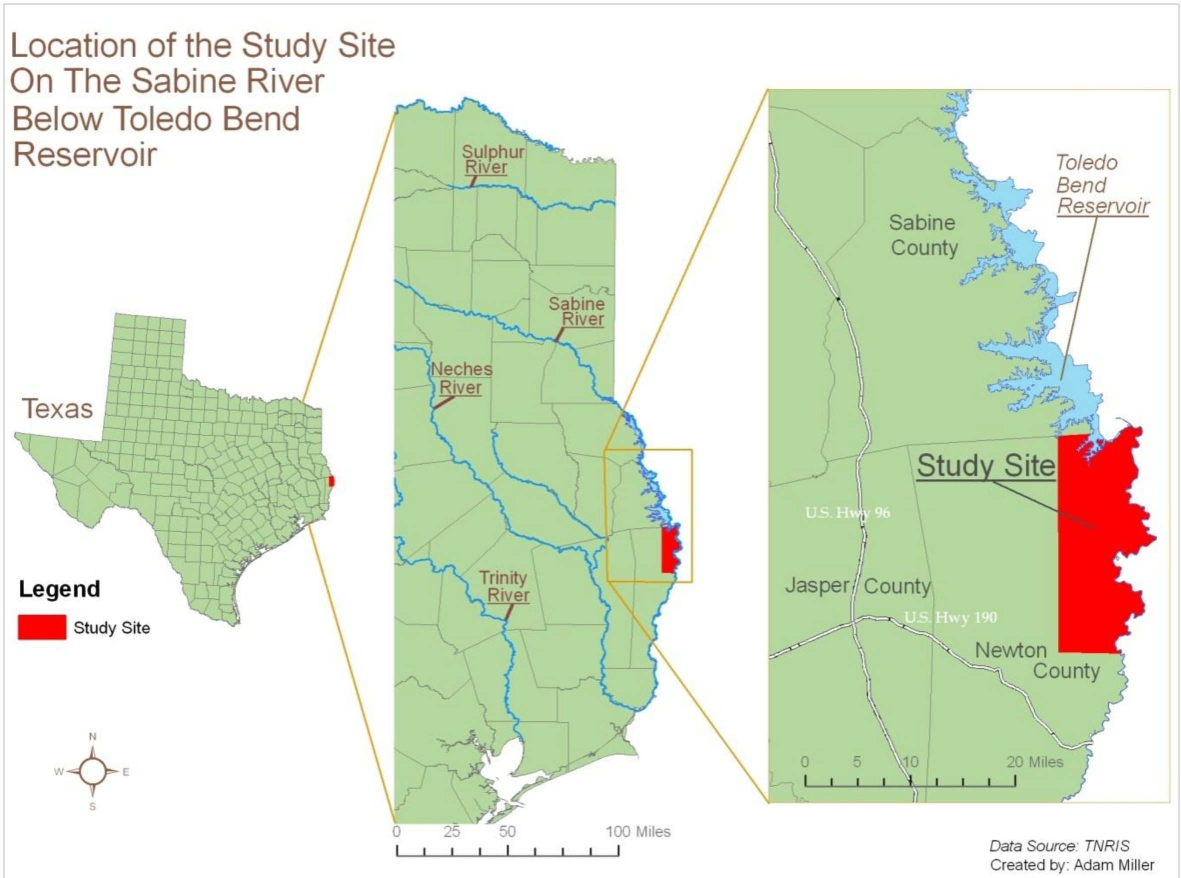

Figure 5.. Study site location along the Sabine River south of the Toledo Bend Reservoir Dam.

A requirement for the delineation of the riparian area is a definition that is clear and concise so it is known what components comprise the riparian area. The all inclusive definition that includes all the components of a riparian system in respect to the Sabine River, and most likely the Southeastern United States is following definition by National Research Council (2002).

> *"Riparian areas are transitional between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect water bodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems (i.e., a zone of influence). Riparian areas are adjacent to perennial, intermittent, and ephemeral streams, lakes, and estuarine-marine shorelines".*

Using this definition a foundation is established in which ecosystems functionally interact to form the riparian area. It is this area that the delineation method and the GIS modeling analysis seek to incorporate.

Technique 1

Methods

Data Acquisition

The following images were obtained from the Texas Natural Resources Information System (TNRIS) website on May 18th, 2009: 2004 National Agriculture Imagery Program (NAIP) 1 meter color infrared, 2006 2 meter color infrared, and 2005 NAIP 2 meter natural color. Because each image is a photo mosaic, numerous flight dates exist within each image. Soil maps and soil information was obtained from the Natural Resource Conservation Service (NRCS). A stream layer was obtained from using a georeference topographic map. A 10 meter digital elevation model (DEM) was obtained from the USDA Geospatial Gateway website.

GIS Riparian Soils

The soils of the Sabine River Basin south of Toledo Bend Reservoir composing the study area are mapped in (Figure 6) and identified in (Table 24). The soils within the model were divided by the taxonomy of the soil. Soils with an aquic, fluvic, or hemic suborder, great group, or subgroup were considered within the riparian area. The abbreviation Aqu indicates aquic conditions, the Fluv abbreviation indicates flood plain, and the Hem abbreviation indicates presence of organic matter.

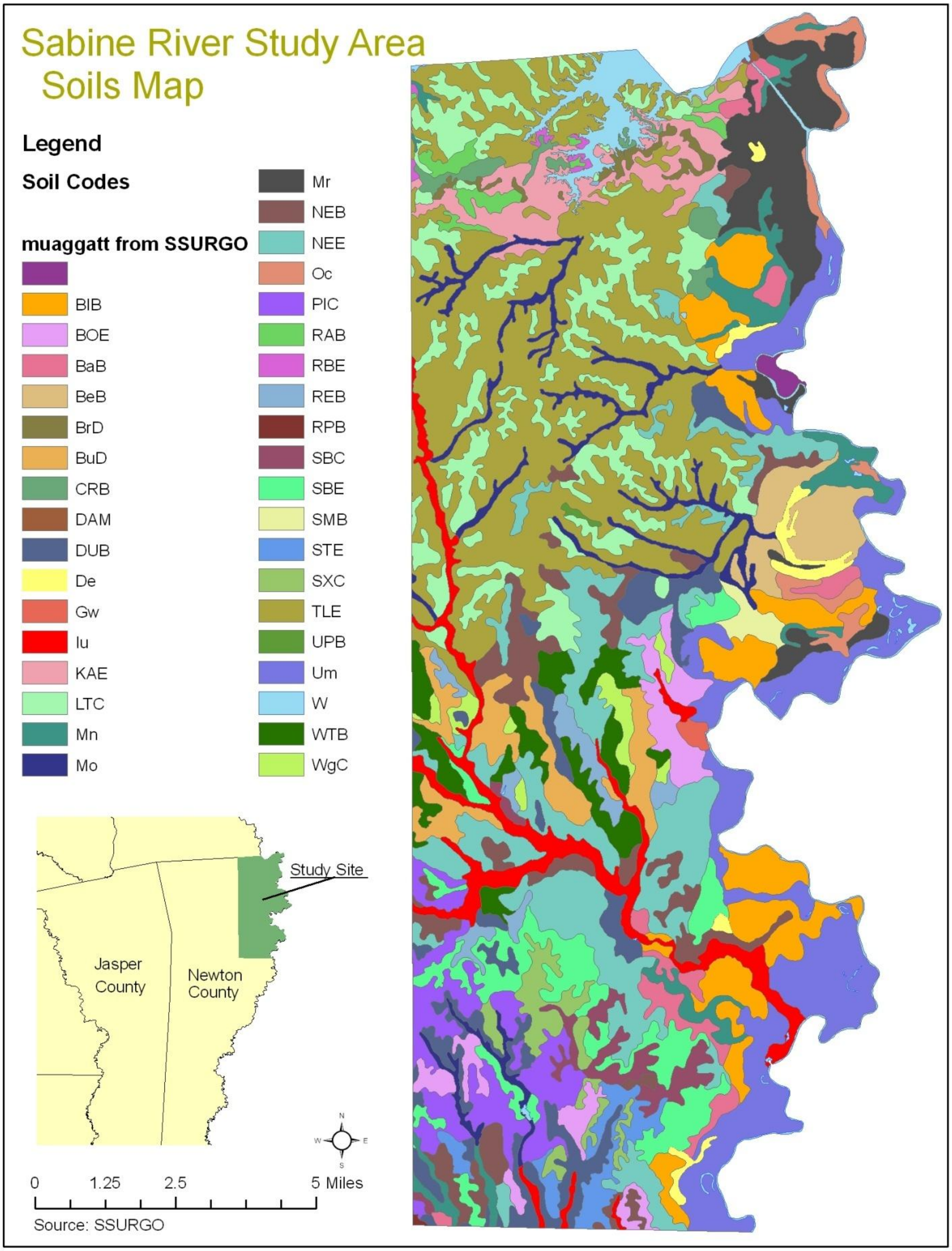

Figure 6. Soil series map of the study area. *See Table 13 for the soil code description (Neitsch 1982).*

Table 24 list soil series that are found in the floodplain and depressional areas. This is not based on the soil description but on the soil classification. Each of the soil series in (Table 25 and Table 26) are classified as either aquic, fluvic, or hemic suborder, great group, or subgroup. Table 27 lists soils not meeting the classification components. By differentiating soil associations in Figure 6 by these classification components a map is created delineating the soils typically located in riparian areas from the soils typically located in upland areas (Figure 7).

Table 24. Map symbols and classification for soils in Newton and Jasper Counties. *Source: Adapted from Neitsch 1982.*

Map Symbol	Soil Name
AtA	Attoyac fine sandy loam, 0 to 3 percent slopes
BaB	Bernaldo-Besner complex, gently undulating
BeB	Besner-Mollville complex, gently undulating
BiB	Bienville-Alaga association, gently undulating
BoE	Bonwier-Stringtown association, hilly
BrD	Browndell-Rock outcrop complex, sloping
BuD	Burkeville clay, 3 to 12 percent slopes
CRB	Corrigan-Rayburn association, gently undulating
De	Deweyville soils, frequently flooded
DUB	Doucette-Boykin association, undulating
EaA	Evadale silt loam, 0 to 1 percent slopes
EdA	Evadale silty clay loam, ponded
EgB	Evadale-Gist complex, gently undulating
EvA	Evadale-Vidrine complex, nearly level
GAB	Gallime-Spurger association, gently undulating
Gw	Gladewater soils, frequently flooded
Iu	Iuka soils, frequently flooded
JaA	Wasco silt loam, 0 to 1 percent slopes
KJB	Kirbyville-Jasco association, gently undulating
KWB	Kirbyville-Waller association, gently undulating
KAE	Kisatchie-Rayburn association, hilly
LTC	Letney-Tehran association, undulating
MaB	Malbis fine sandy loam, 1 to 5 percent slopes
MKB	Malbis-Kirbyville association, gently undulating
Mn	Mantachie and Bleakwood soils, frequently flooded
Mo	Melhomes soils, frequently flooded
Mr	Mooreville soils, occasionally flooded
NEB	Newco-Urland association, gently undulating
NEE	Newco-Urland association, hilly
NfC	Nikful fine sandy loam, 0 to 8 percent slopes
NKB	Niwana-Kirbyville association, gently undulating
Oc	Ochlockonee soils, occasionally flooded
PIC	Pinetucky-Doucette association, undulating
RAB	Rayburn-Corrigan association, undulating
RBE	Rayburn-Kisatchie association, hilly
REB	Redco-Woodville association, gently undulating
RPB	Rogan-Pinetucky association, gently undulating
SBC	Shankler-Boykin association, undulating
SBE	Shankler-Boykin association, hilly
SMB	Spurger-Mollville association, gently undulating
STE	Stringtown-Bonwier association, hilly
SXC	Stringtown-Bonwier association, graded
TaB	Tahoula clay, 1 to 5 percent slopes
TaD	Tahoula clay, 5 to 15 percent slopes
TLE	Tehran-Letney association, hilly
Um	Urbo and Mantachie soils, frequently flooded
UPB	Urland-Pinetucky association, undulating
WAA	Waller-Evadale association, nearly level
WgC	Wiergate clay, 1 to 8 percent slopes
WTB	Woodville-Redco association, gently undulating

Table 25. Soil series meeting the criteria for floodplain soils in the study area. *Source: Neitsch 1982*

Soil Series	Soil Classification	Soil Description
Browndell Series	Clayey, montmorillonitic, thermic, shallow Albaquic Hapludalfs.	Shallow, sloping, loamy, somewhat poorly drained, very slowly permeable soils on uplands.
Corrigan Series:	Fine, montmorillonitic, thermic Typic Albaqualfs.	Moderately deep gently undulating , loamy, somewhat poorly drained, very slowly permeable soils on uplands.
Deweyville Series	Dysic, thermic Typic Medihemists.	Deep nearly level, loamy, very poorly drained soils that formed in acid organic material. The pedon of the Deweyville series is mucky silt loam.
Evadale Series	Fine, mixed, thermic Typic Glossaqualfs.	Deep, nearly level loamy, poorly drained, very slowly permeable soils formed in unconsolidated, clayey sediment.
Iuka Series	Coarse-loamy, siliceous, acid, thermic Aquic Udifluvents.	Deep nearly level, loamy, moderately well drained, moderately permeable soils on bottomlands.
Mantachie Series	Fine-loamy, siliceous, acid, thermic Aeric Fluvaquents.	Deep, nearly level loamy , somewhat poorly drained, moderately permeable soils on bottomlands.
Melhomes Series	Siliceous, thermic Humaqueptic Psammaquents.	Deep, nearly level to gently sloping, poorly drained, rapidly permeable soils, formed in thick beds of sandy colluvium.
Mollville Series	Fine-loamy, mixed, thermic Typic Glossaqualfs.	Deep, nearly level and gently undulating, loamy, poorly drained, slowly permeable soils on terraces
. Mooreville Series	Fine-loamy, siliceous, thermic Fluvaquentic Dystrochrepts.	Deep, nearly level, loamy, moderately well drained, moderately permeable soils on bottomlands.
Newco Series	Clayey, mixed, thermic Aquic Hapludults.	Deep, gently undulating to hilly, moderately well drained, slowly permeable soils on uplands.
Redco Sereis	Very-fine, montmorillonitic, thermic Aquentic Chromuderts.	Deep, gently Undulating, clayey, poorly drained soils on uplands.
Ochlockonee Series	Coarse-loamy, siliceous, acid, thermic Typic Udifluvents.	Deep, nearly level, loamy, well drained, moderately permeable soils on bottomlands.

Table 26. Soil series meeting the criteria for floodplain soils in the study area continued. *Source: Neitsch 1982*

Soil Series	Soil Classification	Soil Description
Spurger Series	Fine, mixed, thermic Albaquultic Hapludalfs.	Deep, gently undulating, Loamy, moderately well drained, slowly permeable soils on terraces.
Urbo Series	Fine, mixed, acid, thermic Aeric Haplaquepts.	Deep, nearly level, clayey, somewhat poorly drained soils on bottomlands.
Urland Series	Clayey, mixed, thermic Typic Hapludults.	Deep, gently undulating to hilly, well drained soils on uplands.

Table 27. Soil series not meeting the criteria for floodplain soils. *Source: Neitsch 1982*

Soil Series	Soil Classification	Soil Description
Bernaldo Series	Fine-loamy, siliceous, thermic Glossic Paleudalfs	Deep, gently undulating, loamy, well drained, moderately permeable soils on stream terraces.
Besner Series	Coarse-loamy, siliceous, thermic Glossic Paleudalfs.	Deep, gently undulating, loamy, well drained, moderately permeable soils on terraces.
Boykin Series	Loamy, siliceous, thermic Arenic Paleudults.	Deep, undulating to hilly, sandy, well drained, moderately permeable soils on uplands.
Doucette Series	Loamy, siliceous, thermic Arenic Plinthic Paleudults.	Deep, undulating, sandy, well drained, moderately permeable soils on uplands.
Kisatchie Series	Fine, montmorillonitic, thermic Typic Hapludults.	Moderatly deep, sloping to hilly, well drained, very slowly permeable soils on uplands.
Letney Series	Loamy, siliceous, thermic Arenic Paleudults.	Deep, undulating to hilly, sandy, well drained soils on uplands.
Pinetucky Series	Fine-loamy, siliceous, thermic Plinthic Paleudults.	Deep, gently undulating and undulating, loamy, moderately well drained soils on uplands.
Rayburn Series	Fine, montmorillonitic, thermic Vertic Hapludalfs	Deep gently undulating to hilly, loamy, moderately well drained, very slowly permeable soils on uplands.
Tehran Series	Loamy, siliceous, thermic Grossarenic Paleudults.	Deep, undulating to hilly somewhat excessively drained soils on uplands.
Woodville Series	Fine, montmorillonitic, thermic Vertic Paleudalfs	Deep, gently undulating, loamy, somewhat poorly drained soils on uplands.

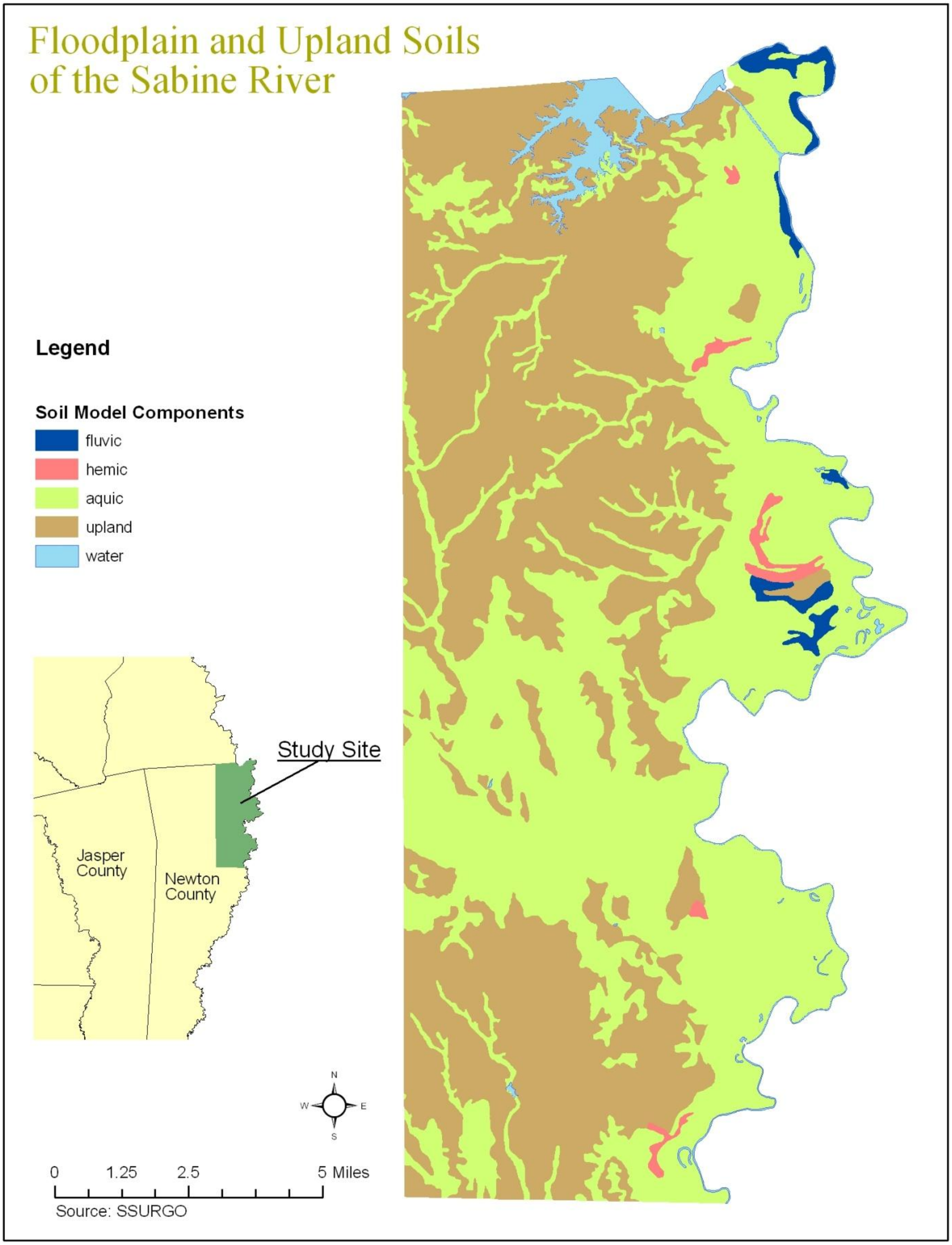

Figure 7.. The hydric and floodplain soils delineated apart from upland soils.

Classification

Unsupervised classification was used to classify the 2005 NAIP 2 meter natural color image. Refer to Figures 8 and 9 to view the imagery of the northern and southern portion of the study area. This technique was chosen due to the fact that it reduces the chance of human error, while not imposing a bias in the classification as is often the case with supervised classification. The Iterative Self-Organizing Data Analysis Technique (ISODATA), built in ERDAS ® IMAGINE 9.2 software, was used to classify the imagery (ERDAS ®, Inc. Atlanta, Georgia).

Initial classification specifications for the image was set at 200 classes with a 99% convergence threshold at 100 iterations to ensure that each pixel is 99% certain that it has been classified correctly and that the convergence threshold will be reached prior to the conclusion of all 100 iterations. After a visual assessment comparing the 200 classes in the image with the references, the image was recoded into 13 classes using the basic principles of photo interpretation which are: pattern, shape, size, shadow, site, texture, and tone (Paine, 1981). The 13 classes were "pine", "shadow", "hw1", "water", "hw2", "hw3", "hw4", "hw5", "dry soil", "wet soil", "hw6", "urban", and "soil/urban". A clump/eliminate process, using a minimum mapping size of 2 pixels (0.001 hectares), was then applied to the image to help clean up the salt/pepper look by removing isolated pixels. The six classes of hardwood vegetation were renamed with dominant species or co-dominant species that was determined after the completion of the field work. Species were recorded for each control point and the most frequently occurring species was recorded for that specific hardwood class. The generically labeled class "hw1" was determined to be *Quercus* species, "hw2" was determined to be an *Ulmus* species, and “hw3” was determined to be water oak (*Quercus nigra)*. The generically labeled “hw4” was sweetgum/maple species (*Liquidambar styraciflua* /*Acer* species) “hw5” was *Quercus* species, and the last hardwood class of “hw6” was determined to be overcup oak (*Quercus lyrata*). Refer to Figure 10 and Figure 11 for the land cover classification of the northern and southern portion of the study area.

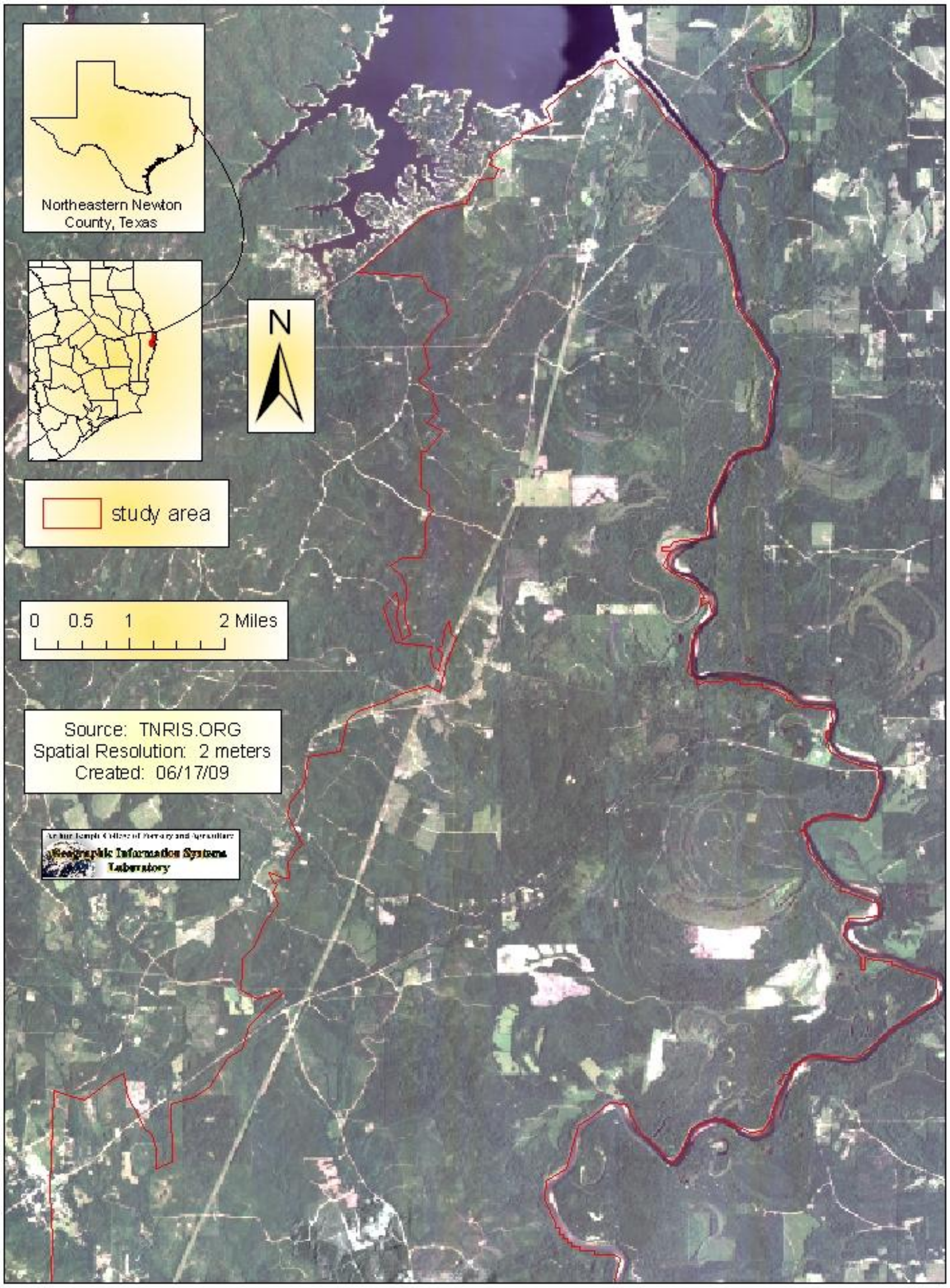

Figure 8. 2005 NAIP 2 meter natural color photo mosaic of the northern section of the Sabine River study area.

