APPENDIX M: INSTREAM FLOW STUDY AND SUPPLEMENTAL DATA CONDUCTED FOR THE PROPOSED LOWER BOIS D'ARC CREEK RESERVOIR

M-1: INSTREAM FLOW STUDY FOR THE PROPOSED LOWER BOIS D'ARC CREEK RESERVOIR

M-2: INSTREAM FLOW STUDY SUPPLEMENTAL DATA FOR THE PROPOSED LOWER BOIS D'ARC CREEK RESERVOIR

Innovative approaches...practical results...outstanding service

Proposed Lower Bois d'Arc Creek Reservoir

Fannin County, Texas

Instream Flow Study

May 2010

prepared for:
North Texas Municipal Water District

prepared by:
Freese and Nichols, Inc.

THE Lower Bois d'Arc Creek RESERVOIR
NORTH TEXAS MUNICIPAL WATER DISTRICT

Proposed Lower Bois d'Arc Creek Reservoir

Fannin County, Texas

INSTREAM FLOW STUDY

May 2010

May 19, 2010

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EXECUTIVE SUMMARY

This report presents the findings and recommendations of the instream flow study on Bois d'Arc Creek in support of permitting activities for the proposed Lower Bois d'Arc Creek Reservoir. The purpose of the study was to characterize the baseline stream conditions of Bois d'Arc Creek within the proposed reservoir site and downstream, develop predictions of conditions within the reservoir pool, and develop a proposed instream flow regime to maintain a sound ecological environment downstream of the proposed dam.

In accordance with the Texas Instream Flow Program, this study evaluated the four technical components that characterize stream conditions: hydrology and hydraulics, fluvial geomorphology, water quality, and aquatic biology. These components were evaluated in the context of the existing and future stream system, and collectively were used to define a sound ecological environment for Bois d'Arc Creek. To achieve a sound ecological environment, the instream flow regime must:

- Provide sufficient stream power to move sediment in the channel while not creating excessive stream bed and bank erosion;
- Support a spectrum of mesohabitats – pools, runs, riffles and structures;
- Provide hydraulic connectivity to support biological communities;
- Maintain existing water quality standards of the stream for High Aquatic Life use;
- Provide seasonally varying flows to support fish reproduction; and
- Maintain or improve existing fish and macroinvertebrate