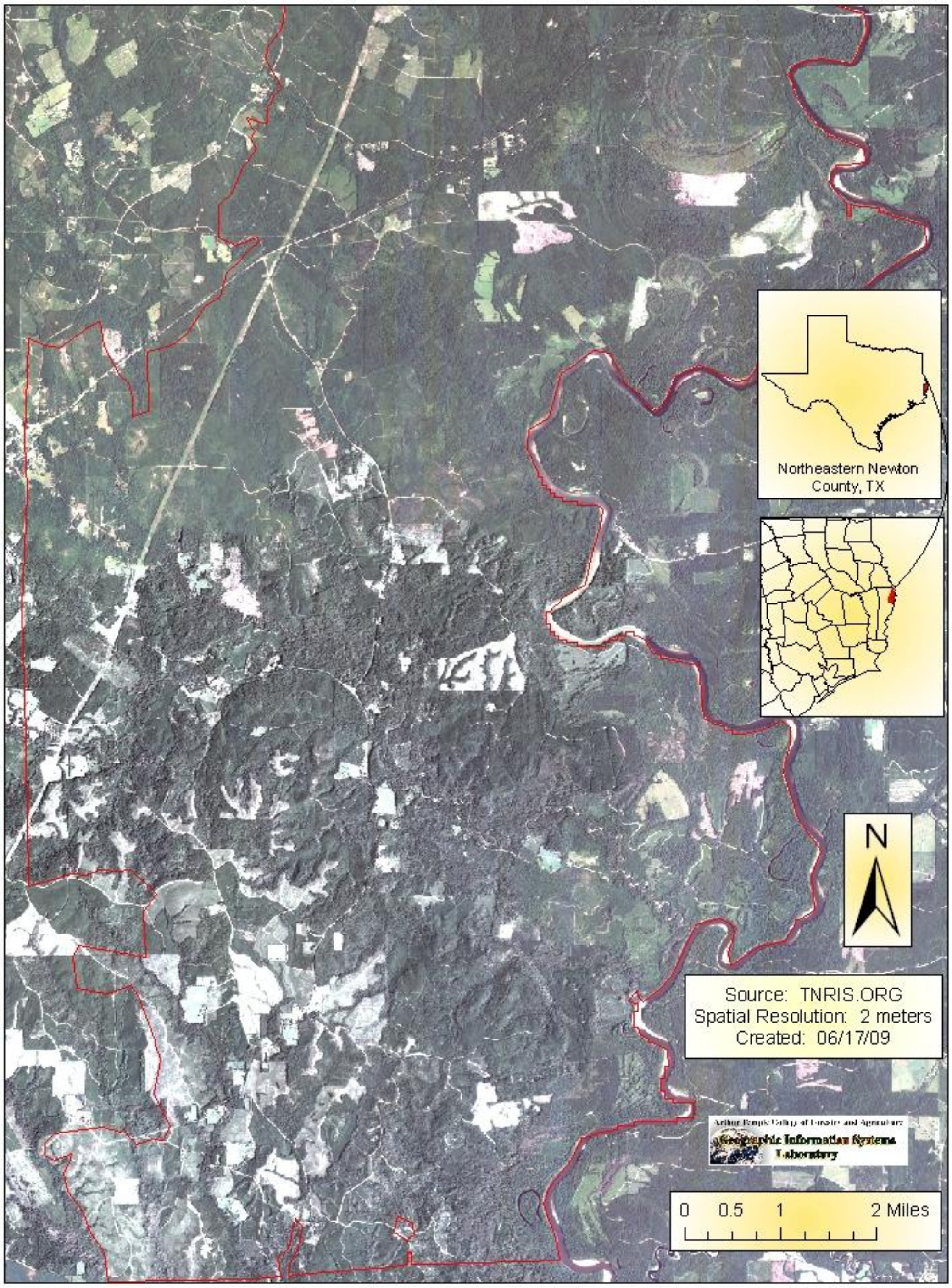

Figure 9. 2005 NAIP 2 meter natural color photo mosaic of the southern section of the Sabine River study area.

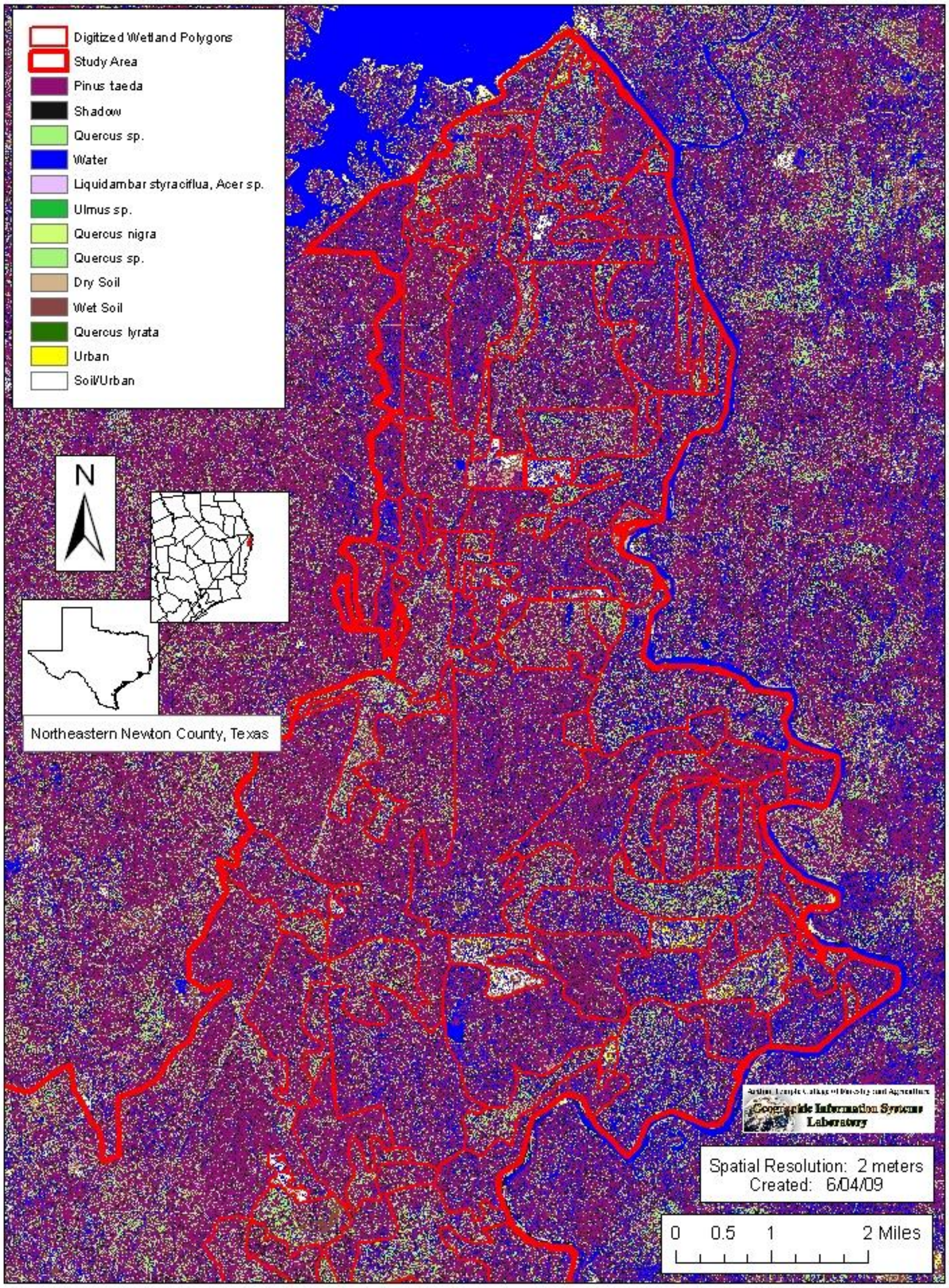

Figure 10. Classification of the northern portion of the Sabine River study area.

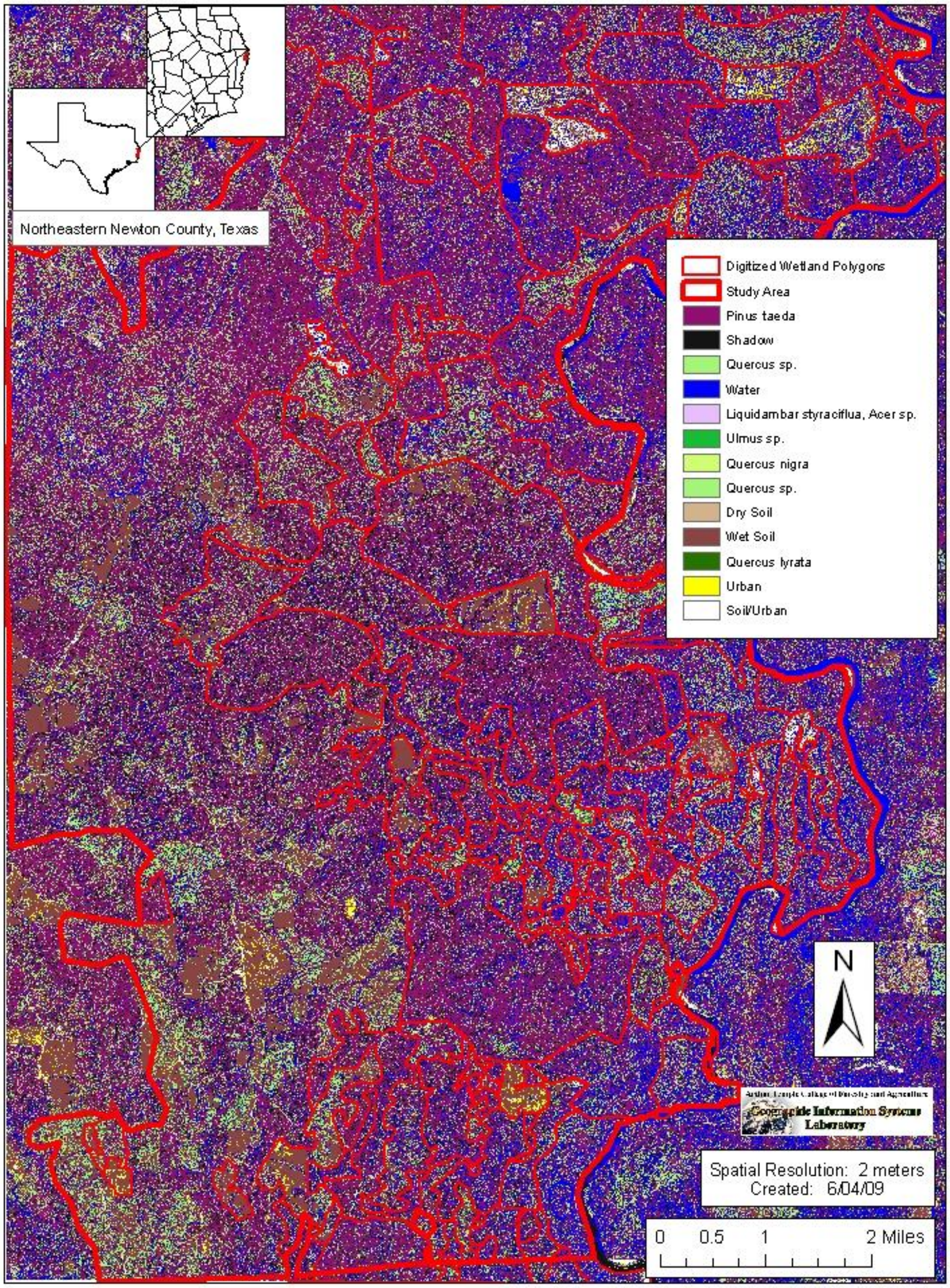

Figure 4. Classification of the southern portion of the Sabine River study area.

The map produced from the classification of the aerial photography image was digitized on the basis of differing vegetation and was used to create riparian boundaries.

Remote Sensing Model Development

Remote Sensing models were created for the study area using a combination of a digitized classification, soil maps, soil information, stream layer, and aerial photography image mosaics. The remote sensing models were developed on ArcGIS® 9.3 Model Builder. Input data for the models were originally in either vector or raster format. Both vector and raster data were recoded from categorical scale to numerical scale. Those inputs that were vectors were converted to raster format through rasterization. In the rasterization process, the attribute field that was desired to be rasterized was selected and the cell size was set as 1 meter. Rasterization is necessary so that the final output of the model would be a raster dataset with pixel values representing riparian and non-riparian areas. These raster inputs were combined using the map algebra tool (addition) to yield a single layer output.

The original model riparian areas must have had hydrophytic vegetation, hydric or fluvic soils, and be adjacent to a stream or river. The first alternative model riparian areas must have had hydric or fluvic soils and be adjacent to a stream or river. A 240 foot buffer was then applied to this model because the vegetation on riparian boundaries is believed to influence an extending area of 240 feet (CRAM 2008). The riparian areas in the second alternative model were similar to those areas in the first alternative model. However a 100 foot buffer was applied to this model because (Verry 2004) suggest that this buffer distance is most appropriate.

The following is a listing of parameters included in the model, the rating given and reason for inclusion.

Soils

The soils shapefile was utilized and recoded for this parameter. This parameter was utilized in all three models: original model, alternative #1 model, and alternative #2 model.

0 - Non Hydric, Non-Aquic, Non-Hemic, or Non- Fluvic Soils

1 - Hydric, Aquic, Hemic, or Fluvic Soils

Hydrology

The streams layer was utilized for this parameter. This parameter was utilized in all three of the models. Any polygon containing a stream or neighboring a stream or river was recoded as having hydrology.

0 - Polygon does not have a stream/river located in it or neighboring it.

1 - Polygon with either a stream/river located in it or neighboring it.

Vegetation

Hydrophytic vegetation is defined as plant life that occurs in areas where the duration and frequency of inundation or saturation of soil produce period or permanent soil saturated soils that influences the plant species present (Environmental Laboratory, 1987). The digitized riparian boundary layer was utilized and recoded for this parameter. This parameter was only utilized in the original model. While it may be obvious from the classification map and reference imagery that hardwood vegetation exists in each polygon, it was not obvious whether such hardwood was hydrophytic in nature. Because the model was developed before the field work was conducted, the recoded values given to each polygon for this parameter were postulated. After field work was done, some of those recoded values were updated appropriately.

0 - Polygon with little to no hydrophytic vegetation

1 - Polygon with heavy hydrophytic vegetation

Determining Number of Control Points

The classification map that was created was digitized into separate riparian polygons based on obvious differences in vegetation. The number of control points was determined using the following formula:

$$N = \frac{Z^2(p)(q)}{E^2}$$

where p is the expected accuracy, q is 100 – p, E is the allowable error, Z is the value for the standard normal deviation for the desired confidence interval, and N is the sample size. Z = 2, from the standard normal deviate of 1.96 at the 95% confidence interval, p was set at 90, q at 10, and E was set at 5.6. The expected accuracy was 90% with an allowable error of 10%. The result was approximately 115 points. In order to ensure no biasness in placement of control points, a random sampling technique was applied using the digitized riparian polygon boundaries on ArcGIS® 9.3 software. The computer's software generated random points showed a few cases of clustering. Some of these clustered random sampling points were removed due to redundancy and other points were added in void areas. The total number of control points was increased from 115 to 117. Refer to Figure 12 for a map of the location points. Of the 117 sampling points, only 40 points could be assessed due to the numerous private gated and poor quality roads. Refer to Appendix Table B2 for coordinates assessed and not assessed.

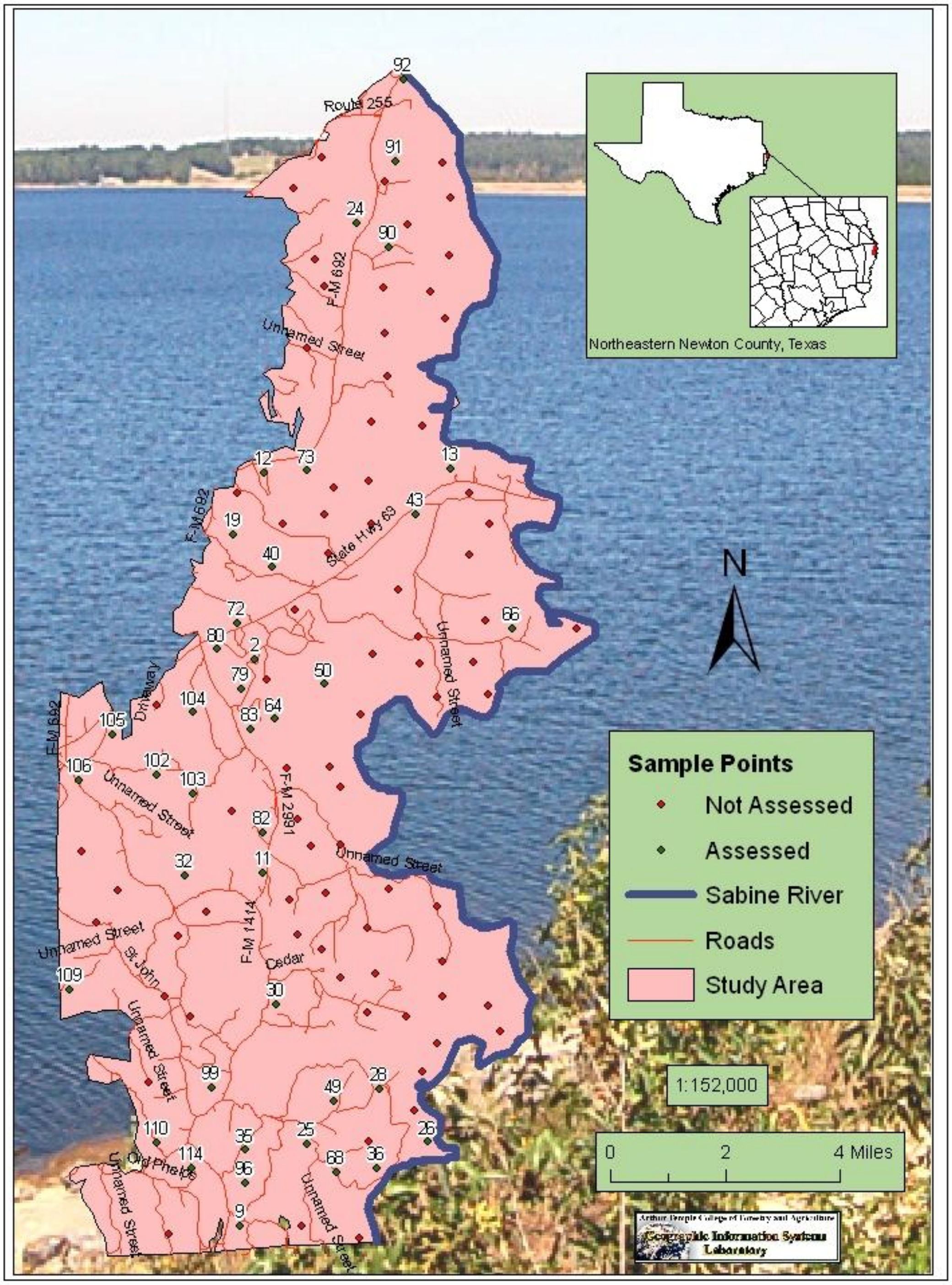

Figure 12. Sabine River riparian model sample points.

Ground Truthing

A TDS Nomad, with sub-meter accuracy, was utilized to navigate to the random point locations. At each random point location, the species were recorded and notes were taken on the presence/ lack of presence of hydrology and hydric, aquic, hemic, or fluvic soils. If it was unclear about whether there was a presence of hydric or fluvic soils, soil pits were dug and examined. Notes were also taken on the border of polygons with differing pixel values.

Statistical Analysis

The overall map accuracy will be calculated by dividing the number of correctly classified pixels by the total number of pixels sampled. Producer's accuracy is a measure of omission error and is the likelihood of a pixel being correctly classified. Producer's accuracy will be calculated by dividing the total number of observations that were correctly classified in a class by the total observations for that class in the error matrix. User's accuracy will be calculated by dividing the total number of observations that are correctly classified in a class by the total observations for that class in the error matrix.

The Kappa statistic (K) is a measure of relative accuracy to what one would expect by pure chance. The Kappa statistic can also be described as the percent better than by random chance assignment. This statistic will be calculated for the land classification map.

$$\hat{K} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} * x_{+i})}$$

N represents the total number of observations, r is the number of rows in the matrix, x_{ii} is the number of correct observations in each category, x_{i+} is the total of each category for the rows, and x_{+I} the total of each category for the columns (Bishop et al., 1975; Conglaton and Green, 1999).

Table 28. Strength of agreement by Kappa Statistic. *Source: Chuang 2001*

Kappa	Strength of agreement
0.00	**Poor**
0.01-0.20	**Slight**
0.21-0.40	**Fair**
0.41-0.60	**Moderate**
0.61-0.80	**Substantial**
0.81-1.00	**Almost perfect**

Results of Technique 1

The output from the Original Model is shown on Figure 13, the output from the First Alternative Model is shown on Figure 14, and the output from the Second Alternative Model is shown on Figure 15. Refer to Figure 16 to view all three models on 10 meter DEM. Refer to Table 28 for the strength of agreement by kappa statistic. Refer to Table 29 and Table 30 for field assessment and model prediction results. The Kappa Statistic Summary Results can be found on Table 31.

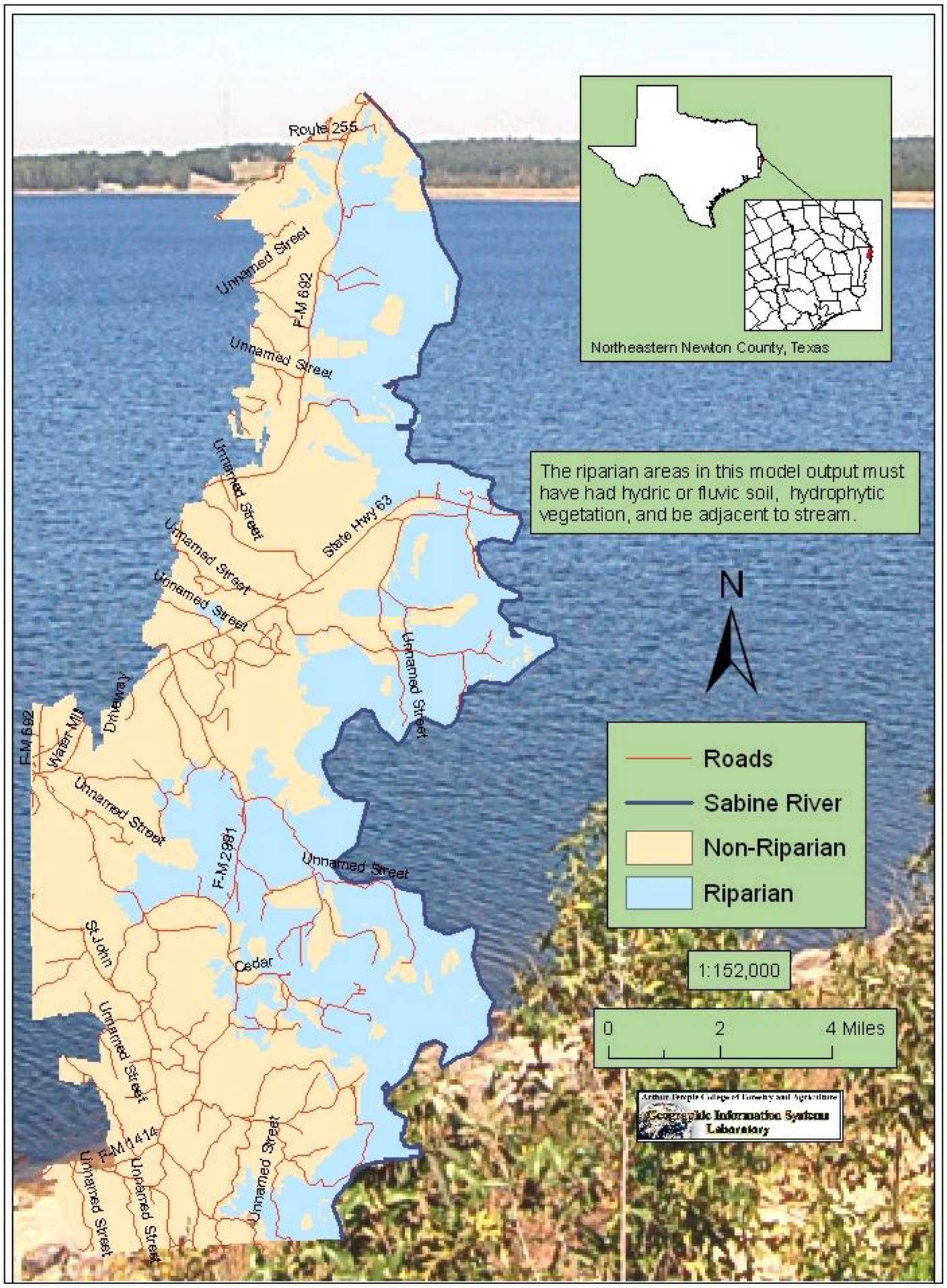

Figure 13. Sabine River riparian original model output.

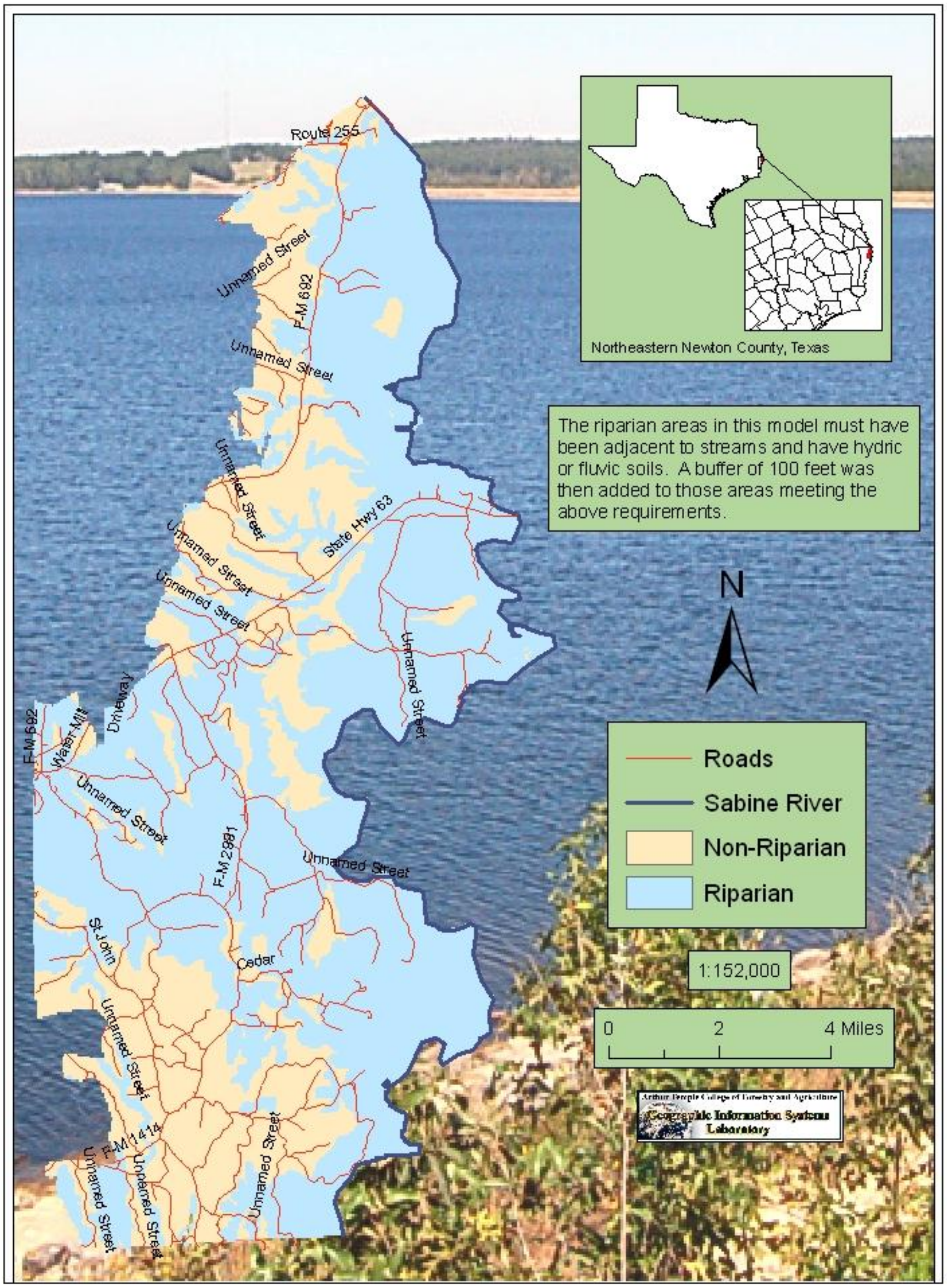

Figure 14. Sabine River riparian first alternative model output.

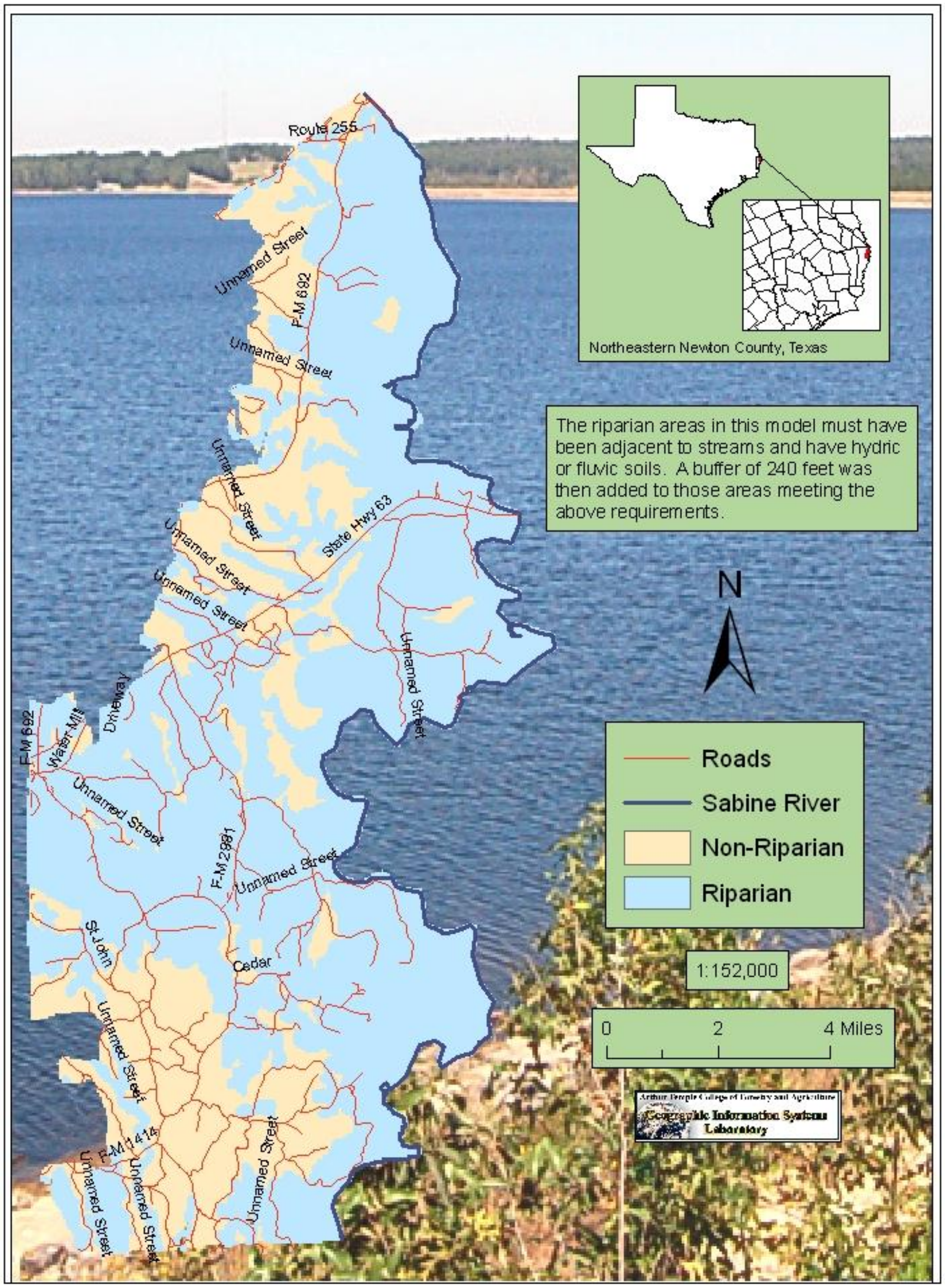

Figure 5. Sabine River riparian second alternative model output.

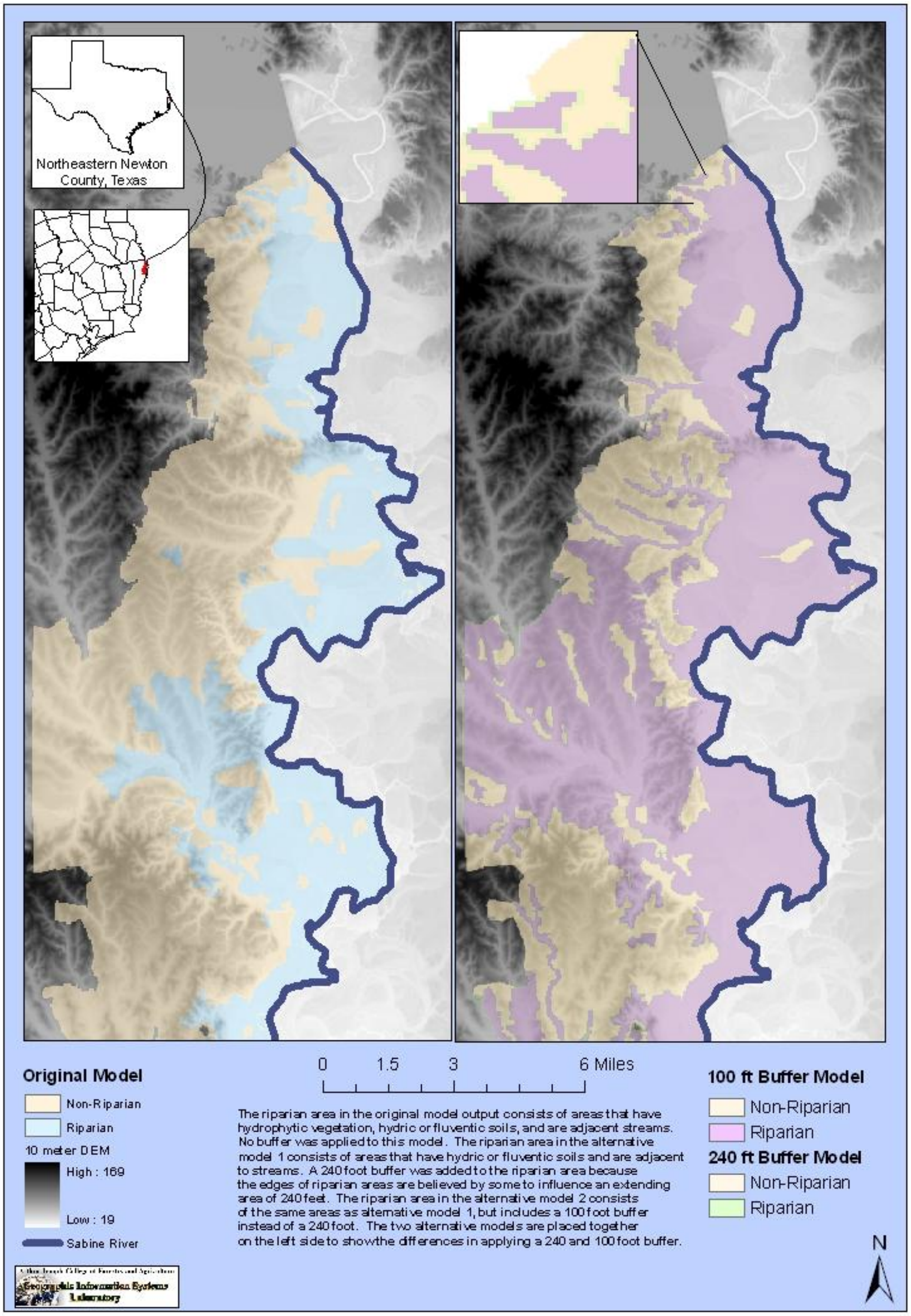

Figure 16. Original, first alternative, and second alternative models on 10 meter DEM.
Source of DEM: USDA Geospatial Data Gateway

Table 29. Field assessment and model predictions results.

Control Point	Field	Original Model	Alternative Model #1	Alternative Model #2
2	not riparian	not riparian	riparian	riparian
9	not riparian	not riparian	not riparian	not riparian
11	riparian	riparian	riparian	riparian
12	not riparian	not riparian	not riparian	not riparian
13	riparian	riparian	riparian	riparian
19	not riparian	not riparian	not riparian	not riparian
24	not riparian	not riparian	riparian	riparian
25	not riparian	not riparian	not riparian	not riparian
28	not riparian	not riparian	riparian	riparian
30	not riparian	riparian	riparian	riparian
35	not riparian	not riparian	not riparian	not riparian
39	riparian	not riparian	not riparian	not riparian
40	not riparian	not riparian	not riparian	not riparian
43	not riparian	not riparian	riparian	riparian
49	not riparian	not riparian	not riparian	not riparian
50	not riparian	not riparian	not riparian	not riparian
64	not riparian	not riparian	riparian	riparian
68	not riparian	not riparian	not riparian	not riparian
72	not riparian	not riparian	riparian	riparian
73	not riparian	not riparian	not riparian	not riparian
79	riparian	not riparian	riparian	riparian
79	not riparian	not riparian	not riparian	not riparian
80	not riparian	not riparian	not riparian	not riparian
82	not riparian	riparian	riparian	riparian
83	not riparian	not riparian	riparian	riparian
86	one side = riparian	one side = riparian	one side = riparian	one side = riparian
86	one side = not riparian	one side = not riparian	one side = riparian	one side = riparian
90	not riparian	riparian	riparian	riparian

Table 30. Field assessment and model predictions results continued.

Control Point	Field	Original Model	Alternative Model #1	Alternative Model #2
91	riparian	riparian	riparian	riparian
92	not riparian	not riparian	riparian	not riparian
93	not riparian	riparian	riparian	riparian
96	not riparian	not riparian	not riparian	not riparian
99	not riparian	not riparian	not riparian	not riparian
102	riparian	not riparian	riparian	riparian
103	riparian	not riparian	riparian	riparian
103	riparian	riparian	riparian	riparian
104	not riparian	not riparian	not riparian	not riparian
105	not riparian	not riparian	not riparian	not riparian
106	riparian	not riparian	riparian	riparian
109	not riparian	not riparian	not riparian	not riparian
110	not riparian	not riparian	not riparian	not riparian

Table 31. Kappa statistic summary results.

	Original	Alternative #1	Alternative #2
Observed Agreement:	0.78	0.66	0.68
Chance Agreement:	0.64	0.48	0.49
Kappa:	0.38	0.34	0.37

Discussion

GIS modeling was effective at delineating the riparian area. The presence of hydric soil is an indicator of wetland hydrology. Soil maps in the forested regions of the Southeastern United States are readily available as GIS shapefiles through the National Resource Conservation Service Soil Survey Geographic Data Set. The hydric soil boundary is a strong indication of land area commonly inundated with water at some frequency and duration.

The use of high resolution imagery was problematic for the classification of the study area. As the spatial resolution increases, so does the amount of miss-classified pixels. For example, the sun shining on one part of a tree may cause the same tree to show up as two different pixels.

Another problem, as mentioned previously, is the inability to get access to many of the control points due to private gated roads. Because of this, those interested in the classification map are cautioned in its overall quality.

Riparian zones are known to have hydrophytic vegetation, but much of East Texas has been manipulated by man and is managed as pine plantations. Several parts of the study area have been managed as pine plantations. While it is easy to identify such areas on imagery, it is unclear whether such areas would be dominated by hydrophytic vegetation if left unmanaged. The original model was the only model that incorporated vegetation as a parameter. Influence on vegetation by man is the cause of the inaccurate reduction of the riparian area in the original model output. This model picks out the riparian areas on the major floodplain very well, but had trouble discriminating riparian areas on the tributaries. No field verification was necessary to realize that such tributaries lacked some riparian areas. The development of a first alternative and second alternative model were necessary due to problems associated with the vegetation parameter.

Another problem that existed within the models is that the model can only be as strong as parameters used in creation. In two instances, soils that were said to be hydric by the soils layer were actually found to be non – hydric. Control point 90 and a location near control point 30 are shown to have hydric soils but the field verification shows the soils to be non-hydric.

According to (Table 28), all three developed models scored in the upper range of the fair category in terms of their strength of agreement to what was verified in the field. These models scored average due to the problems specified previously. The original model output had the highest kappa statistic (0.38) and the first alternative model output had the lowest (0.34). It is believed that both the first and second alternative model kappa statistics would be much higher than the original model's kappa statistic if more control points were able to be visited and assessed. Many of the control points that were unable to be visited existed on the tributaries or problem areas.

Within the major floodplain area, several island polygons exist within each model output that is not riparian. Such areas were not considered riparian due to their locations on terraces. These areas are unique and offer a good management opportunity.

While the three developed models are not perfect in their discrimination of riparian versus non-riparian areas, they show great potential for future modeling of riparian areas. As software capabilities increase and more knowledge on riparian functions is gained, so should the ability to manipulate and model data accurately. An accurate and reliable remote sensing and GIS based approach is necessary as it is the only practical means for dealing with a large amount of land with limited time.

Technique 2

Background

FLOW REQUIREMENTS

Ecology and Geomorphology

Hill et al. (1991) set out to develop a conceptual approach to flow determinations based on ecology and geomorphology. They came up with four potential flow requirements; fishery flows, channel maintenance flows, riparian flows, and valley maintenance flows. According to Orth (1987) Physical Habitat Simulation (PHABSIM) Software is one of the most commonly used models for quantifying instream flow needs of fish species. This program allows managers to predict favorable conditions for select fish species, and set appropriate year-round flows. Channel maintenance flows are moderately high flows that generally restrict vegetation growth in the channel while removing sediment (Reiser et al. 1989). Channel maintenance flows are generally thought of a bankfull discharges. The return interval for bankfull events is variable depending on the stream (Chorley et al. 1984) so bankfull return intervals must be evaluated for specific segments of different streams (Hill et al. 1991). There is no universally accepted method to determine flow needed to maintain the riparian area. Hill et al. (1991) use the HEC-2 method to identify those flow events required to maintain the riparian area by finding the discharge needed to reach those elevations at differing return intervals. Valley maintenance flows are expressed by the magnitude and frequency of high-flow events. Hill et al. (1991) go on to summarize the fundamental understanding needs to be in the fluvial-geomorphic processes that maintain and create the streams and how the aquatic and terrestrial ecosystems function synergistically. In order to protect these parameters multiple flow recommendations are necessary to link all of the vital interconnected ecological components.

Forest Hydrology

Peak flows are typically lower in watersheds with a higher percentage of forested area (Chang and Waters 1984). Thus it can be speculated that the removal of riparian vegetation particularly large trees and saplings may result in increase peak flows. Chang (2003) points out that compounding the removal of vegetation is an increase in soil compaction, more saturated soils, and road construction (Reid and Dunne 1984). Understanding peak flows are particularly important in areas where the potential for flood damage is high. One large scale removal of vegetation is logging. Fortunately in the State of Texas particularly the in East Texas Pineywoods over 91.5% of landowners involved in forestry have complied with the Texas Forestry Best Management Practices (BMP) (Simpson et al. 2008). The main purpose of the implementation of BMP's is maintaining or improving water quality through guidelines related to planning and maintaining roads, harvesting intensity and operations, locations of landings, skid trails and drainages, and the treatment of chemicals and waste. Thomas and Megahan (1998) state that depending on cutting intensity, location in the watershed, and regrowth of vegetation, peak flows can be decreased or remain unchanged after logging, as long as the forest floor remains intact. Management practices like BMP's typify the need to have a healthy riparian vegetation community composed of species growing through the stages of succession with vigor in order to maintain or elevate water quality parameters.

Riparian Vegetation Ecophysiological Response

In order for riparian plant community maintain a state of vigor the plants require water to absorb required nutrients, perform photosynthesis and hydrolytic processes (Chang 2003). The availability of water is the most important environmental factor limiting the distribution and growth of trees (Zimmerman and Brown 1971).

Leighton and Risser (1989) developed a model in an attempt to understand on a large scale the riparian vegetation physiological response to variations in stream flow. This model determines the physiological response of the plant to incoming radiation and water availability given by its leaf water potential, leaf temperature and transpiration. The model simulation results were similar to in the field measurements values for predawn leaf water potential, leaf temperature, and transpiration rate. As a result this model can effectively be run on the two species white alder *(Alms rhombifolia)* and red willow *(Salix laevigata)* to determine their ecophysical response to stream flow. They found little physiological stress relative to all stream flows except during significant reductions in stream flow. Stromberg (1993) developed an instream flow model which displayed an increase in foliage area, stem basal area and riparian stand width in a curvilinear trend with flow volume. Both models infer riparian vegetation loss to be expected from flow reductions.

It is not known whether these models with species specific modifications would be applicable to trees in the Western Gulf Coastal Plain Region, but it appears reasonable that with some modification it could be used in drier western portions of Texas. A model similar to this developed for riparian tree species of interest in the Western Gulf Coastal Plain Region would be very valuable for not only better understanding flow return and duration intervals, but would aid those interested in restoration activities by knowing what conditions will best suit each species.

Gauged streams offer the opportunity to study the relationship between growth rates and stream flow. Stromberg and Patten (1990) collected increment cores from Jeffery pine (Pinus jeffreyi) and black cottonwood (Populus trichocarpa) located throughout the riparian zone in order to develop a composite picture of the trees response to stream flows. The annual tree ring width was plotted with the annual stream flow. They found a strong relationship between growth rates of riparian tree species and the annual and prior year flow volumes. This study was conducted in an arid environment which would relate well to West Texas. A study similar to this conducted in the Pineywoods Ecoregion would be valuable in determining a relationship between growth rates and flows, which could potentially be used in determining flow needs of riparian vegetation (under the assumption that certain levels of growth are required to maintain a population of species of interest).

Because data of this sort is not known to exist for the Sabine River, literature reviewed indicates mimicking pre dam flow regimes in regulated streams should in most cases maintain a healthy riparian area (Hunter et al. 2008).

Methods

Flood Recurrence Interval

Healthy riparian plant communities can be maintained or established with current flow regimes that are similar to historical conditions of overbank flooding return intervals (National Research Council 2002). By using historical gage station data we calculated the flood recurrence interval, matched the stage to mean seal level elevation on the landscape, and matched these elevations to two foot contour LIDAR data within approximately two miles of each gage station. Because there is the risk of danger associated with flooding events the elevations associated with increasing risk are identified.

The National Oceanic and Atmospheric Administration (NOAA) through their advanced hydrologic prediction service have established flood action categories near many USGS gauging stations in Texas. These flood stages begin at the action level, and then progress through flood stage, moderate stage, major stage and record stage (Table 32). The action required based on a particular flood event is listed in Table 33. This service was established to improve flood warnings and water resource forecast. These stages each have a beginning and ending flow and its corresponding stage height at each gage site utilized in this system. Scaled in chart form on the advanced hydrologic prediction service website (http://www.weather.gov/ahps/) are current real-time flow and stage information and how this relates to the scaled flood categories.

Table 32. The terminology used by NOAA advanced hydrologic prediction service in describing stage events.

Stage Category	Description of the flooding event
Action Stage	Occurs when a rising stream level is reached in which the NWS or a partner needs to take some type of mitigation action in preparation of possible significant hydrologic activity.
Flood Stage	Results in minimal or no property damage, but does pose the possibility for some public threat.
Moderate Stage	Results in some inundation of structures and roads near streams. Some evacuations of people and or the transfer of property to higher elevations.
Major Stage	Results in extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations.
Record Stage	Results in flooding which equals or exceeds the highest stage or discharge at a given site during the period of record keeping.

Source: NOAA's National Weather Service website at: http://www.nws.noaa.gov/oh/ahps/

Table 33. Various Flood Stages for Burkeville, Bon Weir, and Ruliff Gages.

Gage Location	"Gage 0" Datum (ft.)	Action Stage (ft.)	Flood Stage (ft.)	Moderate Flood Stage (ft.)	Major Flood Stage (ft.)	Record Stage (ft.)
Burkeville, TX	60.59	38	43	45	47	48.1
Bon Weir, TX	33.42	30	30	33	36	43.5
Ruliff, TX	-5.92	23	24	26	28	32.2

These categories were scaled in elevation on the landscape using LIDAR two foot contours in the immediate vicinity (approximately two miles up and downstream) of the three gage stations (Burkeville and Bon Weir) (Figure 17 and Figure 18; Figure 19 and Figure 20).

Flood recurrence intervals were calculated for the time in which data has been collected for the following gage site locations: USGS 0826000 Sabine River near Burkeville, TX; USGS 08028500 Sabine River near Bon Wier, TX; USGS 08030500 Sabine River near Ruliff, TX. The largest gage height observed for each year was recorded and ranked in descending order. The probability of return was calculated using the following equation (Gumbel 1941) examples in (Chang 1982):

$$1\text{-}F(x)=P(X\geq x) = m/(N+1)$$

The return period or recurrence interval in years was calculated using the following equation (Chang 1982):

$$T= 1/(1\text{-}F(x))$$

The recurrence intervals for Burkeville (Table 34 and Table 35), Bon Weir (Table 36, Table 37, and Table 38), and Ruliff (Table 39, Table 40, and Table 41) highlight the bankfull event that occurs in most years (Verry et al. 2000), the five year, ten year, twenty-five year and fifty year flood recurrence intervals.

Table 34. Burkeville, TX. Flood return period or recurrence interval.

Rank	Event Date	Flow (cfs)	Gage Height (ft.)	Return Interval (years) (Gringorten equation)	Annual Probability (Gringorten equation)	Return Interval (years) (Gumbel equation)	Annual Probability (Gumbel equation)
1	2/1/1999	117000	47.49	93.1	0.01	53.0	0.02
2	5/20/1989	111000	47.45	33.4	0.03	26.5	0.04
3	3/6/2001	84400	45.01	20.4	0.05	17.7	0.06
4	4/20/1991	72500	44.66	14.6	0.07	13.3	0.08
5	1/29/1974	77900	44.2	11.4	0.09	10.6	0.09
6	11/3/2009	71200	43.89	9.4	0.11	8.8	0.11
7	5/21/1958	43200	40.42	7.9	0.13	7.6	0.13
8	5/24/1983	41500	40.2	6.9	0.15	6.6	0.15
9	5/19/1966	42000	40.13	6.1	0.16	5.9	0.17
10	3/7/1997	41300	39.7	5.5	0.18	5.3	0.19
11	5/10/1969	40200	39.56	4.9	0.20	4.8	0.21
12	6/4/1990	38500	39.3	4.5	0.22	4.4	0.23
13	5/10/1975	39100	39.17	4.1	0.24	4.1	0.25
14	5/10/1973	38600	39.11	3.8	0.26	3.8	0.26
15	5/21/1980	35300	38.25	3.6	0.28	3.5	0.28
16	3/8/1992	36300	38.17	3.3	0.30	3.3	0.30
17	1/15/1961	33500	37.63	3.1	0.32	3.1	0.32
18	6/13/1986	34500	37.52	3.0	0.34	2.9	0.34
19	4/7/2008	41200	37.05	2.8	0.36	2.8	0.36
20	5/3/1962	21300	36.58	2.7	0.38	2.7	0.38
21	4/28/1995	32800	35.78	2.5	0.39	2.5	0.40
22	3/5/1979	29100	35.4	2.4	0.41	2.4	0.42
23	12/30/1982	36800	35.05	2.3	0.43	2.3	0.43
24	4/10/1993	29400	34.18	2.2	0.45	2.2	0.45
25	1/23/1998	25800	32.91	2.1	0.47	2.1	0.47
26	4/21/1959	20100	32.54	2.0	0.49	2.0	0.49
27	6/5/1968	21100	32.44	2.0	0.51	2.0	0.51
28	12/31/1960	21100	32.22	1.9	0.53	1.9	0.53
29	3/5/2003	27700	31.91	1.8	0.55	1.8	0.55
30	5/14/2004	28300	31.48	1.8	0.57	1.8	0.57
31	1/5/1972	19100	31.41	1.7	0.59	1.7	0.58
32	4/17/2002	26200	31.29	1.7	0.61	1.7	0.60
33	6/3/1976	18700	31.23	1.6	0.62	1.6	0.62
34	2/27/1987	21000	31	1.6	0.64	1.6	0.64
35	3/6/1984	19800	30.63	1.5	0.66	1.5	0.66
36	4/28/1964	16000	29.83	1.5	0.68	1.5	0.68
37	3/10/1994	19700	29.57	1.4	0.70	1.4	0.70
38	4/2/1965	15500	29.39	1.4	0.72	1.4	0.72

Table 35. Burkeville, TX. Flood return period or recurrence interval continued.

Rank	Event Date	Flow (cfs)	Gage Height (ft.)	Return Interval (years) (Gringorten equation)	Annual Probability (Gringorten equation)	Return Interval (years) (Gumbel equation)	Annual Probability (Gumbel equation)
39	1/20/1988	17700	29.16	1.4	0.74	1.4	0.74
40	4/19/1970	15600	29.14	1.3	0.76	1.3	0.75
41	7/30/2007	19600	28.27	1.3	0.78	1.3	0.77
42	3/4/1977	12000	28.23	1.3	0.80	1.3	0.79
43	3/13/1985	15300	27.78	1.2	0.82	1.2	0.81
44	2/10/2005	18800	27.38	1.2	0.84	1.2	0.83
45	3/29/1978	9000	26.5	1.2	0.85	1.2	0.85
46	12/18/1971	15700	26.05	1.1	0.87	1.2	0.87
47	5/19/1963	6700	26.03	1.1	0.89	1.1	0.89
48	5/27/1981	7710	25.83	1.1	0.91	1.1	0.91
49	7/14/2000	12200	25.49	1.1	0.93	1.1	0.92
50	10/18/2006	18000	23.39	1.1	0.95	1.1	0.94
51	6/2/1967	5110	21.99	1.0	0.97	1.0	0.96
52	2/5/1996	5400	21.57	1.0	0.99	1.0	0.98

Table 36. Bon Weir, TX. Flood return period or recurrence interval.

Rank	Event Date	Flow (cfs)	Gage Height (ft.)	Return Interval (years) (Gringorten equation)	Annual Probability (Gringorten equation)	Return Interval (years) (Gumbel equation)	Annual Probability (Gumbel equation)
1	5/19/1953	115000	38.7	150.2	0.01	83.0	0.01
2	7/4/1989	98200	37.9	53.9	0.02	41.5	0.02
3	2/3/1999	92600	37.58	32.9	0.03	27.7	0.04
4	12/29/1982	83800	36.86	23.6	0.04	20.8	0.05
5	3/7/2001	78100	36.74	18.4	0.05	16.6	0.06
6	1/29/1974	78600	36.53	15.1	0.07	13.8	0.07
7	5/22/1935	72600	36.4	12.8	0.08	11.9	0.08
8	6/6/1950	73400	36.35	11.1	0.09	10.4	0.10
9	4/22/1991	68500	36.2	9.8	0.10	9.2	0.11
10	4/17/1945	75500	36.1	8.8	0.11	8.3	0.12
11	8/2/1933	63000	36.04	8.0	0.13	7.5	0.13
12	2/13/1966	62200	35.81	7.3	0.14	6.9	0.14
13	12/13/1940	51600	35.48	6.7	0.15	6.4	0.16
14	5/9/1944	54500	35.33	6.2	0.16	5.9	0.17
15	5/17/1957	51800	35.3	5.8	0.17	5.5	0.18
16	4/9/1938	46300	35.2	5.4	0.18	5.2	0.19
17	3/8/1997	50500	34.78	5.1	0.20	4.9	0.20
18	2/20/1946	44500	34.75	4.8	0.21	4.6	0.22
19	4/21/1927	38900	34.6	4.5	0.22	4.4	0.23
20	5/11/1973	41600	34.52	4.3	0.23	4.2	0.24
21	1/21/1947	37500	34.45	4.1	0.24	4.0	0.25
22	5/12/1969	43000	34.4	3.9	0.26	3.8	0.27
23	3/30/1934	35200	34.4	3.7	0.27	3.6	0.28
24	12/25/1923	35800	34.35	3.6	0.28	3.5	0.29
25	3/9/1992	39900	34.33	3.4	0.29	3.3	0.30
26	3/26/1929	35800	34.3	3.3	0.30	3.2	0.31
27	11/9/1925	35800	34.3	3.2	0.32	3.1	0.33
28	1/28/1995	50600	34.29	3.1	0.33	3.0	0.34
29	5/4/1958	39600	34.22	2.9	0.34	2.9	0.35
30	5/23/1980	37000	34.15	2.8	0.35	2.8	0.36
31	6/5/1990	38200	34.14	2.8	0.36	2.7	0.37
32	1/12/1961	35200	33.98	2.7	0.38	2.6	0.39
33	4/9/2008	40000	33.75	2.6	0.39	2.5	0.40
34	4/25/1952	33200	33.72	2.5	0.40	2.4	0.41
35	2/13/1984	35600	33.47	2.4	0.41	2.4	0.42
36	5/15/2004	39500	33.16	2.4	0.42	2.3	0.43
37	12/21/1961	32700	33.15	2.3	0.43	2.2	0.45
38	8/11/1940	28700	33	2.2	0.45	2.2	0.46
39	6/14/1986	31500	32.92	2.2	0.46	2.1	0.47
40	4/11/1993	31400	32.9	2.1	0.47	2.1	0.48

Table 37. Bon Weir, TX. Flood return period or recurrence interval continued.

Rank	Event Date	Flow (cfs)	Gage Height (ft.)	Return Interval (years) (Gringorten equation)	Annual Probability (Gringorten equation)	Return Interval (years) (Gumbel equation)	Annual Probability (Gumbel equation)
41	12/31/2006	38400	32.87	2.1	0.48	2.0	0.49
42	4/13/1942	27900	32.79	2.0	0.49	2.0	0.51
43	1/8/1998	31300	32.77	2.0	0.51	1.9	0.52
44	8/6/1955	29700	32.65	1.9	0.52	1.9	0.53
45	4/13/1948	28100	32.46	1.9	0.53	1.8	0.54
46	3/3/1939	26300	32.4	1.8	0.54	1.8	0.55
47	6/14/1930	26100	32.4	1.8	0.55	1.8	0.57
48	10/2/1958	28900	32.38	1.8	0.57	1.7	0.58
49	1/17/1931	24600	32.2	1.7	0.58	1.7	0.59
50	4/24/1982	30500	32.1	1.7	0.59	1.7	0.60
51	2/27/1987	29100	32.06	1.7	0.60	1.6	0.61
52	12/14/2001	35000	32	1.6	0.61	1.6	0.63
53	3/31/1949	26300	32	1.6	0.62	1.6	0.64
54	3/6/1979	30100	31.85	1.6	0.64	1.5	0.65
55	11/5/2002	32200	31.57	1.5	0.65	1.5	0.66
56	11/25/2004	33300	31.51	1.5	0.66	1.5	0.67
57	1/25/1937	22700	31.5	1.5	0.67	1.5	0.69
58	12/12/1935	22700	31.5	1.5	0.68	1.4	0.70
59	5/12/1975	41900	31.45	1.4	0.70	1.4	0.71
60	4/7/1928	18600	31.1	1.4	0.71	1.4	0.72
61	4/1/1951	23400	31.05	1.4	0.72	1.4	0.73
62	1/28/1994	26800	30.45	1.4	0.73	1.3	0.75
63	4/10/1968	23000	30.43	1.3	0.74	1.3	0.76
64	1/5/1972	24500	30.26	1.3	0.76	1.3	0.77
65	2/27/1960	23300	30.1	1.3	0.77	1.3	0.78
66	6/3/1976	23300	29.47	1.3	0.78	1.3	0.80
67	5/3/1954	20000	29.45	1.3	0.79	1.2	0.81
68	12/21/1987	22300	29.41	1.2	0.80	1.2	0.82
69	7/7/1943	18500	29.28	1.2	0.82	1.2	0.83
70	3/21/1985	21000	28.5	1.2	0.83	1.2	0.84

Table 38. Bon Weir, TX. Flood return period or recurrence interval continued.

Rank	Event Date	Flow (cfs)	Gage Height (ft.)	Return Interval (years) (Gringorten equation)	Annual Probability (Gringorten equation)	Return Interval (years) (Gumbel equation)	Annual Probability (Gumbel equation)
71	4/2/1965	17600	28.24	1.2	0.84	1.2	0.86
72	4/29/1964	17600	27.72	1.2	0.85	1.2	0.87
73	3/5/1977	18600	27.53	1.2	0.86	1.1	0.88
74	4/20/1970	15600	26.94	1.1	0.87	1.1	0.89
75	2/10/1956	14700	26.72	1.1	0.89	1.1	0.90
76	4/15/1967	13400	25.86	1.1	0.90	1.1	0.92
77	1/19/1925	10000	25.5	1.1	0.91	1.1	0.93
78	12/30/1962	11600	24.7	1.1	0.92	1.1	0.94
79	7/15/2000	13600	24.43	1.1	0.93	1.1	0.95
80	1/25/1978	11700	24.14	1.1	0.95	1.0	0.96
81	12/19/1995	10400	22.76	1.0	0.96	1.0	0.98
82	6/6/1981	10100	22.62	1.0	0.97	1.0	0.99
83	4/30/2006	10500	22.16	1.0	0.98	1.0	1.00
84	1/20/1971	7430	21.26	1.0	0.99	1.0	1.01

Table 39. Ruliff, TX. Flood return period or recurrence interval.

Rank	Event Date	Flow (cfs)	Gage Height (ft.)	Return Interval (years) (Gringorten equation)	Annual Probability (Gringorten equation)	Return Interval (years) (Gumbel equation)	Annual Probability (Gumbel equation)
1	7/6/1989	109000	39.15	148.0	0.01	84.0	0.01
2	5/22/1953	121000	29.98	53.1	0.02	42.0	0.02
3	2/6/1999	92800	28.18	32.4	0.03	28.0	0.04
4	12/31/1982	90000	28	23.3	0.04	21.0	0.05
5	10/22/2006	58200	27.93	18.2	0.06	16.8	0.06
6	3/11/2001	86300	27.84	14.9	0.07	14.0	0.07
7	12/16/1940	86000	27.81	12.6	0.08	12.0	0.08
8	2/1/1974	84600	27.73	11.0	0.09	10.5	0.10
9	4/22/1945	85300	27.59	9.7	0.10	9.3	0.11
10	6/9/1950	79500	27.28	8.7	0.12	8.4	0.12
11	2/16/1966	62000	27.25	7.8	0.13	7.6	0.13
12	1/30/1995	63100	26.7	7.2	0.14	7.0	0.14
13	4/25/1991	59600	26.51	6.6	0.15	6.5	0.15
14	1/11/1961	52400	26.42	6.1	0.16	6.0	0.17
15	11/7/2002	57400	26.38	5.7	0.18	5.6	0.18
16	5/8/1944	61900	26.32	5.3	0.19	5.3	0.19
17	9/16/1998	55000	26.24	5.0	0.20	4.9	0.20
18	4/20/1973	47600	26.1	4.7	0.21	4.7	0.21
19	4/11/2008	37900	25.97	4.5	0.22	4.4	0.23
20	5/21/1957	53800	25.96	4.2	0.24	4.2	0.24
21	3/10/1997	48700	25.9	4.0	0.25	4.0	0.25
22	2/22/1946	54700	25.89	3.8	0.26	3.8	0.26
23	1/22/1947	52900	25.8	3.7	0.27	3.7	0.27
24	2/16/1984	46100	25.74	3.5	0.28	3.5	0.29
25	11/28/1986	43800	25.67	3.4	0.30	3.4	0.30
26	3/8/1992	45700	25.66	3.2	0.31	3.2	0.31
27	9/25/1958	41300	25.6	3.1	0.32	3.1	0.32
28	4/27/1952	49300	25.57	3.0	0.33	3.0	0.33
29	12/21/1961	38000	25.52	2.9	0.34	2.9	0.35
30	12/17/2001	39300	25.44	2.8	0.36	2.8	0.36

Table 40. Ruliff, TX. Flood return period or recurrence interval continued.

Rank	Event Date	Flow (cfs)	Gage Height (ft.)	Return Interval (years) (Gringorten equation)	Annual Probability (Gringorten equation)	Return Interval (years) (Gumbel equation)	Annual Probability (Gumbel equation)
31	3/25/1969	41200	25.44	2.7	0.37	2.7	0.37
32	5/19/1980	40700	25.43	2.6	0.38	2.6	0.38
33	2/16/2004	40500	25.37	2.5	0.39	2.5	0.39
34	4/23/1979	42000	25.35	2.5	0.40	2.5	0.40
35	5/14/1975	40700	25.33	2.4	0.42	2.4	0.42
36	4/12/1993	36600	25.29	2.3	0.43	2.3	0.43
37	1/27/1990	35000	25.2	2.3	0.44	2.3	0.44
38	4/26/1982	35300	25.15	2.2	0.45	2.2	0.45
39	6/17/1986	33900	25.14	2.1	0.47	2.2	0.46
40	11/28/2004	33100	25.09	2.1	0.48	2.1	0.48
41	10/29/1970	31000	25.03	2.0	0.49	2.0	0.49
42	4/12/1942	38500	24.98	2.0	0.50	2.0	0.50
43	2/1/1994	28700	24.81	1.9	0.51	2.0	0.51
44	4/16/1955	34700	24.8	1.9	0.53	1.9	0.52
45	1/9/1972	27400	24.78	1.9	0.54	1.9	0.54
46	3/1/1985	27900	24.77	1.8	0.55	1.8	0.55
47	4/3/1949	34000	24.73	1.8	0.56	1.8	0.56
48	12/24/1987	24900	24.64	1.7	0.57	1.8	0.57
49	2/28/1948	28600	24.56	1.7	0.59	1.7	0.58
50	3/1/1960	23400	24.54	1.7	0.60	1.7	0.60
51	4/14/1968	23500	24.5	1.6	0.61	1.6	0.61
52	5/7/1954	28900	24.46	1.6	0.62	1.6	0.62
53	3/7/1964	22800	24.45	1.6	0.63	1.6	0.63
54	6/6/1976	22800	24.39	1.5	0.65	1.6	0.64
55	4/4/1951	27000	24.36	1.5	0.66	1.5	0.65
56	4/18/1967	21400	24.35	1.5	0.67	1.5	0.67
57	9/19/1963	21400	24.33	1.5	0.68	1.5	0.68
58	3/9/1977	20300	24.21	1.4	0.69	1.4	0.69
59	12/22/1995	16800	24.08	1.4	0.71	1.4	0.70
60	2/13/1956	23400	24.08	1.4	0.72	1.4	0.71
61	5/25/1935	76600	24.08	1.4	0.73	1.4	0.73
62	4/6/1965	18000	24.07	1.3	0.74	1.4	0.74
63	1/28/1978	18400	24.05	1.3	0.75	1.3	0.75
64	5/5/2006	17400	23.96	1.3	0.77	1.3	0.76
65	7/10/1943	20400	23.95	1.3	0.78	1.3	0.77

Table 41. Ruliff, TX. Flood return period or recurrence interval continued.

Rank	Event Date	Flow (cfs)	Gage Height (ft.)	Return Interval (years) (Gringorten equation)	Annual Probability (Gringorten equation)	Return Interval (years) (Gumbel equation)	Annual Probability (Gumbel equation)
66	4/22/1970	16700	23.92	1.3	0.79	1.3	0.79
67	8/5/1933	68600	23.53	1.2	0.80	1.3	0.80
68	5/8/2000	11200	23.12	1.2	0.82	1.2	0.81
69	6/11/1981	11100	23.12	1.2	0.83	1.2	0.82
70	3/3/1932	62800	23.08	1.2	0.84	1.2	0.83
71	8/12/1940	52000	22.38	1.2	0.85	1.2	0.85
72	6/1/1929	52500	22.38	1.2	0.86	1.2	0.86
73	4/13/1938	50900	22.33	1.1	0.88	1.2	0.87
74	3/29/1934	47100	22.13	1.1	0.89	1.1	0.88
75	1/4/1927	48200	22.12	1.1	0.90	1.1	0.89
76	11/12/1925	45200	21.88	1.1	0.91	1.1	0.90
77	12/13/1935	31600	21.08	1.1	0.92	1.1	0.92
78	1/17/1931	29000	20.83	1.1	0.94	1.1	0.93
79	3/5/1939	29400	20.73	1.1	0.95	1.1	0.94
80	1/28/1937	28800	20.66	1.0	0.96	1.1	0.95
81	4/12/1928	25000	20.48	1.0	0.97	1.0	0.96
82	6/17/1930	23700	20.38	1.0	0.98	1.0	0.98
83	1/23/1925	22800	20.28	1.0	1.00	1.0	0.99

Results of Technique 2

The flood stage, moderate stage, and major stage flood levels for the Burkeville Gage can be viewed on Figure 17 and the flood stage, moderate stage, and major stage all the way to the river flood levels for Burkeville Gage can be viewed on Figure 18. Figure 19 and Figure 20 show the same flood stage levels for the Bon Weir Gage. Figure 21 and Figure 22 shows the 2, 5, and 10 year calculated flood levels for the area surrounding the Burkeville and Bon Weir Gage.

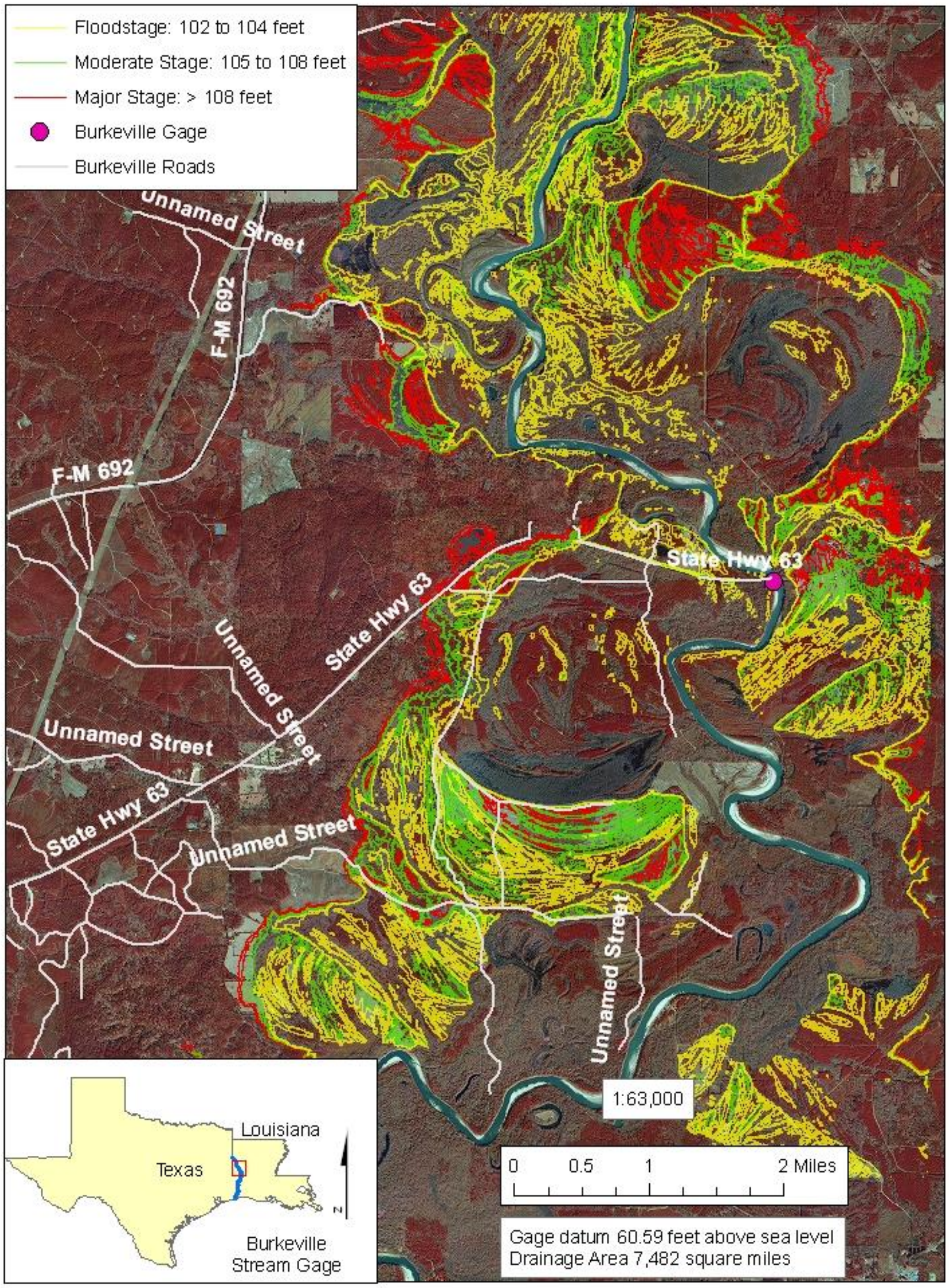

Figure 17. Flood stage, moderate stage, and major stage for Burkeville Gage.

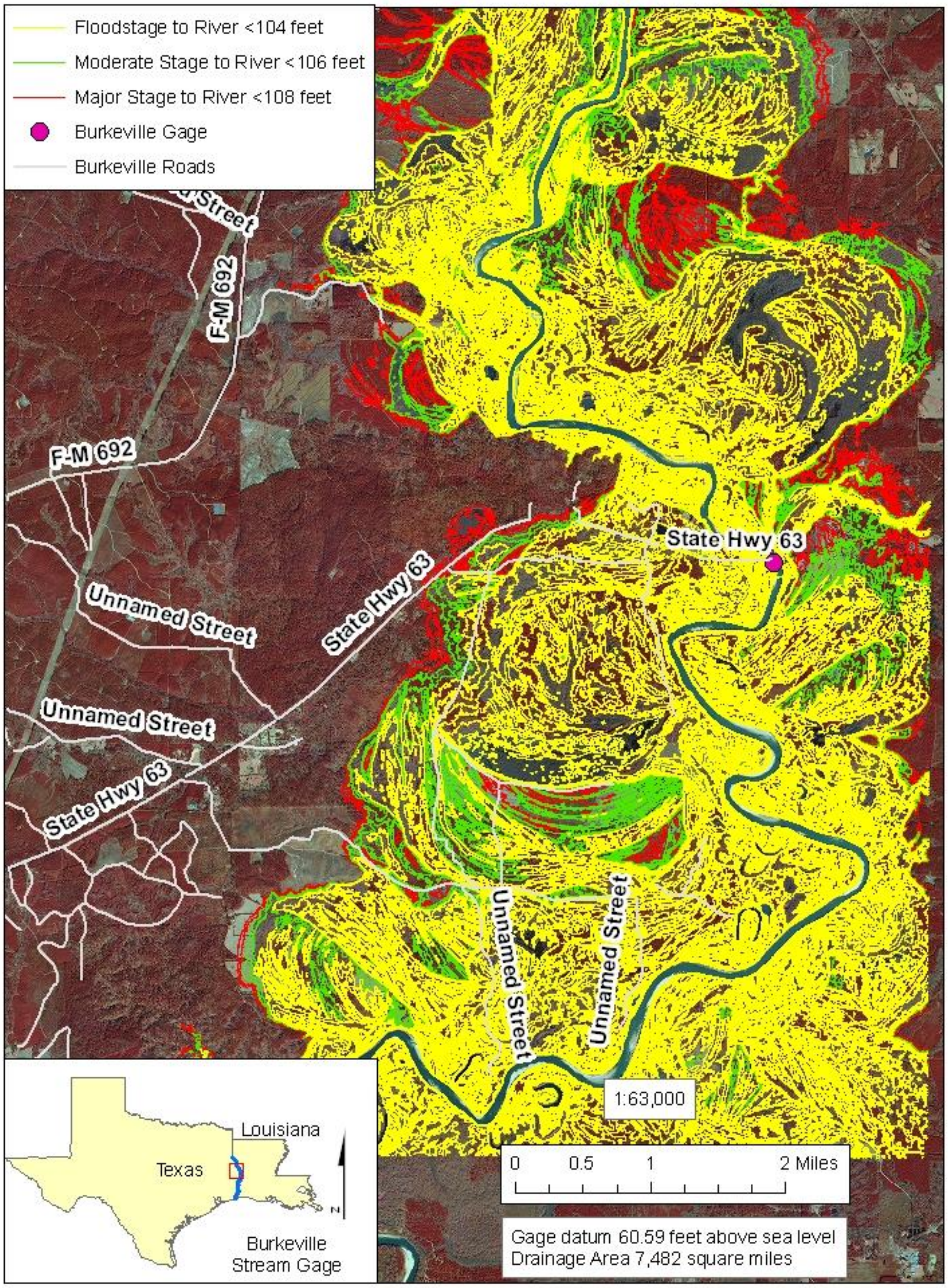

Figure 18. Flood stage, moderate stage, and major stage to river for Burkeville Gage.

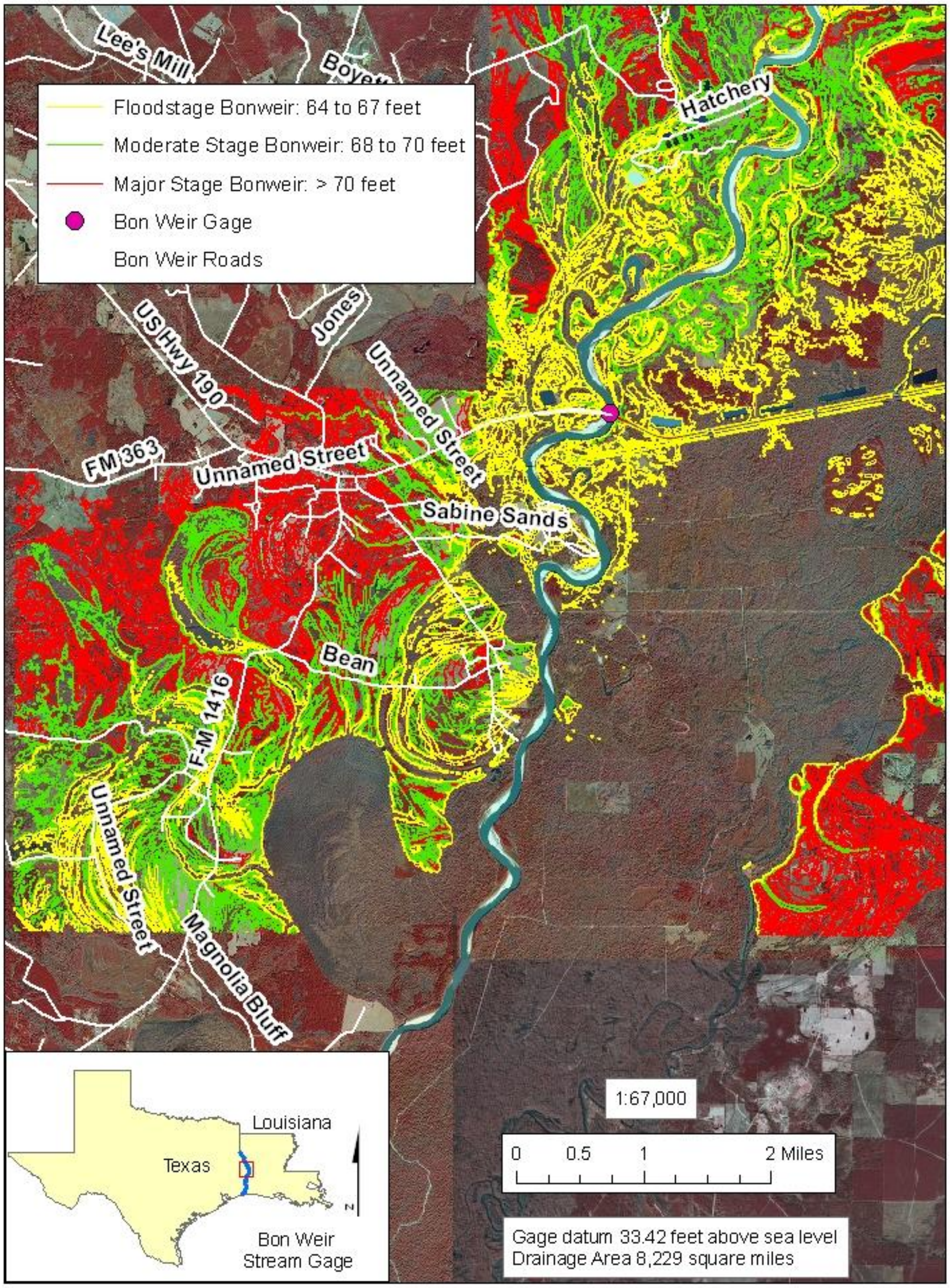

Figure 19. Flood stage, moderate stage, and major stage for Bon Weir Gage.

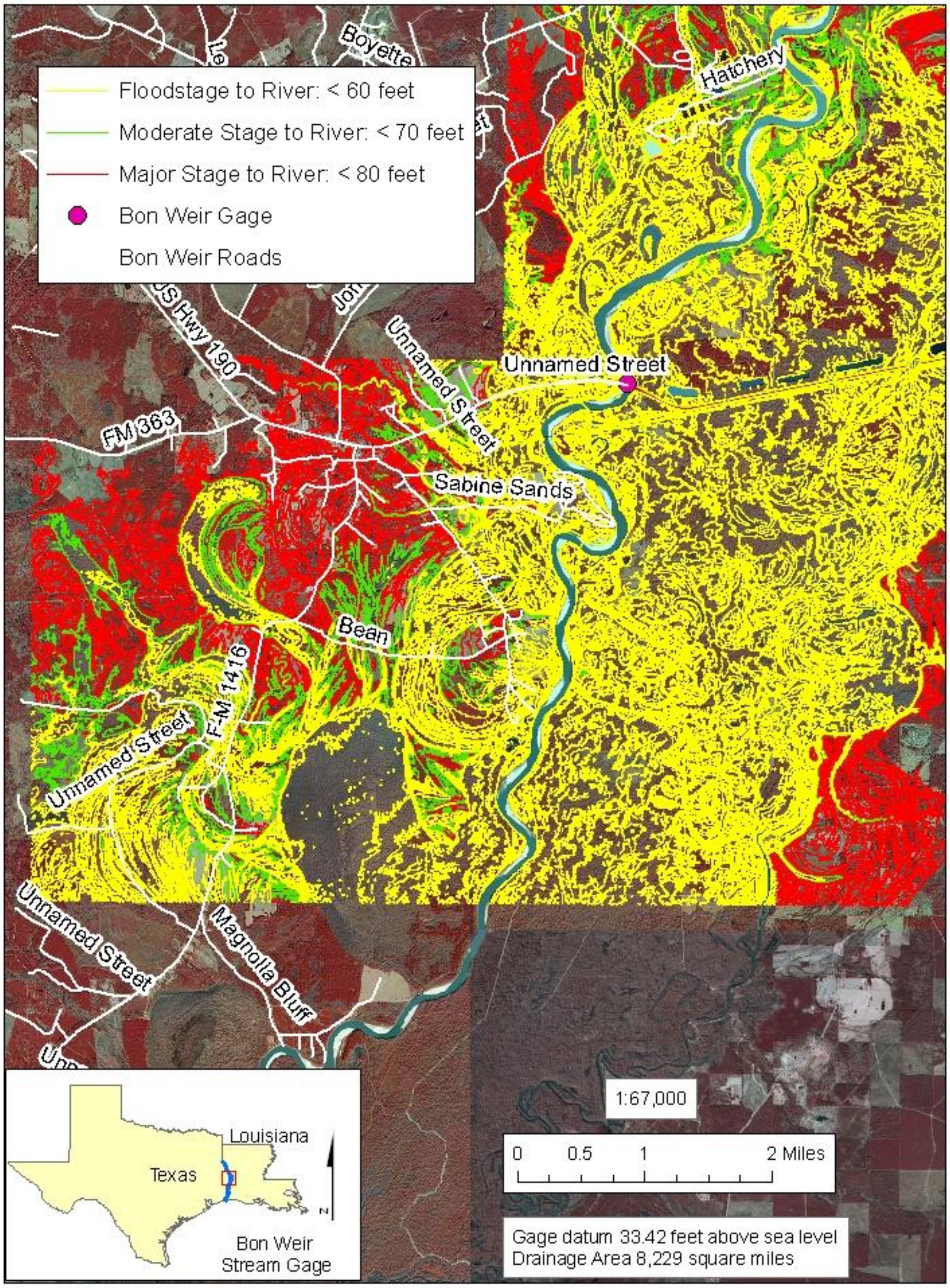

Figure 6. Flood stage, moderate stage, and major stage to river for Bon Weir Gage.

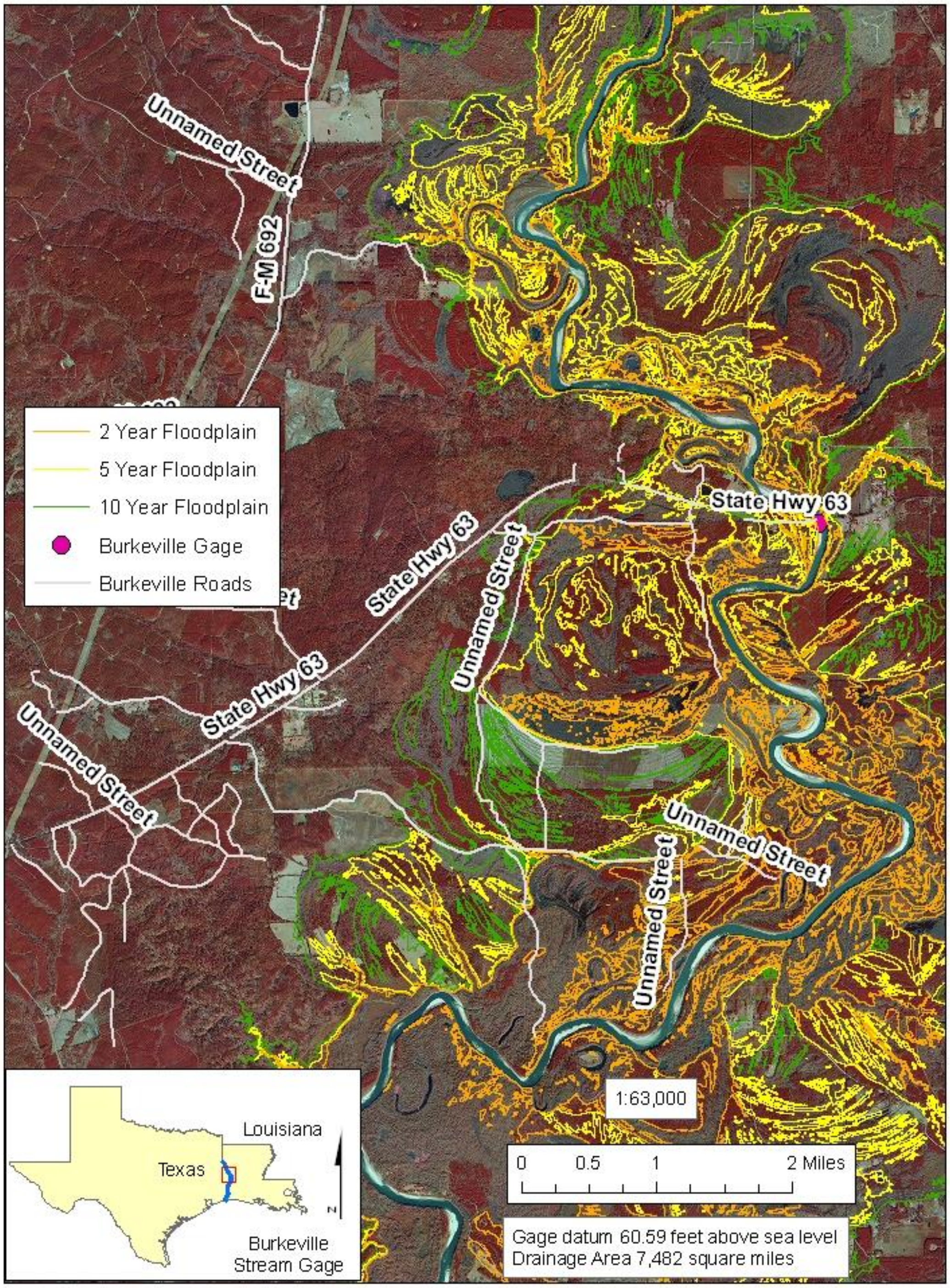

Figure 7. 2, 5, and 10 Year Flood Event for Burkeville Gage.

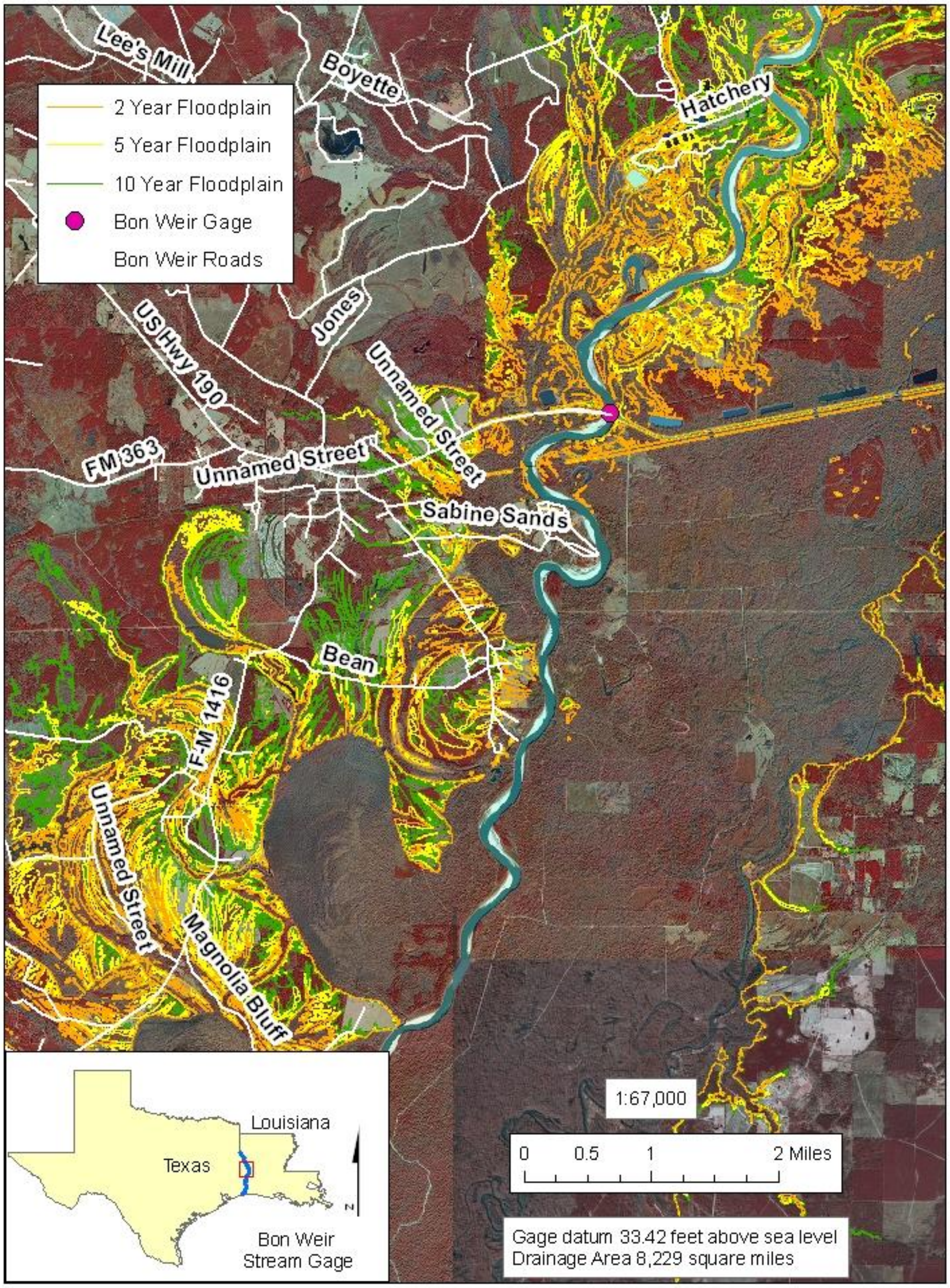

Figure 8. 2, 5, and 10 Year Flood Event for Bon Weir Gage.

Discussion

The five year floodplain (Figure 21 and Figure 22) is very similar to the flood stage event for both the Burkeville (Figure 17) and Bon Weir Gages (Figure 19). The ten year floodplain (Figure 21 and Figure 22) is very similar to the moderate stage event for both Burkeville (Figure 18) and Bon Weir Gages (Figure 20).

This technique gives one the ability to see the differences in the amount of area affected among the different flood stage events and compare them to the areas affected in the 2, 5, and 10 year flood events. The USGS website includes the stream discharge along with the different gage heights allowing one to understand the effects of stream discharge and how it correlates to different flood events.

Problems associated with this technique is that stream gages are located a distance from one another leaving a lot of variation for the area that exists between them. Another is that while these historical values for various flood stages are easily obtained, they provide no determination for a cutoff in what is and is not riparian. The only true way of determining whether an area is riparian is by the presence of hydrology, hydrophytic vegetation, and hydric soils.

Technique 3

Methods

This technique came about due to problem in the last technique with the lack of information for the areas between the gage stations. Landsat satellite images with a date close enough to a calculated flood year event were acquired for the area south of the Toledo Bend Reservoir from USGS (http://glovis.usgs.gov). Those images with high cloud cover over the area of interest were thrown out due to their inability to be used. Landsat Images acquired were February 19th, 1974, March 1st, 1979, and December 7th, 2004. If a flood event is not known for a particular image, it must be calculated which requires the use of technique 2. The satellite image bands were all then placed on band 4, a band which has an application for use in monitoring soil moisture. The soil moisture in the area of interest (Texas side only) was then digitized in each satellite image.

The same area of interest (Texas side only) was digitized and classified based on stand composition from the same Landsat Image. This was done to be used in conjunction with the digitized wet layer mentioned previously to identify the type and amount of vegetation that were wet.

Results

Figure 23 shows the February 19th, 1974 Landsat Image with the digitized flooding on the Texas side only while Figure 24 and Figure 25 both show the December 7th, 2004 Landsat Image with the digitized flooding on the Texas side only. Figure 26 shows the digitized flooding on the Texas side only for March 1st, 1979. Figure 27 represents the digitized and classified stand composition only and Figure 28 represents the digitized and classified stand composition along with the wet digitized area from March 1st, 1979. Refer to Figure 29 for the March 1st, 1979 digitized wet area overlaid on the original model output. Figure 30 shows the daily discharge for Burkeville Gage, while Figure 31 shows the daily discharge for Bon Weir and Figure 32 shows the daily discharge for Ruliff.

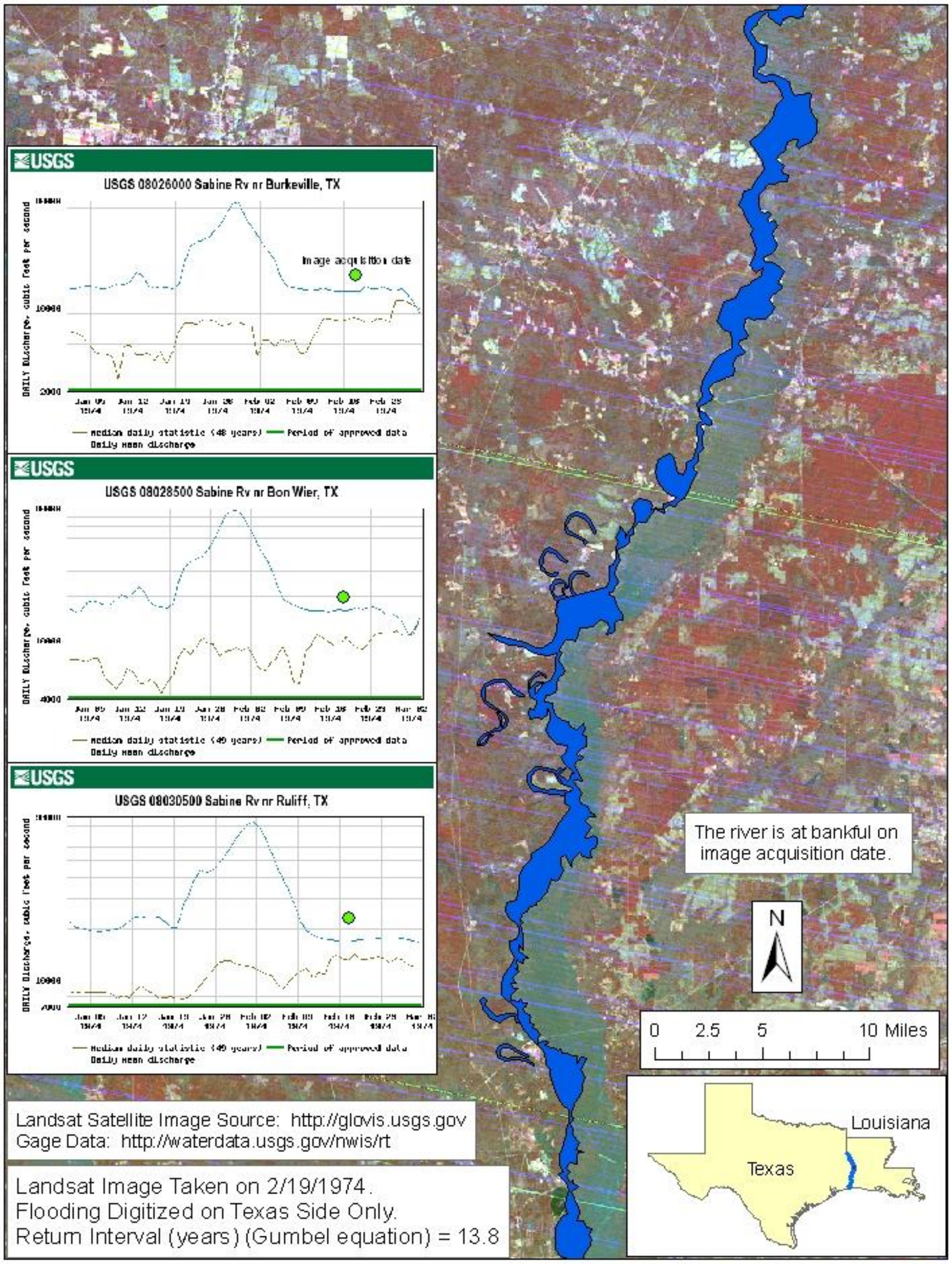

Figure 23. Landsat Satellite image taken on 2/19/74, 16 days following a 10 year flood event.

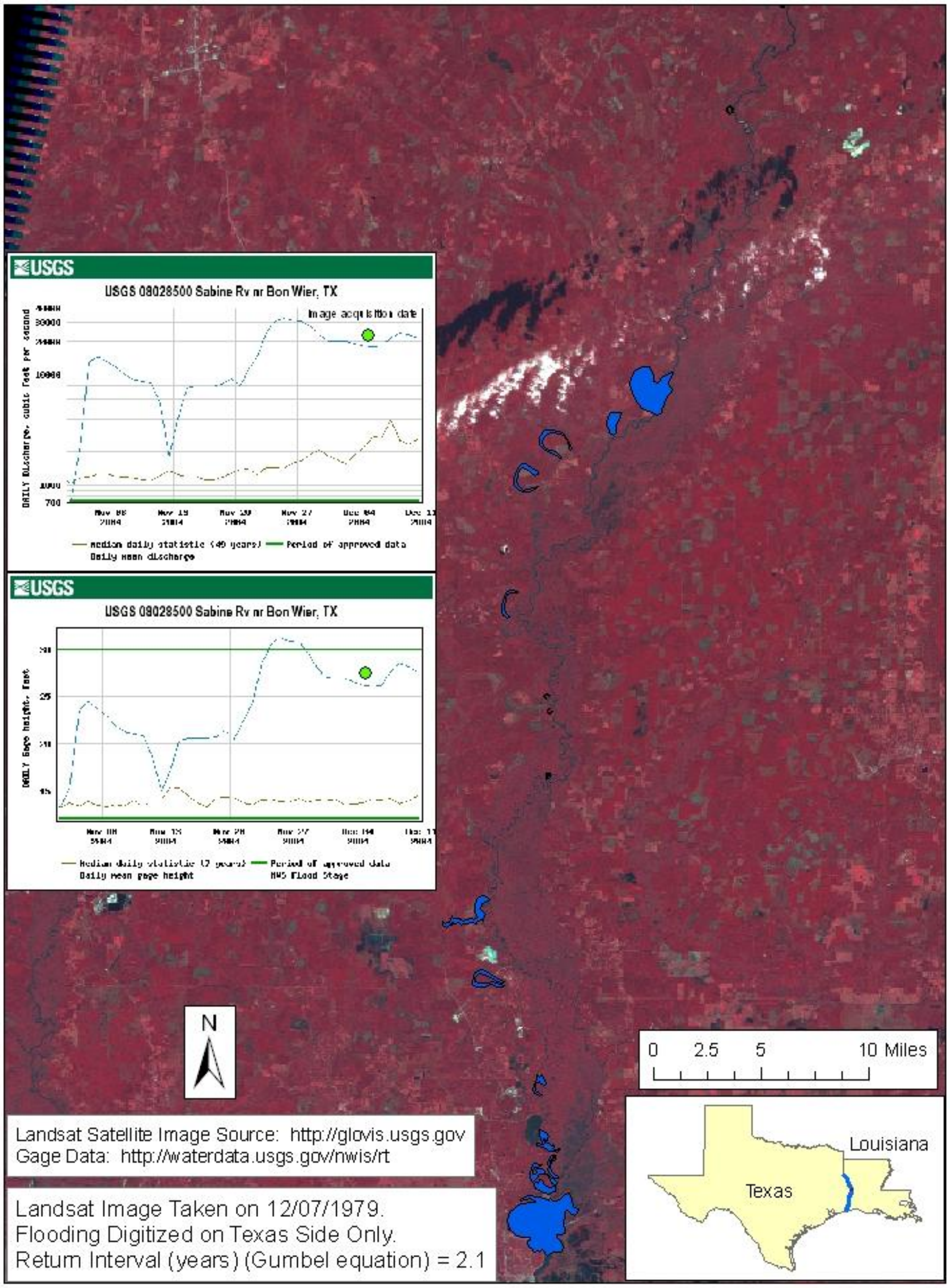

Figure 9. Landsat Satellite image taken on 12/07/79, a 2 year flood event (Bon Weir Gage).

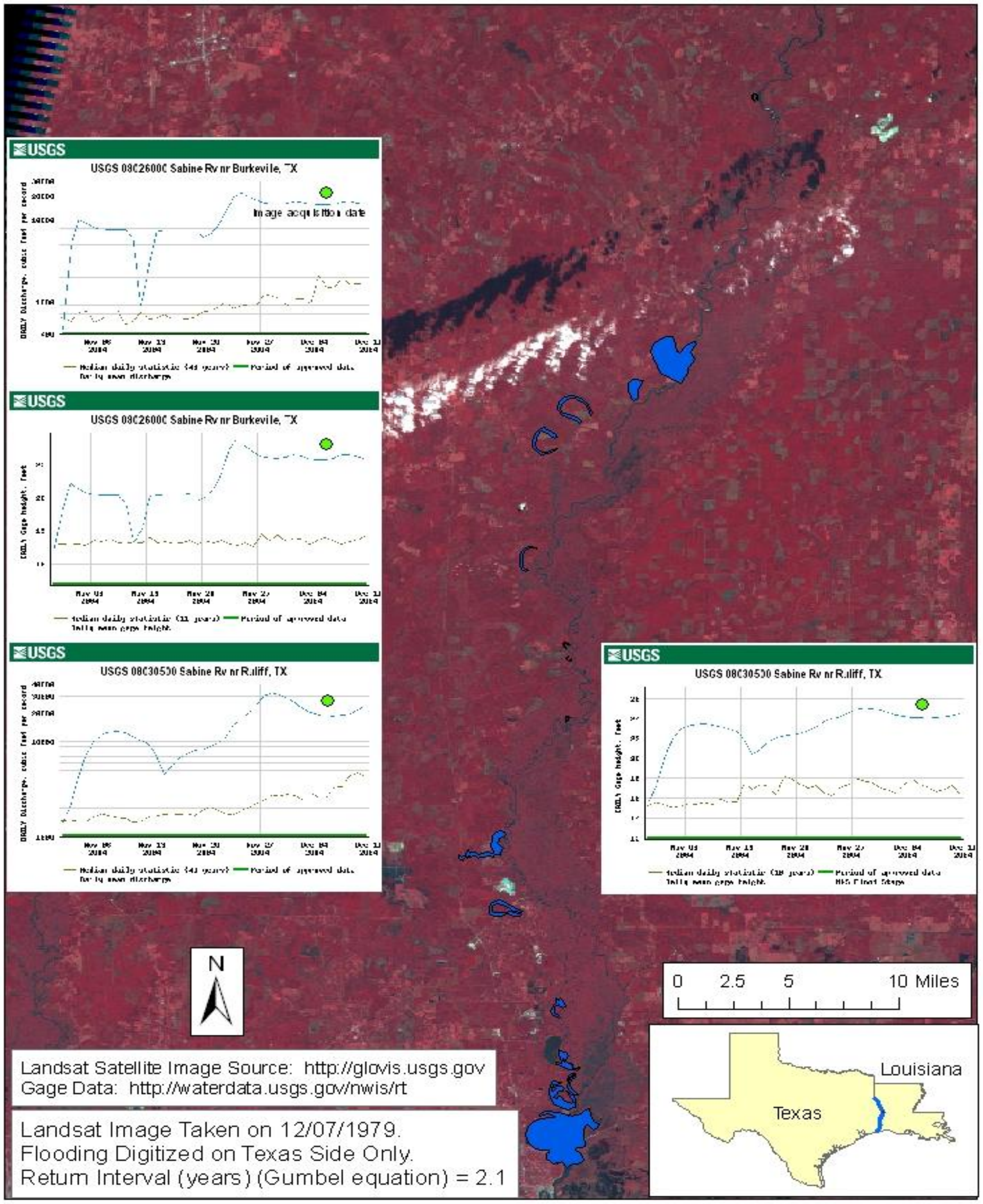

Figure 25. Landsat Satellite image taken on 12/07/79, a 2 year flood event (Burkeville and Ruliff Gages).

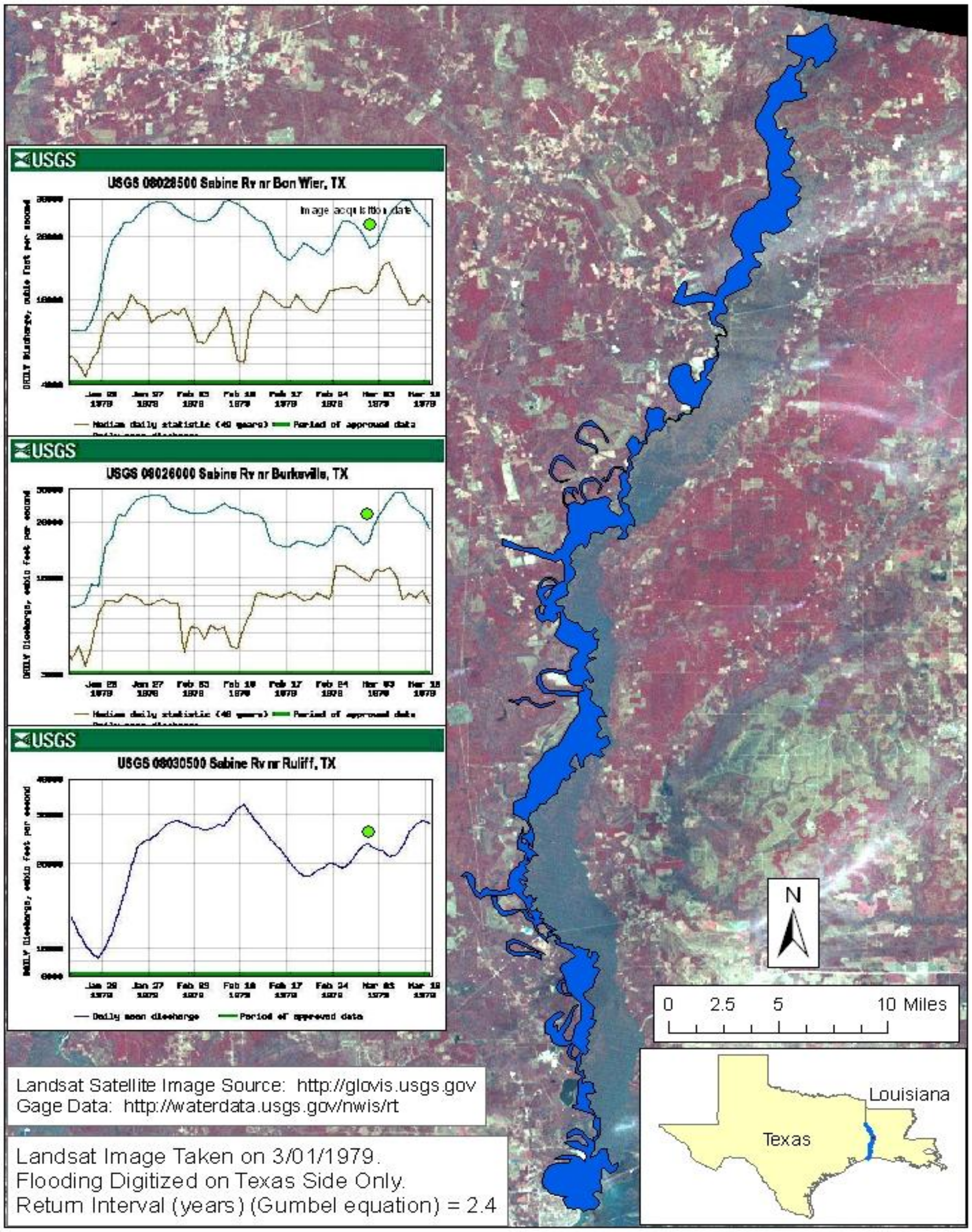

Figure 26. Landsat Satellite image taken on 03/01/79, a 2 year flood event.

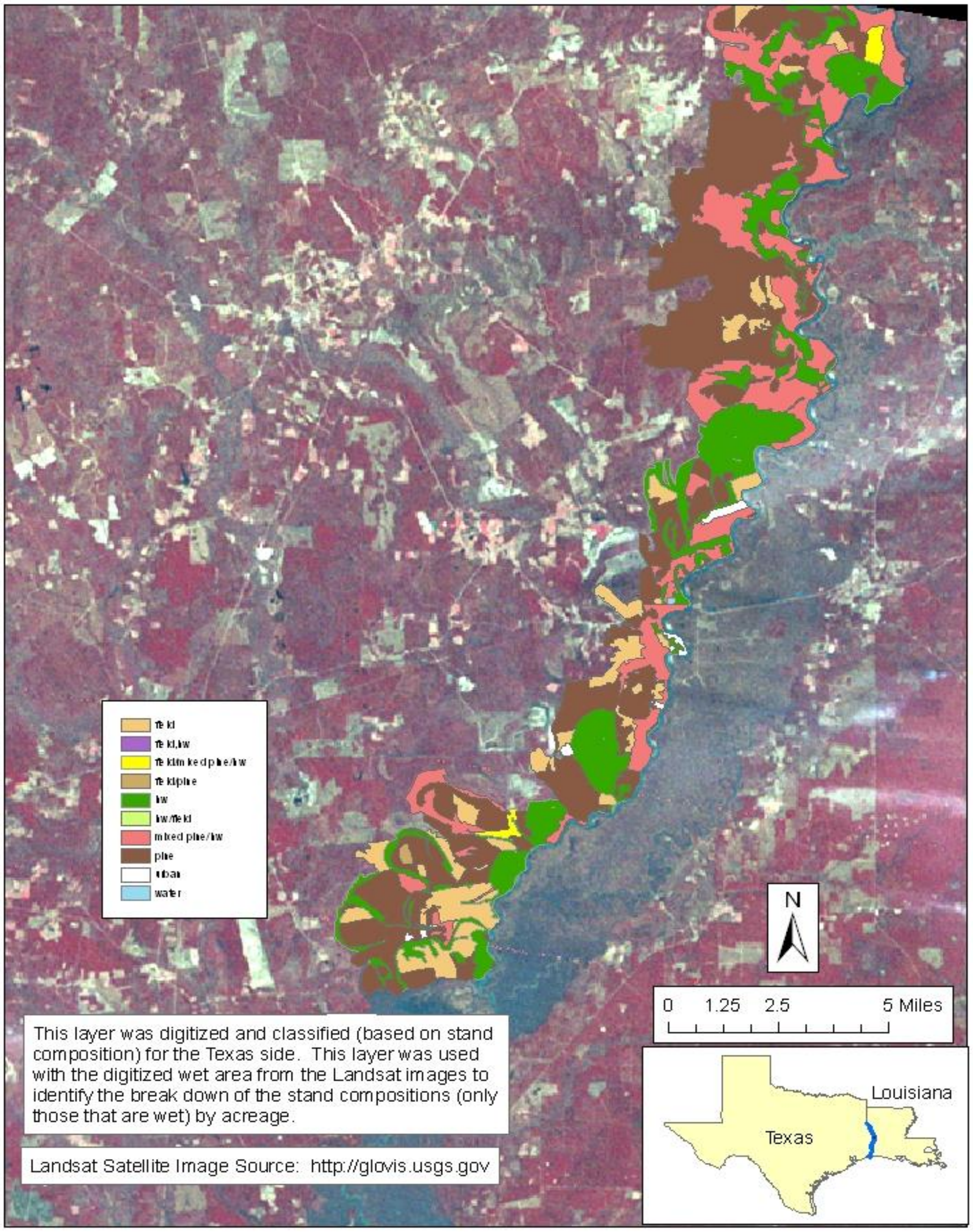

Figure 27. Digitized stand from 3/01/79 Landsat satellite image.

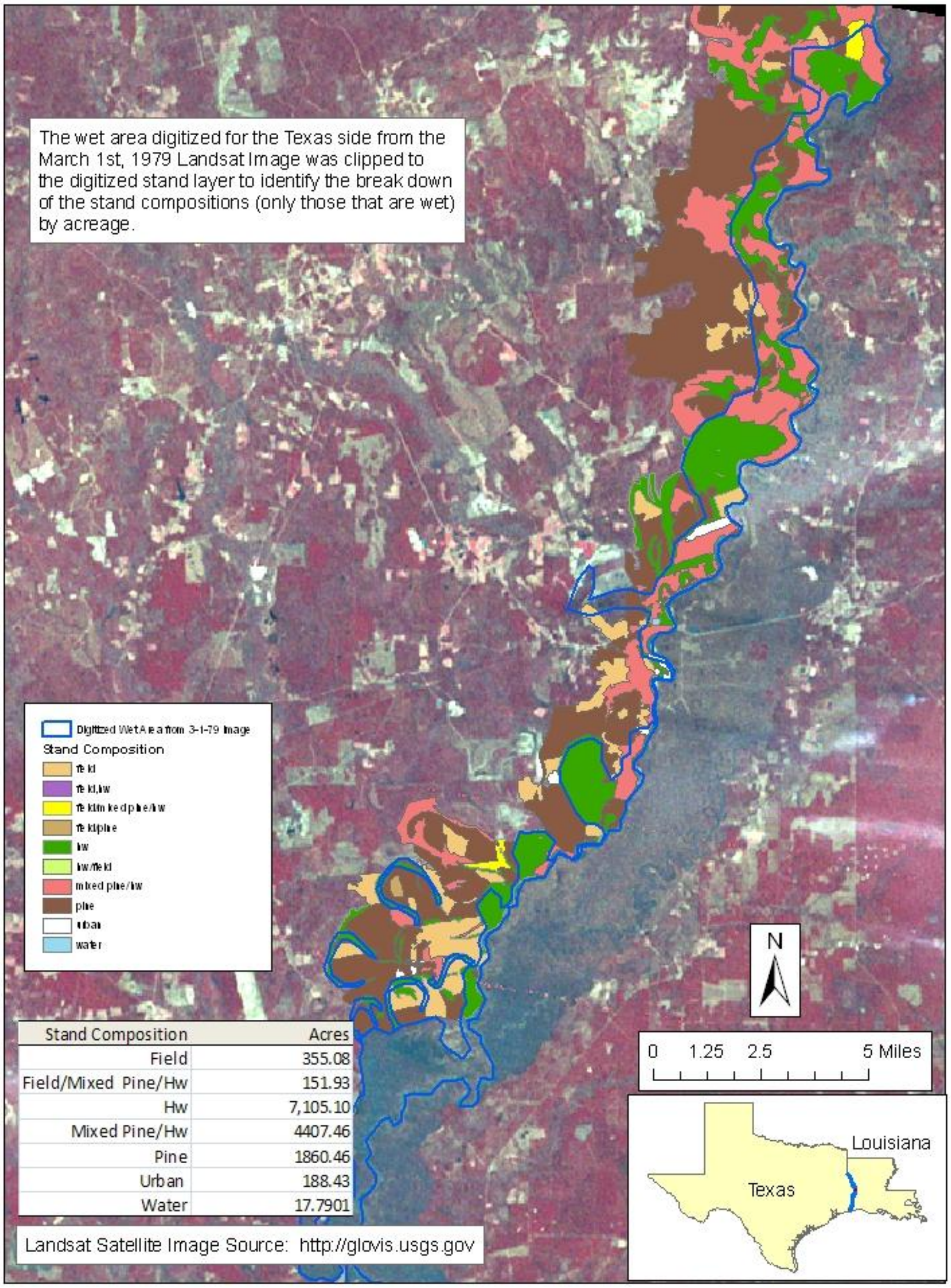

Figure 10. Digitized stand and digitized wet area from 3/01/79 Landsat Satellite image.

Discussion

The February 19th, 1974 image was taken 16 days following a 10 year flood event, while the December 7th, 2004 image was taken 9 days following a 2 year flood event and the March 1st, 1979 image was taken on a 2.5 year flood event.

Because the March 1st, 1979 flood event was a 2.5 year flood event (the requested flood event), it was utilized to compare the stand composition to the digitized wet area. Hardwood consisted of 7,105 acres of the total 14,086 acres. The next largest stand composition consisted of mixed pine and hardwood (hw) with 4,407 acres. Water made up the least of the total acres with approximately 18 acres. While urban did not consist of a very large portion of the wet area, it is still important to note that 188 acres were included in the flooded area.

This technique was extremely easy to do and provided excellent results. One problem associated with this technique was trying to find cloud free or minimal cloud cover Landsat satellite images on a date near a particular flood year event. Of the 25 images sought after to represent various flood year events, only three had minimal cloud cover and were close to a particular flood event of interest.

Analysis of Combining First and Third Techniques

Method

Because each method provides slightly different results, two or more methods can be compared by simply overlaying them. In this particular comparison, the digitized wet area and classified stand from technique 3 were overlaid on the original model output from technique 1.

Results

Figure 29 shows the results of combining the original model output from the first technique and the third technique. The pink striping represents the riparian area from the original model output while the purple hollow represents the digitized wet area from the March 1st, 1979 image. The stand composition was clipped to only those areas that were both designated as riparian in the first technique and in the wet area.

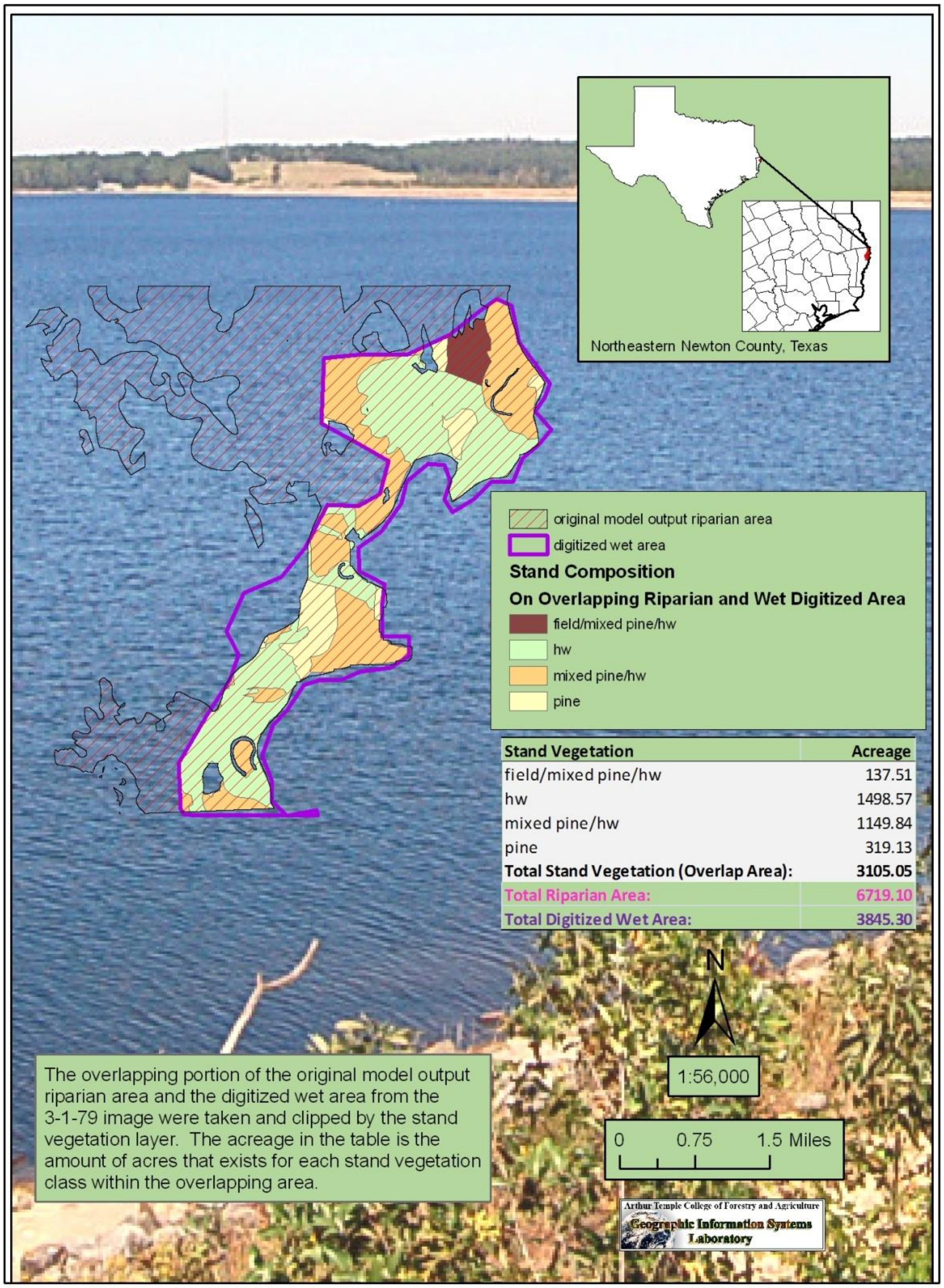

Figure 29. 3/1/79 digitized wet area overlaid on the original model output.

Discussion

The purpose of this analysis was to compare the results of different techniques. The original model output (shown in pink) from technique 1 had a total riparian area of 6,719 acres while the 2.5 year digitized flood event from March 1, 1979 (shown in purple hollowed border) was 3845 acres. The overlap area between the riparian portion of the original model output and the digitized flood event (area shown as stands) was 3105 acres (Figure 29).

There is quite a difference in the acreage of the first technique and the acreage of the third technique. This difference exists due to the first technique modeling the true riparian area and the third technique modeling a specific flood event (in this example, a 2.5 year flood event). If a slightly larger flood event were utilized, the difference would more than likely narrow. While the different techniques can easily be compared, it is important to note that no technique is considered to be more accurate than another.

Conclusion

The literature review identified some vital functions provided by a healthy riparian area that is being maintained by the flood return interval:

- Improving water Quality
  - Stabilizing stream banks against cutting actions
  - Filtering sediment
  - Capturing bed load
  - Aiding in floodplain development
  - Denitrification
- Supporting high levels of biodiversity
  - Developing diverse ponding
  - Dynamic channel characteristics
  - Unique set of plant species that change in composition up the landscape
  - Reducing stream temperature
  - Corridor for the movement of animals and seed dispersal
- Flood control
  - Dissipating stream energy
  - Reduce height, force and volume of floodwater

The most applicable definition for the riparian areas found throughout Texas is:

Riparian areas are transitional between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect water bodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems (i.e., a zone of influence). Riparian areas are adjacent to perennial, intermittent, and ephemeral streams, lakes, and estuarine-marine shorelines.
National Research Council 2002

All three GIS based techniques can be utilized to determine the riparian area or at least an area of flooding based on a specific flood event. While the techniques are all formulated for a similar purpose, each offers a user a slightly different perspective and thus use. These techniques were developed to utilize data that was free to download, and using common software packages to manipulate these datasets.

If a user is interested in determining the riparian boundary based on ecological concepts of looking at the riparian area as a system, the first technique should be utilized. If the user is interested in utilizing the flood stage, as it relates to discharge from the reservoir at a gage station area the method of calculating the return interval and annual probability (Gringorten and Gumbel Equations) with a particular event date, flow, or gage height of interest, the second technique should be utilized. The third technique should be utilized to view a particular flood event of interest on the landscape or to identify what vegetation types and how much of each were wet. The third technique is potentially the most definitive method for displaying exactly where soil moisture is during or following a flood or rain event. This illustrates differences in soil texture, site characteristics, and ridge-swale complexes.

There are numerous on the ground survey methods and classification techniques that can be used for surveying the riparian area. The method to be used should be selected based on location and purpose of the delineation. Due to the high variability of sites that fall under the category of riparian, literature suggest no single technique was sensitive enough the extent that any and all riparian areas could be clearly delineated. Regional guidebooks or parts of different guidebooks could be used as tools to identify components that would illustrate the riparian area of interest.

Riparian Ecological Effects Downstream of Dams

The impact a dam has on riparian areas below the structure is to some extent well documented in the literature where common consensus is it changes the flow of water, sediment, energy, nutrients, biota, and in general alter to some extent the important ecological processes of the riparian area (Gup 1994; Ligon et al 1995; Petts 1980). The majority of the resources identified in the scientific literature devoted to identifying the effects of dams on riparian areas are generally short term biological studies. These biological studies reveal vitally important information about the health of the stream and riparian area. Ligon et al. (1995) describes the need to understand the geomorphic impacts below dams, because as they put it "If a stream's physical foundation is pulled out from under the biota, even the most insightful biological research program will fail to preserve ecosystem integrity". They go on to state that geomorphological adjustments may lead to ecological changes in the flux of energy and nutrients, while altering the habitat for riparian vegetation, mammal and herps, invertebrates, and fish. This implies that one crucial component to protecting the biological integrity of a river would be to minimize or mitigate the physical geomorphic changes. So the logical approach to maintaining the riparian area below dams would be to maintain the "natural" morphology of the river system by managing water and sediment release in ways that mimic the pre-dam geomorphic processes. For a complete review of the geomorphic processes, controls and transition zones in the lower Sabine River *see:* Phillips and Slattery (2007).

Flood Pulsing

The flood pulse interconnects the river channel to the floodplain and drives the functions of production, decomposition, and consumption (Sparks et al. 1990). Junk et al. (1989) emphasizes the flood pulse concept as being the water to land interactions that create and maintain riparian areas, which are some of the most productive and diverse ecosystems in the world. These water fluctuations drive succession in floodplains (Middleton 1990). Unfortunately, through river regulation, the majority of the riverine forested wetlands in the southeastern United States have had a hydrologic regime change. The reestablishment of the original water dynamics in changed systems is a critical aspect in wetland restoration, even more so than the reestablishment of the plant community (Middleton 2002). When the discharge from dams is abnormally high during summer months of the growing season, the regeneration of riparian forest species can be disrupted (Schneider et al. 1989). At the other end of the spectrum, when discharge is abnormally low parts of the floodplain may become disconnected from the river and thereby change the composition of plant species (Williams and Wolman 1984). In order to sustain the diverse riparian vegetation composition along a regulated river, the post-dam flow regime must closely mimic the pre-dam flow regime. The most important factor in managing a riparian area is sustaining the hydrological characteristics of the system (Naiman and Decamps 1997).

Ligon et al. (1995) does not believe there is a general method for determining flow regimes that are applicable to most or all streams. They go on to say what is needed for each river is an individual prescription that involves both water and sediment. This water and sediment prescription should be based on the geomorphic and ecological assessments of the effects the dam has on the river ecosystem. Predicting the geomorphic and biological changes prior to a dam being created may be extremely difficult, and mitigating stream changes below existing dams could prove to be even more difficult. Meade et al. (1990) explains that much of this difficulty arises from the altered sediment supply that is greatly reduced immediately below the dam and increases downstream due to tributary and bank inputs. Ideally flows should be scheduled to transport post-dam sediment that is similar to pre-dam sediment transport. Developing a schedule like this however is generally not possible (Ligon et al. 1995).

Pre and Post Toledo Bend Dam Flow Regime

Evidence suggest there in no reduction in the annual discharge following the construction of Toledo Bend in 1967 (Phillips 2003). Phillips (2001) found that peak flows did not notably change in the lower Sabine River between pre and post dam conditions. In fact, the pattern of dam release is highly variable, creating artificial flow regimes that mimic the pre-dam flow regime (Phillips 2003).

The annual peak flows for USGS gage station 08026000 on the Sabine River near Burkeville, TX were graphed in Figure 30. This gage is located at Latitude 31°03'50", Longitude 93°31'10" (NAD 27) in Newton county Texas within hydrologic unit 12010005. The contributing drainage area is 7, 482 square miles. The period of record at the Burkeville does not have many data points prior to the construction of Toledo Bend Reservoir, so pre and post dam peak flow comparisons could not be made at this gage location.

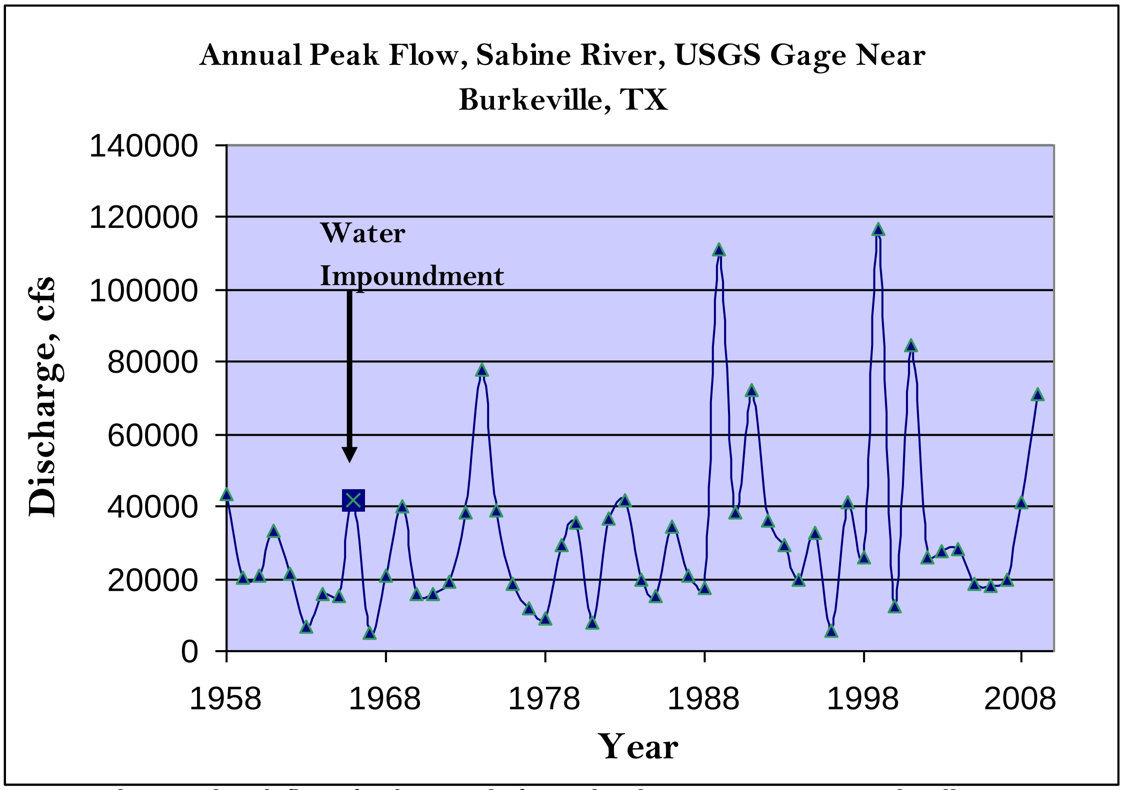

Figure 30. The annual peak flows for the period of record at the gage station near Burkeville, TX.
Source: USGS

The annual peak flows for USGS gage station 08028500 on the Sabine River near Bon Wier, TX were graphed in Figure 31. This gage is located at Latitude 31°44’49”, Longitude 93°36’30” (NAD 27) in Newton county Texas within hydrologic unit 12010005. The contributing drainage area is 8,229 square miles. Peak flow pre and post dam have not been greatly changed for the period of record at the gage station near Bon Weir, TX.

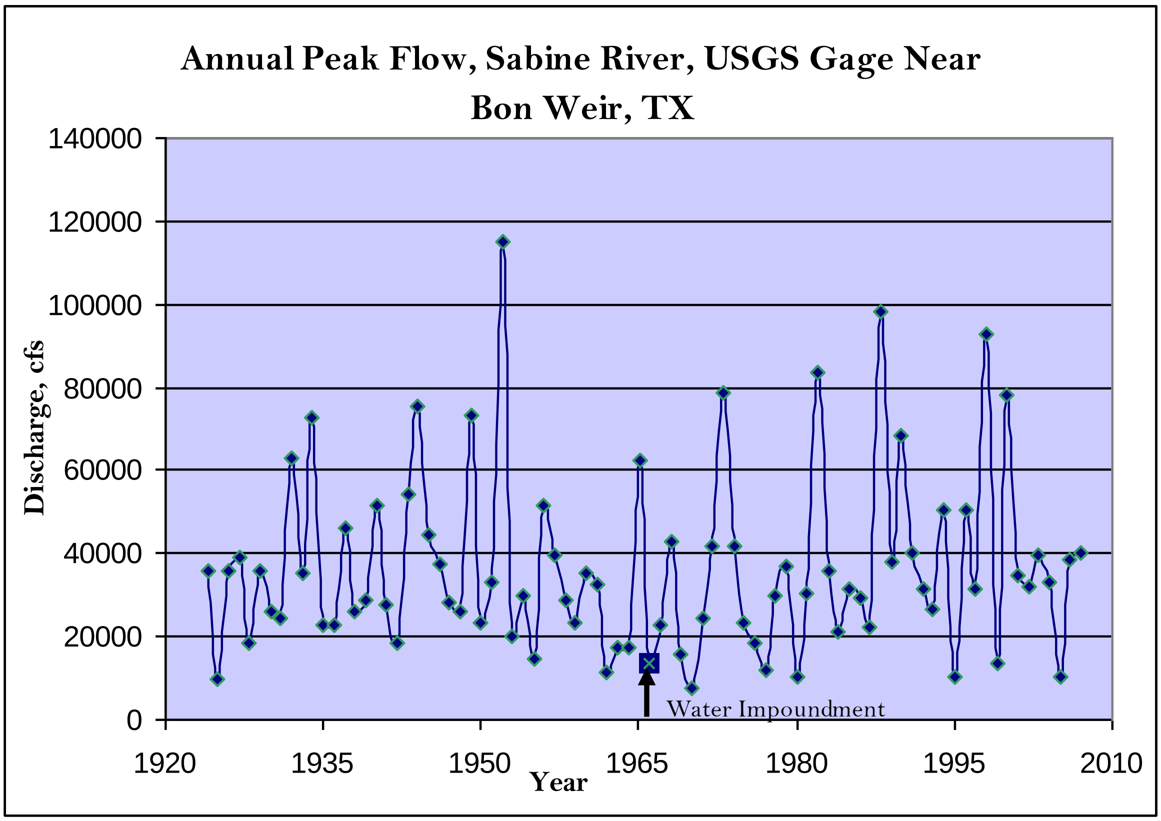

Figure 11. The annual peak flows for the period of record at the gage station near Bon Weir, TX. *Source: USGS*

The annual peak flows for USGS gage station 08030500 on the Sabine River near Ruliff, TX were graphed in Figure 32. This gage is located at Latitude 30°18'13", Longitude 93°44'17" (NAD 27) in Newton County, Texas within hydrologic unit 12010005. The contributing drainage area is 9,329 square miles. Peak flow pre and post dam have not been greatly changed for the period of record at the gage station near Ruliff, TX.

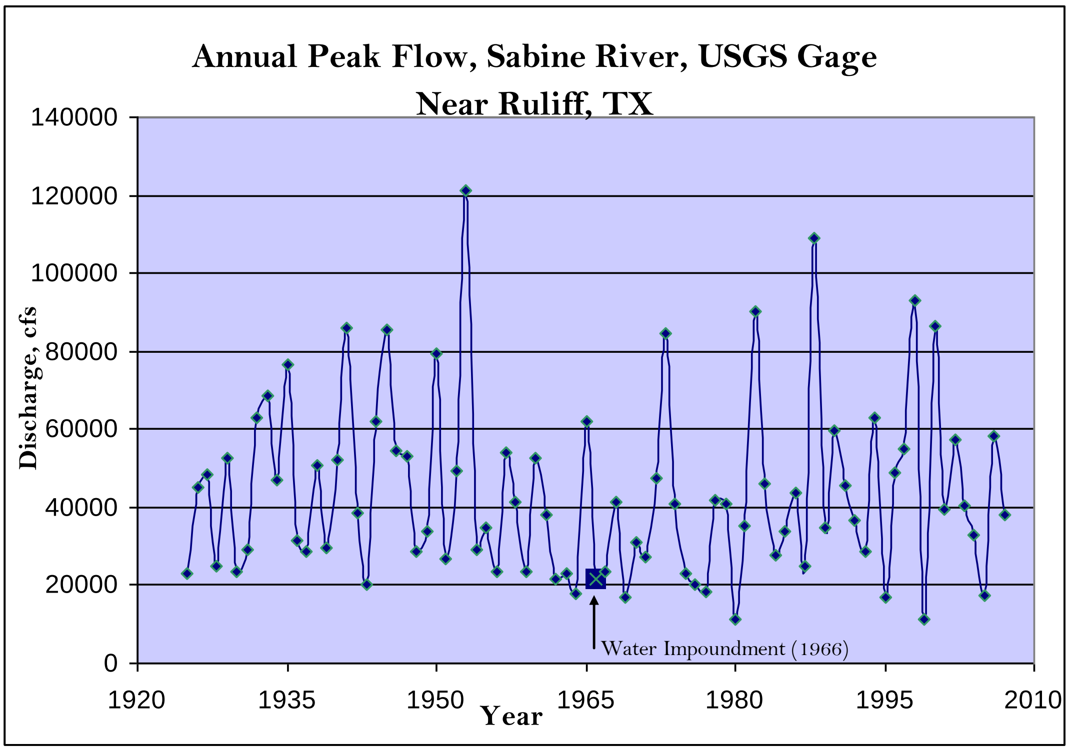

Figure 12. The annual peak flows for the period of record at the gage station near Ruliff, TX.
Source: USGS

Phillips (2003) states the dam may unnaturally and abruptly release water, but when looking at the long-term pattern of release the pre and post dam hydrologic regime similarity is evident. Figures 30 – 32 illustrates at least for the time during which discharge has been recorded the flow regime pre and post dam are similar. Rivers flood in the winter and spring and are lower in the summer and fall months (Bayley 1991). Tables 42-45 demonstrate that seasonal patterns of release on the Sabine River below Toledo Bend are similar between the pre- and post - dam hydrologic conditions (Freese and Nichols).

Table 42. Comparison of **Winter** (January - March) Pre-Dam (1941 - 1960) and Post-Dam (1971 - 2005) flows of the Sabine River at Sabine Lake.

	Pre-Dam Dry Hydrologic Conditions (Dry 25th Percentile)	Post-Dam Dry Hydrologic Conditions (Dry 25th Percentile)	Pre-Dam Average Hydrologic Condition (Ave. 50th Percentile)	Post-Dam Average Hydrologic Conditions (Ave. 50th Percentile)	Pre-Dam Wet Hydrologic Conditions (Wet 75th Percentile)	Post-Dam Wet Hydrologic Conditions (Wet 75th Percentile)
Pulse Characteristics						
Frequency (per season)	2	3	2	2	1	1
Duration (days)	15	10	23	19	38	28
Peak Flows (cfs)	16643	16391	35389	38160	61265	56217
Volume (acre-feet)	368571	281667	847385	1058454	2352705	1836286
Base Flow (cfs)	5744	5600	12864	21809	27166	35503

	Pre Dam:	Post Dam:
Return Period (years)	6.7	11.7
Volume (acre-feet)	5349924	3427220
Duration (days)	47	28
Peak Flow (cfs)	144103	156575
Subsistence Flow (csf)	N/A	N/A

Source: (Freese and Nichols HERF Model Output)

Table 43. Comparison of Spring (April - June) Pre-Dam (1941 - 1960) and Post-Dam (1971 - 2005) flows of the Sabine River at Sabine Lake.

	Pre-Dam Dry Hydrologic Conditions (Dry 25th Percentile)	Post-Dam Dry Hydrologic Conditions (Dry 25th Percentile)	Pre-Dam Average Hydrologic Condition (Ave. 50th Percentile)	Post-Dam Average Hydrologic Conditions (Ave. 50th Percentile)	Pre-Dam Wet Hydrologic Conditions (Wet 75th Percentile)	Post-Dam Wet Hydrologic Conditions (Wet 75th Percentile)
Pulse Characteristics						
Frequency (per season)	2	3	1	2	1	1
Duration (days)	4	5	23	15	34	24
Peak Flows (cfs)	18231	7250	31036	15207	48142	48255
Volume (acre-feet)	296272	72404	799361	317646	1844017	1265935
Base Flow (cfs)	3760	4143	10360	7154	24213	25043

	Pre Dam:	Post Dam:
Return Period (years)	6.7	11.7
Volume (acre-feet)	5349924	3427220
Duration (days)	47	28
Peak Flow (cfs)	144103	156575
Subsistence Flow (cfs)	N/A	N/A

Source: (Freese and Nichols HERF Model Output)

Table 44. Comparison of **Summer** (July – September) Pre-Dam (1941 – 1960) and Post-Dam (1971 – 2005) flows of the Sabine River at Sabine Lake.

	Pre-Dam Dry Hydrologic Conditions (Dry 25th Percentile)	Post-Dam Dry Hydrologic Conditions (Dry 25th Percentile)	Pre-Dam Average Hydrologic Condition (Ave. 50th Percentile)	Post-Dam Average Hydrologic Conditions (Ave. 50th Percentile)	Pre-Dam Wet Hydrologic Conditions (Wet 75th Percentile)	Post-Dam Wet Hydrologic Conditions (Wet 75th Percentile)
Pulse Characteristics						
Frequency (per season)	2	4	1	2	1	1
Duration (days)	14	5	20	15	35	23
Peak Flows (cfs)	6354	8151	11884	10794	35984	16804
Volume (acre-feet)	129120	77921	328888	278593	672030	586770
Base Flow (cfs)	1703	4476	2252	6262	3134	8935

	Pre Dam:	Post Dam:
Return Period (years)	6.7	11.7
Volume (acre-feet)	5349924	3427220
Duration (days)	47	28
Peak Flow (cfs)	144103	156575
Subsistence Flow (cfs)	561	1012

Source: (Freese and Nichols HERF Model Output)

Table 45. Comparison of **Fall** (October-December) Pre-Dam (1941- 1960) and Post-Dam (1971 - 2005) flows of the Sabine River at Sabine Lake.

	Pre-Dam Dry Hydrologic Conditions (25th Percentile)	Post-Dam Dry Hydrologic Conditions (25th Percentile)	Pre-Dam Average Hydrologic Condition (50th Percentile)	Post-Dam Average Hydrologic Conditions (50th Percentile)	Pre-Dam Wet Hydrologic Conditions (75th Percentile)	Post-Dam Wet Hydrologic Conditions (75th Percentile)
Pulse Characteristics						
Frequency (per season)	2	3	1	2	0	1
Duration (days)	12	5	23	16	30	21
Peak Flows (cfs)	6812	6365	15196	12040	37201	32042
Volume (acre-feet)	156465	59138	397760	220166	1027343	739311
Base Flow (cfs)	1636	4048	2347	4936	3906	6493

	Pre Dam:	Post Dam:
Return Period (years)	6.7	11.7
Volume (acre-feet)	5349924	3427220
Duration (days)	47	28
Peak Flow (cfs)	144103	156575
Subsistence Flow (cfs)	799	914

Source: (Freese and Nichols HERF Model Output)

Lewis et al. (2003) points out that sediment production, transportation, deposition and storage is a complex yet balanced system in which the modification of one component will affect other parts. This system is a functioning component of the riparian area. When a reservoir is placed on a river, ideally post dam flows of sediment loads would mimic a frequency and morphological effect similar to pre-dam conditions (Ligon et al. 1995). There is a large amount of sediment supplied by the Sabine, Trinity, Brazos, Colorado, and Rio Grande Rivers which nourish deltas, barrier islands, and fringing lagoons along the Texas Gulf Coast (Swanson 1995). Sediment yield estimates indicate ample alluvium will be supplied by the lower Sabine even if the Toledo Bend Reservoir is effective at trapping all incoming sediment (Phillips 2003). Much of the sediment supply is greatly reduced immediately below the dam and increasing downstream due to tributary and bank inputs (Meade et al. 1990). A very expensive solution would be to add sediment directly below the dam. The best designed reservoir would be one in which it passes sediment on a regular basis with a frequency of natural sediment transport regimes.

PROBABILITY OF INUNDATION CURVE

Tambacci's curve (See: Petts and Kennedy 2005) in (Figure 33) represents the riparian area as the sum of the transitional gradients based on a probability of inundation. This illustration corresponds well to the ecology of large floodplains of the Southeast U.S. This is due to the gently sloping topography moving away from the river bank which leads to the flood frequency and depth to be inversely proportional to floodplain elevation (Brinson 1990). This curve accurately conveys the concept described by Odum (1978) that hydrologic regime is the major driving force that creates and maintains the riparian area. The riparian area as defined in this study continues up the landscape, this is a component the curve fails to illustrate. A component in which this curve may not be applicable in the southeast is its applicability to first and second order streams such as headwater streams. These streams may not overbank flood as a result of the small watershed draining into that section of the stream. This curve would imply the aquatic area is directly adjacent to the terrestrial area effectively bypassing the riparian area. This review was unable to apply Tambacci's curve to riparian area delineation or flow requirements.

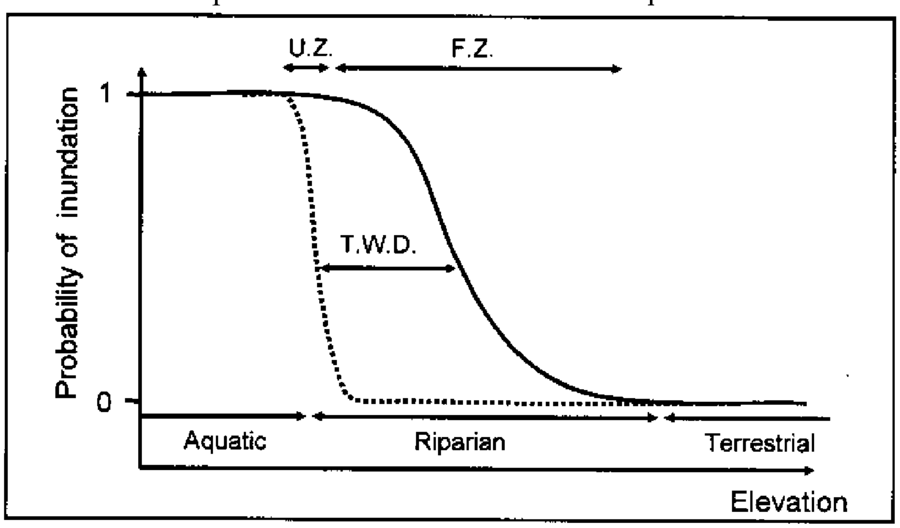

Figure 13. The probability of inundation curve as it relates to the riparian area.
Source: Adapted from Tabbacchi 2001: In Petts and Kennedy 2005.

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APPENDIX

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A2. Riparian Area Definitions Reviewed

Below is a list of commonly cited definitions of the riparian area from regulatory agencies, and peer reviewed scientific literature. In order to maintain the author's complete meaning of the term 'riparian' each definition is in the author's original words.

Author: U.S. Department of Agriculture Natural Resources Conservation Service
Year: 1991
Title: General Manual, 190-GM, part 411.
Definition: Riparian areas are ecosystems that occur along watercourses and water bodies. They are distinctly different from the surrounding lands because of unique soil and vegetation characteristics that are strongly influenced by free or unbound water in the soil. Riparian ecosystems occupy the transitional area between the terrestrial and aquatic ecosystems. Typical examples include floodplains, stream banks, and lakeshores.

Author: U.S. Environmental Protection Agency
Year: 1993
Title: Guidance specifying management measures for sources of nonpoint pollution in Coastal waters.
Definition: Riparian areas are vegetated ecosystems along a water body through which energy, materials and water pass; characterize riparian areas as having a high water table, subject to periodic flooding and encompassing wetlands.

Author: Forest Management Assessment Team

Year: 1993

Title: Forest ecosystem management: An ecological, economic, and social assessment.

Definition: Riparian reserves are portions of watersheds where riparian-dependent resources receive primary emphasis and where special standards and guidelines apply to attain Aquatic Conservation Strategy objectives. Riparian Reserves include those portions of a watershed required for maintaining hydrologic, geomorphic, and ecologic processes that directly affect standing and flowing water bodies such as lakes and ponds, wetlands, and streams.

Author: U.S. Department of Agriculture Forest Service

Title: Watershed protection and management

Year: 1994

Definition: Riparian areas include the aquatic ecosystem, the riparian ecosystem and wetlands. While this broadly defined riparian areas, it also defined `riparian ecosystem' as restricted to those areas with soil characteristics or distinctive vegetation that requires free or unbound water.

Author: E.S. Veery, C.A. Dolloff, M.E. Manning

Year: 2004

Title: Riparian Ecotone: A functional definition and delineation for resource assessment.

Definition: Riparian ecotones are a three-dimensional space of interaction that include terrestrial and aquatic ecosystems that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at a variable width.

Author: USDI Fish and Wildlife Service

Year: 1997

Definition: Riparian areas are plant communities contiguous to and affected by surface and subsurface hydrologic features of perennial or intermittent lotic and lentic water bodies (rivers, streams, lakes, or drainage ways). Riparian areas have one or both of the following characteristics: (1) distinctly different vegetative species than adjacent areas, and (2) species similar to adjacent areas but exhibiting more vigorous or robust growth forms. Riparian areas are usually transitional between wetland and upland.

Author: USDA Forest Service, Region 9 (Parrott et al. 1989)

Year: 1997

Definition: Riparian areas are composed of aquatic ecosystems, riparian ecosystems and wetlands. They have three dimensions: longitudinal extending up and down streams and along the shores; lateral to the estimated boundary of land with direct land-water interactions; and vertical from below the water table to above the canopy of mature site-potential trees.

Authors: B.L. Ilhardt, E.S. Veery, B.J. Palik

Year: 2000

Title: Defining Riparian Areas

Definition: Riparian areas are three-dimensional ecotones of interaction that include terrestrial and aquatic ecosystems that extend down into the groundwater, up above the canopy, outward across the floodplain, up the near-slopes that drain to the water, laterally into the terrestrial ecosystem, and along the water course at a variable width.

Author: U.S. Department of Agriculture Forest Service.

Year: 2000

Title: Forest Service Manual, Title 2500, Watershed and Air Management

Definition: Riparian areas are geographically delineated areas, with distinctive resource values and characteristics that are comprised of the aquatic and riparian ecosystems. They give special attention to the area within a horizontal distance of 30 m from the edge of perennial streams or other water bodies. A riparian ecosystem is a transition between the aquatic ecosystem and the adjacent terrestrial ecosystem; identified by soil characteristics or distinctive vegetation communities that require free and unbound water. (Revision of 1994)

Author: National Research Council

Year: 2002

Title: Riparian areas: Functions and Strategies for Management

Definition: Riparian areas are transitional between terrestrial and aquatic ecosystems and are distinguished by gradients in biophysical conditions, ecological processes, and biota. They are areas through which surface and subsurface hydrology connect water bodies with their adjacent uplands. They include those portions of terrestrial ecosystems that significantly influence exchanges of energy and matter with aquatic ecosystems (i.e., a zone of influence). Riparian areas are adjacent to perennial, intermittent, and ephemeral streams, lakes, and estuarine-marine shorelines.

Author: U.S. Department of the Interior Bureau of Land Management

Year: 1999

A riparian area is an area of land directly influenced by permanent water. It has visible vegetation or physical characteristics reflective of permanent water influence. Lake shores and stream banks are typical riparian areas. Excluded are such sites as ephemeral streams or washes that do not exhibit the presence of vegetation dependent upon free water in the soil.

Authors: L.M Cowardin, V. Carter, F.C. Golet and E.T. LaRoe

Year: 1979

Title: Classification of wetlands and deepwater habitats of the United States.

Definition: Classification of wetlands and deepwater habitats in the United States.

The word 'riparian' is never used in this reference, yet it forms the basis for subsequent F&WS and some BLM riparian mapping protocols. Wetlands and deepwater habitats are defined separately because traditionally the term wetland has not included deep permanent water; however, both must be considered in an ecological approach to classification. We define five major Systems: Marine, Estuarine, Riverine, Lacustrine, and Palustrine. The first four of these include both wetland and deepwater habitats but the Palustrine includes only wetland habitats.

The upland limit of wetland is designated as (1) the boundary between land with predominantly hydrophytic cover and land with predominantly mesophytic or xerophytic cover; (2) the boundary between soil that is predominantly hydric and soil that is predominantly nonhydric; or (3) in the case of wetlands without vegetation or soil, the boundary between land that is flooded or saturated at some time during the growing season each year and land that is not.

Author: M.L. Hunter Jr.

Year: 1990

Title: Wildlife, Forest, and Forestry: Principals of Managing Forest for Biological Diversity

Definition: The riparian zone, at the smallest scale, is the immediate water's edge, where some aquatic plants and animals form a distinct community. At the next scale, the riparian zone includes those areas periodically inundated by high water. At the largest scale (and in forested regions), the riparian zone is 'the band of forest that has a significant influence or conversely is significantly influenced by the stream.

Author: Texas Forest Service

Year: 2004

Title: Texas Forestry Best Management Practices

Definition: The riparian area is the land that borders a creek, stream, or other water body.

Author: Society for Range Management

Year: 1985

Definition: Riparian zones or areas are the banks and adjacent areas of water bodies, water courses, seeps and springs whose waters provide soil moisture sufficiently in excess of that otherwise available locally so as to provide a more moist habitat than that of contiguous flood plains and uplands.

Author: E.W. Anderson

Year: 1987

Title: Riparian area definition – A viewpoint.

Definition: A riparian area is a distinct ecological site, or combination of sites, in which soil moisture is sufficiently in excess of that otherwise available locally, due to run-on and/or subsurface seepage, so as to result in an existing or potential soil-vegetation complex that depicts the influence of that extra soil moisture. Riparian areas may be associated with lakes; reservoirs; estuaries; potholes springs; bogs; wet meadows; muskegs; and intermittent of perennial streams. The distinctive soil-vegetation complex is the differentiating criteria.

Authors: Leonard et al. 1992. U.S. Department of the Interior Bureau of Land Management
Year: 1992

Title: Riparian area management: Procedures for ecological site inventory – with special reference to riparian-wetland sites.

Definition: Riparian areas are a form of wetland transition between permanently saturated wetlands and upland areas. These areas exhibit vegetation or physical characteristics reflective of permanent surface or subsurface water influence. Lands along, adjacent to, or contiguous with perennially and intermittently flowing rivers and streams, glacial potholes, and the shores of lakes and reservoirs with stable water levels are typical of riparian areas.

Western Definitions

Authors: Pase, C.P. and Layser, E.F.

Year: 1977

Title: Classification of riparian habitat in the southwest.

Definition: "Riparian" type habitats are streamside or riverside communities, stretching from high forest to low desert. Soil moisture is seldom a limiting factor, at least for successfully establishing perennials, although surface water may be lacking at times in marginal areas. The wide array of habitats thus included sustains an equally wide array of plant and animal communities.

Author: Lowe, C.H.

Year: 1964

Title: Arizona's natural environment; landscape and habitats.

Definition: A riparian community or association is one that occurs in or adjacent to a drainage way and/or its floodplain and which is further characterized by species and/or life forms different from those of the immediately surrounding non-riparian climax.

B1. Discharge of Flood Event Corresponding to Image Acquistion Date

Gage Station ID	Date	Discharge (cfs) (Mean)
8026000	1/1/1974	14500
8026000	1/2/1974	14500
8026000	1/3/1974	15100
8026000	1/4/1974	15300
8026000	1/5/1974	15000
8026000	1/6/1974	14500
8026000	1/7/1974	14400
8026000	1/8/1974	15400
8026000	1/9/1974	16000
8026000	1/10/1974	15700
8026000	1/11/1974	16600
8026000	1/12/1974	19800
8026000	1/13/1974	18800
8026000	1/14/1974	15400
8026000	1/15/1974	14700
8026000	1/16/1974	15200
8026000	1/17/1974	14800
8026000	1/18/1974	14500
8026000	1/19/1974	15600
8026000	1/20/1974	24000
8026000	1/21/1974	32900
8026000	1/22/1974	36300
8026000	1/23/1974	37200
8026000	1/24/1974	39500
8026000	1/25/1974	45100
8026000	1/26/1974	50400
8026000	1/27/1974	63000
8026000	1/28/1974	75700
8026000	1/29/1974	77900
8026000	1/30/1974	58000
8026000	1/31/1974	48100
8026000	2/1/1974	41400
8026000	2/2/1974	34300
8026000	2/3/1974	29200
8026000	2/4/1974	25200
8026000	2/5/1974	17900
8026000	2/6/1974	15400
8026000	2/7/1974	14800
8026000	2/8/1974	14500
8026000	2/9/1974	14200
8026000	2/10/1974	14100
8026000	2/11/1974	14200
8026000	2/12/1974	14700
8026000	2/13/1974	14200
8026000	2/14/1974	13900
8026000	2/15/1974	13800
8026000	2/16/1974	13900
8026000	2/17/1974	13900
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8026000	2/21/1974	14500
8026000	2/22/1974	15000
8026000	2/23/1974	14200
8026000	2/24/1974	14000
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8026000	2/26/1974	13000
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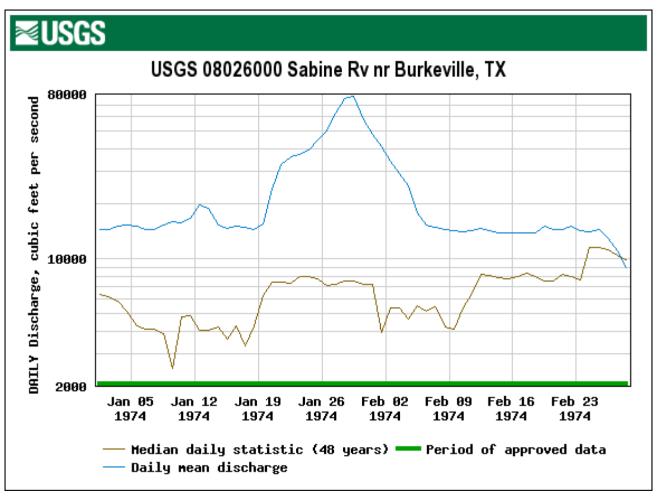
8026000	2/28/1974	8920



Bon Wier, TX

Gage Station ID	Date	Discharge (cfs) (Mean)
8028500	1/1/1974	16400
8028500	1/2/1974	15600
8028500	1/3/1974	16000
8028500	1/4/1974	18200
8028500	1/5/1974	18600
8028500	1/6/1974	18100
8028500	1/7/1974	17500
8028500	1/8/1974	17500
8028500	1/9/1974	19100
8028500	1/10/1974	20300
8028500	1/11/1974	19700
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8028500	1/14/1974	21500
8028500	1/15/1974	18300
8028500	1/16/1974	17200
8028500	1/17/1974	17000
8028500	1/18/1974	16600
8028500	1/19/1974	18000
8028500	1/20/1974	26100
8028500	1/21/1974	31700
8028500	1/22/1974	34400
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8028500	1/25/1974	41100
8028500	1/26/1974	47900
8028500	1/27/1974	57800
8028500	1/28/1974	70400
8028500	1/29/1974	76900
8028500	1/30/1974	77100
8028500	1/31/1974	71600
8028500	2/1/1974	61100
8028500	2/2/1974	52200
8028500	2/3/1974	42500
8028500	2/4/1974	36500
8028500	2/5/1974	32100
8028500	2/6/1974	24600
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8028500	2/8/1974	18200
8028500	2/9/1974	17500
8028500	2/10/1974	16800
8028500	2/11/1974	16300
8028500	2/12/1974	16100
8028500	2/13/1974	16100
8028500	2/14/1974	16000
8028500	2/15/1974	15700
8028500	2/16/1974	16000
8028500	2/17/1974	16300
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8028500	2/20/1974	16800
8028500	2/21/1974	16300
8028500	2/22/1974	16700
8028500	2/23/1974	17000
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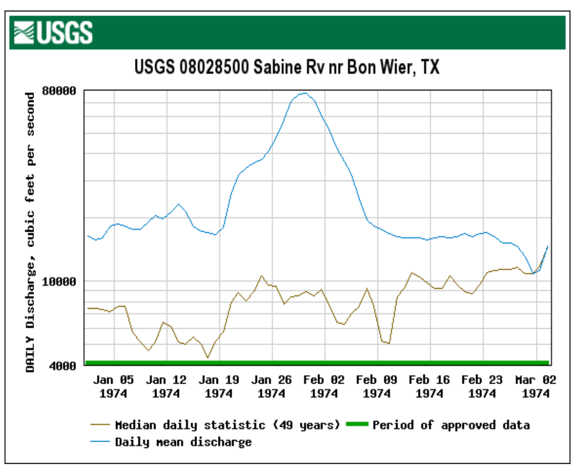
8028500	2/27/1974	14600
8028500	2/28/1974	13100



Ruliff, TX

Gage Station ID	Date	Discharge (cfs) (Mean)
8030500	1/1/1974	21900
8030500	1/2/1974	20300
8030500	1/3/1974	20200
8030500	1/4/1974	19800
8030500	1/5/1974	19300
8030500	1/6/1974	19100
8030500	1/7/1974	19400
8030500	1/8/1974	19800
8030500	1/9/1974	20000
8030500	1/10/1974	20700
8030500	1/11/1974	22200
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8030500	1/19/1974	20300
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8030500	1/24/1974	42800
8030500	1/25/1974	44200
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8030500	1/27/1974	53000
8030500	1/28/1974	60000
8030500	1/29/1974	67600
8030500	1/30/1974	75300
8030500	1/31/1974	82000
8030500	2/1/1974	84000
8030500	2/2/1974	78300
8030500	2/3/1974	67000
8030500	2/4/1974	55700
8030500	2/5/1974	45800
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8030500	2/12/1974	17800
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8030500	2/16/1974	16900
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8030500	2/18/1974	17000
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8030500	2/27/1974	17200
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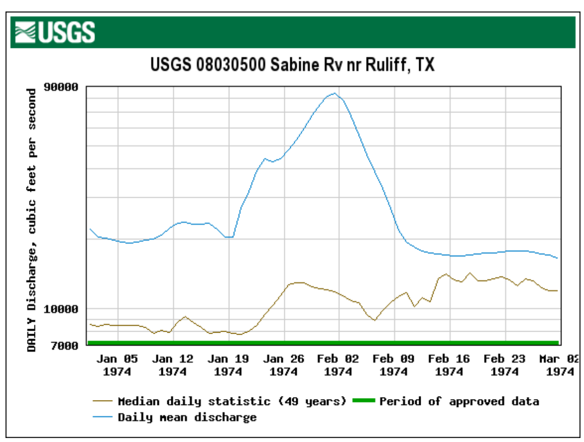
8030500	3/1/1974	16600



Burkeville March 1979

Gage Station ID	Date	Discharge (cfs) (Mean)
8026000	1/15/1979	6850
8026000	1/16/1979	6980
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8026000	1/18/1979	9180
8026000	1/19/1979	8990
8026000	1/20/1979	14700
8026000	1/21/1979	16400
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8026000	1/23/1979	21600
8026000	1/24/1979	24600
8026000	1/25/1979	26700
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8026000	3/1/1979	15900
8026000	3/2/1979	20300
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8026000	3/4/1979	26200
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8026000	3/6/1979	28900
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8026000	3/8/1979	23400
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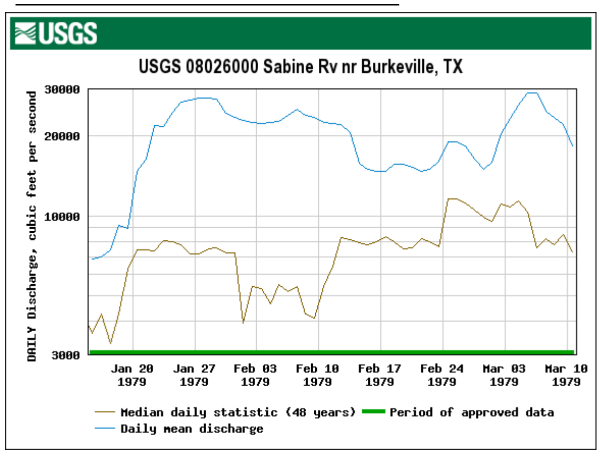
8026000	3/10/1979	18400



Bon Wier March 1979

Gage Station ID	Date	Discharge (cfs) (Mean)
8026000	1/15/1979	6850
8026000	1/16/1979	6980
8026000	1/17/1979	7410
8026000	1/18/1979	9180
8026000	1/19/1979	8990
8026000	1/20/1979	14700
8026000	1/21/1979	16400
8026000	1/22/1979	21900
8026000	1/23/1979	21600
8026000	1/24/1979	24600
8026000	1/25/1979	26700
8026000	1/26/1979	27400
8026000	1/27/1979	27800
8026000	1/28/1979	27800
8026000	1/29/1979	27500
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8026000	1/31/1979	23400
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8026000	2/8/1979	23900
8026000	2/9/1979	23500
8026000	2/10/1979	22500
8026000	2/11/1979	22200
8026000	2/12/1979	22100
8026000	2/13/1979	20600
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8026000	2/16/1979	14700
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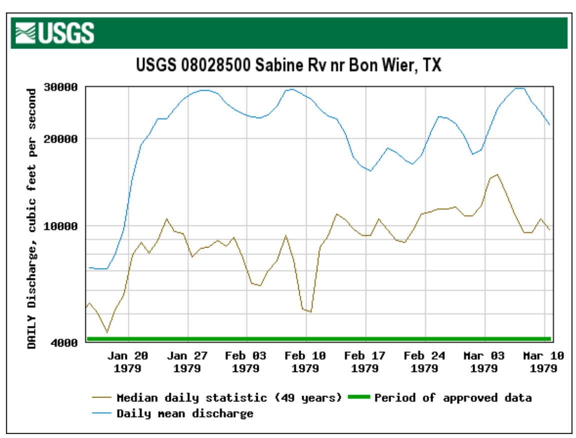
8026000	2/22/1979	14900
8026000	2/23/1979	16100
8026000	2/24/1979	19000
8026000	2/25/1979	19000
8026000	2/26/1979	18400
8026000	2/27/1979	16300
8026000	2/28/1979	15000
8026000	3/1/1979	15900
8026000	3/2/1979	20300
8026000	3/3/1979	23200
8026000	3/4/1979	26200
8026000	3/5/1979	29100
8026000	3/6/1979	28900
8026000	3/7/1979	24800
8026000	3/8/1979	23400
8026000	3/9/1979	22000
8026000	3/10/1979	18400



Ruliff March 1979

Gage Station ID	Date	Discharge (cfs) (Mean)
8030500	1/15/1979	12900
8030500	1/16/1979	11300
8030500	1/17/1979	10300
8030500	1/18/1979	9650
8030500	1/19/1979	9260
8030500	1/20/1979	10100
8030500	1/21/1979	11400
8030500	1/22/1979	13300
8030500	1/23/1979	15900
8030500	1/24/1979	19700
8030500	1/25/1979	23100
8030500	1/26/1979	24200
8030500	1/27/1979	24600
8030500	1/28/1979	25700
8030500	1/29/1979	27100
8030500	1/30/1979	28300
8030500	1/31/1979	28500
8030500	2/1/1979	28000
8030500	2/2/1979	27200
8030500	2/3/1979	26900
8030500	2/4/1979	26400
8030500	2/5/1979	26700
8030500	2/6/1979	27500
8030500	2/7/1979	27300
8030500	2/8/1979	29200
8030500	2/9/1979	31400
8030500	2/10/1979	32600
8030500	2/11/1979	30000
8030500	2/12/1979	28100
8030500	2/13/1979	26300
8030500	2/14/1979	24400
8030500	2/15/1979	23200
8030500	2/16/1979	21900
8030500	2/17/1979	20200
8030500	2/18/1979	19000
8030500	2/19/1979	18200
8030500	2/20/1979	18200
8030500	2/21/1979	18900
8030500	2/22/1979	19400
8030500	2/23/1979	20100
8030500	2/24/1979	19800
8030500	2/25/1979	19400
8030500	2/26/1979	20000
8030500	2/27/1979	21800
8030500	2/28/1979	23300
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8030500	3/2/1979	22500
8030500	3/3/1979	22200
8030500	3/4/1979	21200
8030500	3/5/1979	21500
8030500	3/6/1979	23100
8030500	3/7/1979	26000
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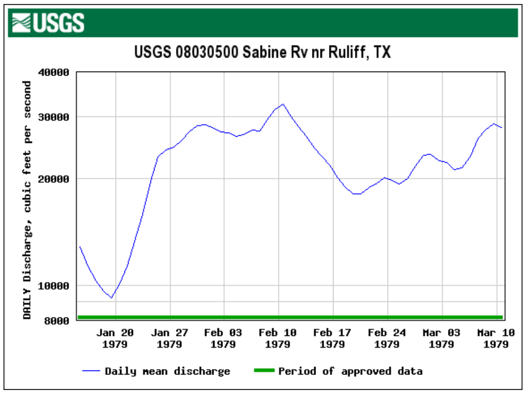
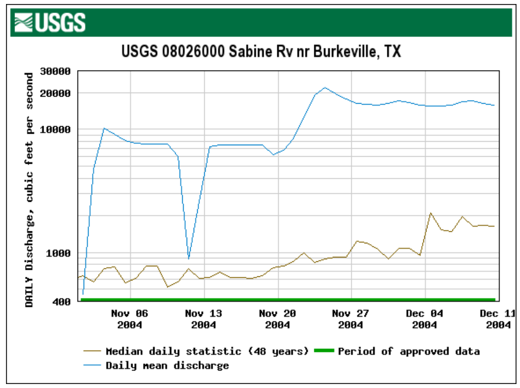
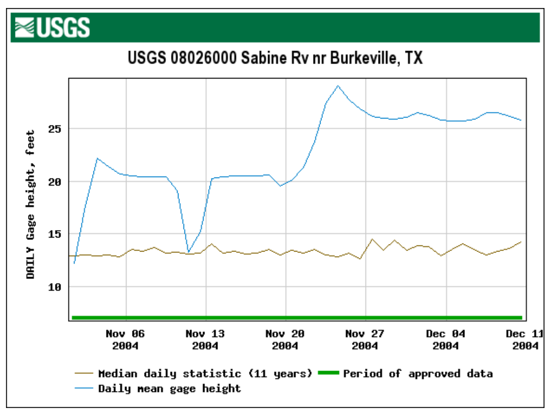
8030500	3/10/1979	27900



Burkeville, TX 2004

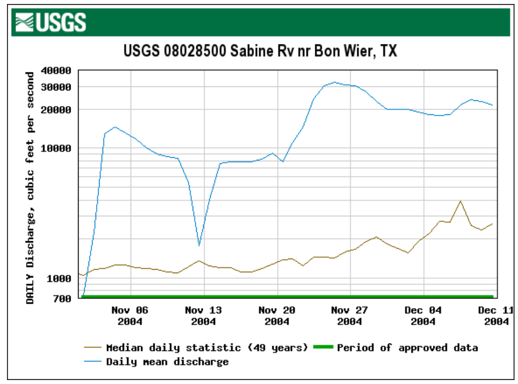
Gage Station ID	Date	Discharge (cfs) (Mean)
11/1/2004	459	12.2
11/2/2004	4820	17.65
11/3/2004	10300	22.13
11/4/2004	9150	21.41
11/5/2004	8090	20.7
11/6/2004	7760	20.49
11/7/2004	7660	20.44
11/8/2004	7590	20.41
11/9/2004	7550	20.41
11/10/2004	6040	19.13
11/11/2004	883	13.29
11/12/2004	2590	15.22
11/13/2004	7220	20.25
11/14/2004	7430	20.44
11/15/2004	7440	20.46
11/16/2004	7440	20.49
11/17/2004	7440	20.51
11/18/2004	7500	20.58
11/19/2004	6250	19.55
11/20/2004	6820	20.08
11/21/2004	8380	21.28
11/22/2004	12400	23.78
11/23/2004	18800	27.38
11/24/2004	22100	29.03
11/25/2004	19500	27.73
11/26/2004	17600	26.8
11/27/2004	16400	26.14
11/28/2004	16000	25.94
11/29/2004	15800	25.83
11/30/2004	16200	26.06
12/1/2004	17100	26.51
12/2/2004	16500	26.22
12/3/2004	15700	25.8
12/4/2004	15500	25.67
12/5/2004	15500	25.66
12/6/2004	15800	25.85
12/7/2004	16900	26.45
12/8/2004	17100	26.51
12/9/2004	16300	26.1
12/10/2004	15700	25.77

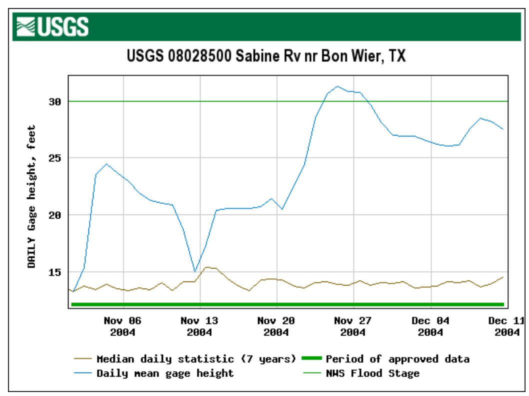




Bon weir 2004

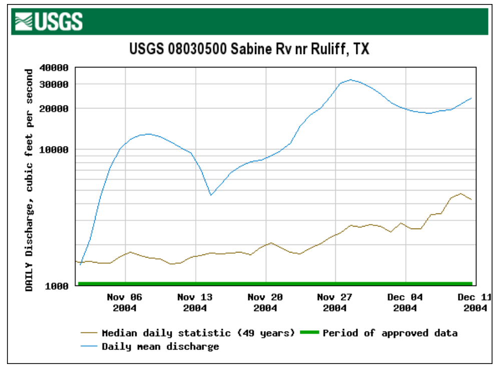
ge ation ID	Date	Discharge (cfs) (Mean)	Gage Height (ft)
028500	11/1/2004	733	13.22
028500	11/2/2004	2230	15.32
028500	11/3/2004	13000	23.53
028500	11/4/2004	14700	24.51
028500	11/5/2004	13200	23.68
028500	11/6/2004	11800	22.92
028500	11/7/2004	10000	21.88
028500	11/8/2004	9060	21.28
028500	11/9/2004	8620	21.01
028500	11/10/2004	8360	20.84
028500	11/11/2004	5420	18.66
028500	11/12/2004	1760	14.97
028500	11/13/2004	4020	17.24
028500	11/14/2004	7650	20.38
028500	11/15/2004	7880	20.53
028500	11/16/2004	7900	20.54
028500	11/17/2004	7910	20.55
028500	11/18/2004	8190	20.73
028500	11/19/2004	9250	21.4
028500	11/20/2004	7850	20.5
028500	11/21/2004	11100	22.52
028500	11/22/2004	14600	24.44
028500	11/23/2004	23900	28.48
028500	11/24/2004	30200	30.64
028500	11/25/2004	32500	31.28
028500	11/26/2004	30800	30.82
028500	11/27/2004	30500	30.74
028500	11/28/2004	27100	29.66
028500	11/29/2004	22800	28.1
028500	11/30/2004	19900	26.97
028500	12/1/2004	19800	26.95
028500	12/2/2004	19800	26.93
028500	12/3/2004	19000	26.55
028500	12/4/2004	18200	26.19
028500	12/5/2004	17800	26.03
028500	12/6/2004	18100	26.16
028500	12/7/2004	21400	27.54
028500	12/8/2004	23800	28.5
028500	12/9/2004	22900	28.15
028500	12/10/2004	21400	27.55

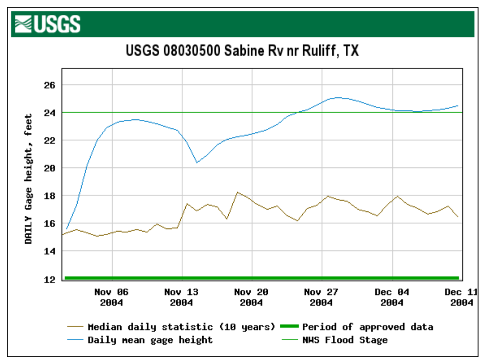




Ruiliff, 2004

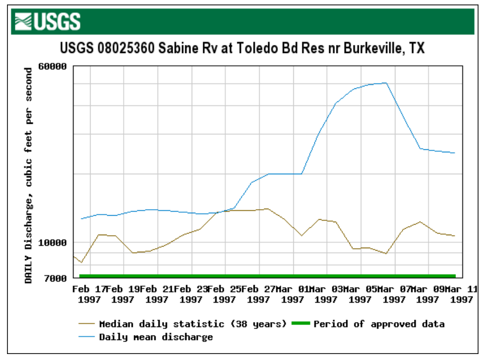
Gage Station ID	Date	Discharge (cfs) (Mean)	Gage Height (ft)
8030500	11/1/2004	1420	15.62
8030500	11/2/2004	2200	17.31
8030500	11/3/2004	4460	20.16
8030500	11/4/2004	7410	21.93
8030500	11/5/2004	10100	22.86
8030500	11/6/2004	11900	23.26
8030500	11/7/2004	12800	23.41
8030500	11/8/2004	13000	23.45
8030500	11/9/2004	12400	23.34
8030500	11/10/2004	11300	23.14
8030500	11/11/2004	10300	22.93
8030500	11/12/2004	9420	22.67
8030500	11/13/2004	7110	21.79
8030500	11/14/2004	4610	20.34
8030500	11/15/2004	5550	20.95
8030500	11/16/2004	6760	21.66
8030500	11/17/2004	7520	22.03
8030500	11/18/2004	8100	22.25
8030500	11/19/2004	8320	22.32
8030500	11/20/2004	8940	22.53
8030500	11/21/2004	9750	22.77
8030500	11/22/2004	11100	23.09
8030500	11/23/2004	14800	23.68
8030500	11/24/2004	17800	24
8030500	11/25/2004	20000	24.18
8030500	11/26/2004	24400	24.51
8030500	11/27/2004	30800	24.94
8030500	11/28/2004	32600	25.06
8030500	11/29/2004	31000	24.96
8030500	11/30/2004	28600	24.8
8030500	12/1/2004	25400	24.58
8030500	12/2/2004	22200	24.34
8030500	12/3/2004	20200	24.19
8030500	12/4/2004	19200	24.11
8030500	12/5/2004	18700	24.08
8030500	12/6/2004	18500	24.06
8030500	12/7/2004	19100	24.11
8030500	12/8/2004	19400	24.14
8030500	12/9/2004	21400	24.28
8030500	12/10/2004	23600	24.44





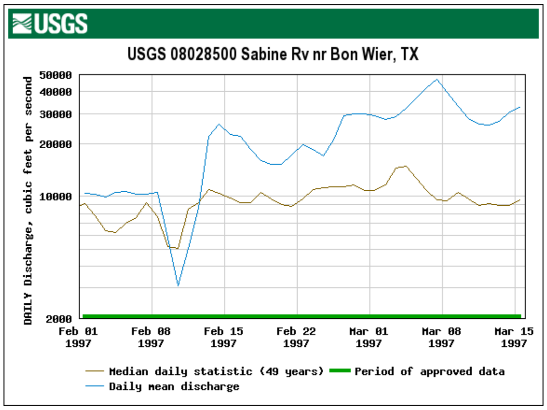
Burkeville, TX 1997

Gage Station ID	Date	Discharge (cfs) (Mean)
8025360	2/5/1997	8770
8025360	2/6/1997	9500
8025360	2/7/1997	8820
8025360	2/8/1997	204
8025360	2/9/1997	204
8025360	2/10/1997	4040
8025360	2/11/1997	6830
8025360	2/12/1997	10100
8025360	2/13/1997	11400
8025360	2/14/1997	11000
8025360	2/15/1997	13400
8025360	2/16/1997	12800
8025360	2/17/1997	13300
8025360	2/18/1997	13200
8025360	2/19/1997	13700
8025360	2/20/1997	14000
8025360	2/21/1997	13800
8025360	2/22/1997	13600
8025360	2/23/1997	13400
8025360	2/24/1997	13500
8025360	2/25/1997	14200
8025360	2/26/1997	18300
8025360	2/27/1997	20100
8025360	2/28/1997	20000
8025360	3/1/1997	20000
8025360	3/2/1997	30300
8025360	3/3/1997	41100
8025360	3/4/1997	47300
8025360	3/5/1997	49900
8025360	3/6/1997	50400
8025360	3/7/1997	35800
8025360	3/8/1997	25900
8025360	3/9/1997	25200
8025360	3/10/1997	24900



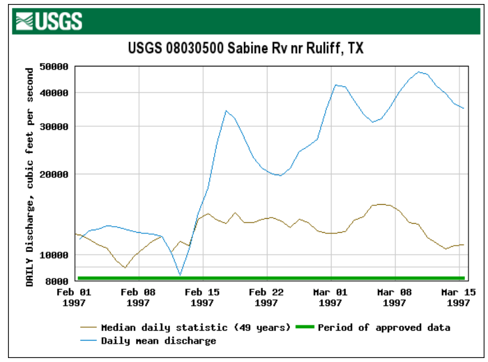
Bon Wier 1997

Gage Station ID	Date	Discharge (cfs) (Mean)
8028500	2/1/1997	10400
8028500	2/2/1997	10300
8028500	2/3/1997	9930
8028500	2/4/1997	10600
8028500	2/5/1997	10700
8028500	2/6/1997	10300
8028500	2/7/1997	10300
8028500	2/8/1997	10600
8028500	2/9/1997	5780
8028500	2/10/1997	3090
8028500	2/11/1997	5050
8028500	2/12/1997	8590
8028500	2/13/1997	22200
8028500	2/14/1997	26000
8028500	2/15/1997	22600
8028500	2/16/1997	22100
8028500	2/17/1997	18600
8028500	2/18/1997	16000
8028500	2/19/1997	15300
8028500	2/20/1997	15400
8028500	2/21/1997	17400
8028500	2/22/1997	19800
8028500	2/23/1997	18700
8028500	2/24/1997	17200
8028500	2/25/1997	21100
8028500	2/26/1997	29000
8028500	2/27/1997	29900
8028500	2/28/1997	30000
8028500	3/1/1997	29100
8028500	3/2/1997	27700
8028500	3/3/1997	28600
8028500	3/4/1997	32300
8028500	3/5/1997	36900
8028500	3/6/1997	42300
8028500	3/7/1997	47000
8028500	3/8/1997	39800
8028500	3/9/1997	33000
8028500	3/10/1997	28000
8028500	3/11/1997	25900
8028500	3/12/1997	25700
8028500	3/13/1997	27000
8028500	3/14/1997	30700
8028500	3/15/1997	32700



Ruliff, TX 1997

Gage Station ID	Date	Discharge (cfs) (Mean)
8030500	2/1/1997	11400
8030500	2/2/1997	12300
8030500	2/3/1997	12400
8030500	2/4/1997	12800
8030500	2/5/1997	12700
8030500	2/6/1997	12400
8030500	2/7/1997	12200
8030500	2/8/1997	12000
8030500	2/9/1997	11900
8030500	2/10/1997	11700
8030500	2/11/1997	10200
8030500	2/12/1997	8360
8030500	2/13/1997	10500
8030500	2/14/1997	14200
8030500	2/15/1997	17700
8030500	2/16/1997	26000
8030500	2/17/1997	34300
8030500	2/18/1997	31900
8030500	2/19/1997	27100
8030500	2/20/1997	23000
8030500	2/21/1997	21000
8030500	2/22/1997	19900
8030500	2/23/1997	19600
8030500	2/24/1997	20900
8030500	2/25/1997	24100
8030500	2/26/1997	25300
8030500	2/27/1997	26800
8030500	2/28/1997	34700
8030500	3/1/1997	42600
8030500	3/2/1997	42100
8030500	3/3/1997	37400
8030500	3/4/1997	33200
8030500	3/5/1997	31100
8030500	3/6/1997	32000
8030500	3/7/1997	35600
8030500	3/8/1997	40200
8030500	3/9/1997	44800
8030500	3/10/1997	47700
8030500	3/11/1997	46800
8030500	3/12/1997	42400
8030500	3/13/1997	39700
8030500	3/14/1997	36200
8030500	3/15/1997	34900



Appendix Table B2. Coordinates of control points assessed and not assessed.

Control Point	Assessed	Latitude	Longitude
1		30.97657	-93.58319163
2		30.96410	-93.58733056
3	yes	31.02315	-93.60877916
4		31.02487	-93.57384584
5		31.02292	-93.54431281
6		31.11723	-93.57138544
7		31.12562	-93.55213570
8		30.92637	-93.55459888
9		30.88001	-93.59403594
10	yes	30.87993	-93.61208274
11		30.98472	-93.61515962
12	yes	30.96920	-93.60602803
13	yes	31.07038	-93.60606597
14	yes	31.07166	-93.55122091
15		31.05770	-93.53968918
16		31.03134	-93.51423419
17		31.04098	-93.56671140
18		31.12441	-93.59133124
19		30.95009	-93.58844885
20	yes	31.05477	-93.61500714
21		31.06844	-93.57531286
22		31.09493	-93.57004604
23		31.14896	-93.55408075
24		31.15036	-93.58968243
25	yes	31.13380	-93.57932600
26	yes	30.90078	-93.59235897
27	yes	30.90145	-93.55686205
28		30.90138	-93.57431130
29	yes	30.91488	-93.57138295
30		30.94393	-93.57275967
31	yes	30.93602	-93.60160508
32		30.95927	-93.62222127
33	yes	30.96857	-93.62890506
34		30.96113	-93.55479966
35		30.93577	-93.53960491
36	yes	30.89914	-93.61039980
37	yes	30.89464	-93.57186441
38		30.98274	-93.59587580
39		30.99627	-93.58632302
40		31.01798	-93.60513162
41	yes	31.04652	-93.60350427
42		31.05023	-93.58725620
43		31.06684	-93.58554999
44	yes	31.06020	-93.56140092
45		31.04989	-93.54567158

Appendix Table B2 continued.

Control Point	Assessed	Latitude	Longitude
46		31.13335	-93.56424395
47		31.14015	-93.55161666
48		31.14253	-93.59807923
49		31.10209	-93.59360479
51	yes	31.01702	-93.58825731
52		31.00929	-93.57736681
53		31.01405	-93.55510600
54		31.02908	-93.56061574
55		30.93831	-93.55286197
56		30.94713	-93.55291275
57		30.96522	-93.56867192
58		30.95533	-93.57523590
59		30.93307	-93.56366626
60		31.03566	-93.59680763
61		31.08252	-93.55972350
62		31.10953	-93.55324863
63		31.11626	-93.55750910
64		30.96249	-93.59815843
65	yes	31.00813	-93.60265989
66		31.05743	-93.60055967
67	yes	31.03127	-93.53291223
68		30.91909	-93.55876964
69	yes	30.89355	-93.58389120
70		30.99110	-93.58327999
71		30.97601	-93.59161876
72		31.05755	-93.57464460
73	yes	31.03247	-93.61365868
74	yes	31.07096	-93.59341132
75		31.08349	-93.57480063
76		31.10582	-93.57071410
77		31.11767	-93.58887719
78		30.94285	-93.58298674
79		30.99570	-93.59896786
80	yes	31.01587	-93.61234744
81	yes	31.02569	-93.61964016
82		30.93406	-93.57510849
83	yes	30.97958	-93.60609360
84	yes	31.00550	-93.60987173
85		31.02233	-93.55997378
86		31.03331	-93.54075666
87		31.06546	-93.54576043
88		30.92956	-93.53595869
89		30.90922	-93.56111934
90		30.95368	-93.59569538

Appendix Table B2 continued.

Control Point	Assessed	Latitude	Longitude
91	yes	31.12762	-93.56963825
92	yes	31.14942	-93.56795874
93	yes	31.17018	-93.56566898
94		31.14421	-93.57094394
95		31.06515	-93.61386844
96		30.95300	-93.63060912
97	yes	30.89083	-93.61034714
98		31.01464	-93.54004875
99		30.87698	-93.57717353
100	yes	30.91491	-93.62041762
101		30.93781	-93.63438220
102		30.97427	-93.65930522
103	yes	30.99394	-93.63722212
104	yes	30.98932	-93.62632956
105	yes	31.00974	-93.62646302
106	yes	31.00409	-93.65012824
107	yes	30.99255	-93.65992470
108		30.96454	-93.64837938
109		30.95643	-93.65474071
110	yes	30.93937	-93.66251981
111	yes	30.90080	-93.63660429
112		30.87785	-93.63300048
113		31.01138	-93.63733811
114		30.93275	-93.62694732
115	yes	30.89447	-93.62620455
116		30.91610	-93.63917230
117		31.06011	-93.58825419

Appendix Table B3. Site characteristics of east Texas bottomland hardwood species. (***Source: Ortego 1986***)

Species	Tree Association Component1	River System Origin2	Location3	Floodplain Zone4	Flood Tolerance5	Soil Moisture6	Precipitation7	Growing Season8	Soil pH9	Shade10
Acer rubrum red maple	82, 89, 104	CP, BP	All sites, except swamp	III & IV	MT	M - W			N	T
Betula nigra river birch	95	CP	New river front	IV	MT	W			A	I
Carya, spp. hickory	82, 88, 91, 93, 96	CP, BP, WP	2nd terrace	III & IV	MT-WT	D-M	25-65	120-280	N	VT
C. illinoensis pecan	94,95	WP	Loamy river fronts		WT		30-60	150-270		MT
Celtis laevigata sugarberry	92, 93, 94, 95,96	BP, WP	all bottoms	IV	MT-I		20-60	150-270		VT
Diospyros virginiana common persimmon	95	BP	1st bottom	III	MT	M-W	48		A	VT
Fagus grandifolia American beech		CP	Creek bottoms	V	MT	W	30-50	100-280	N	VT
Fraxinus pennsylvanica green ash	63, 88, 91, 92, 93, 94, 95, 96	CP, BP, WP	1st bottom	IV	MT	M	15-60	120-280	N-B	I
Gleditsia triacanthos honeylocust	88	WP	all bottoms	IV	MT	M	20-70	140-340	N	I
Liquidambar styraciflua sweetgum	82, 88, 91, 92, 93, 94, 104	CP, BP, WP	All sites, except swamp	IV	MT	M - W	40-60	180-320	N	I
Magnolia spp. Magnolia	82, 89, 104	CP	Swamps to 2nd terrace	II-V	MT-WT	M	40-60	210	N	MT
Nyssa aquatica water tupelo	101, 102, 103	CP	swamp	II	T		52	231		I
Nyssa sylvatica swamp tupelo	82, 91, 101, 102, 103,	CP, WP	swamp	II	T	M	53	267	N	MI

Appendix Table B3 Continued

Species	Tree Association Component1	River System Origin2	Location3	Floodplain Zone4	Flood Tolerance5	Soil Moisture6	Precipitation7	Growing Season8	Soil pH9	Shade10
Pinus taeda loblolly pine	81, 82	CP	All terraces	V	MT	M - W	40-60		A-N	I
Platanus occidentalis American sycamore	94, 95	CP, WP	River front	III & IV	MT	W	30-80	100-300	N	VI
Populus deltoides eastern cottonwood	63, 94, 95	BP, WP	Newly deposited soil	III & IV	WT -MT	W	51		N	VI
Quercus alba white oak	91	CP, WP	2nd terrace	I - WT	D - M				A-N	MI
Quercua falcata cherrybark oak	82, 91	CP, BP, WP	2nd terrace	V	WT - I	D - M	50-60	230-290	A-N	I
Quercus laurifolia laural oak	88, 104	CP, BP	All bottoms	IV	MT - WT		50-60	200-300		I
Quercus lyrata overcup oak	88, 93, 96	CP, BP, WP	Sloughs	III	MT		45-60			MI
Quercus michauxii swamp chestnut oak	82, 91	CP, BP, WP	2nd terrace	V	WT		50-60	200-250		MI
Quercus nigra water oak	82, 88, 89, 92, 93, 94, 104	CP, BP, WP	2nd terrace and bottom	V	WT - MT		40-60	200-260		I
Quercus nuttallii nuttall oak	88, 92, 93, 96	CP, BP, WP	All bottoms		MT		50-65			I
Quercus phellos	88, 92, 93	CP, BP,	2nd bottom	VI	WT - MT		40-60	200-260		I

willow oak	WP

Appendix Table B3 Continued

Species	Tree Association Component1	River System Origin2	Location3	Floodplain Zone4	Flood Tolerance5	Soil Moisture6	Precipitation7	Growing Season8	Soil pH9	Shade10
Quercus shumardii shumard oak	91	BP	2nd terrace	V	WT		45-55	210-250		I
Salix nigra black willow	63, 94, 95, 101, 102, 103	CP, BP, WP	Water edge	III	T	W	51		N	VI
Taxodium distichum bald cypress	95, 101, 102, 103	CP	Swamp	II	T	W			A	I
Ulmus, spp. elm	63, 82, 92, 93, 94, 95, 96	CP, BP, WP	All bottoms	IV	MT	M - W	15 - 60	80 - 32	N	T

[1]Eyre 1980: Society of American Foresters tree association number.
[2] Broadfoot 1964: CP= Coastal Plain, BP= Blackland Prairie, WP= Western Plain.
[3]Putnam et al. 1960
[4]United States Fish and Wildlife Service 1984.
[5]McNight et al. 1980: T= tolerant, MT= moderately tolerant, WT= weekly tolerant, I= intolerant.
[6]Soil moisture: D= dry, M= medium, W= wet.
[7]Fowells 1965: Precipitation in inches.
[8]Fowells 1965: Growing season in days.
[9]Soil pH: A= acidic, N= neutral, B= basic.
[10]Putnam et al. 1960: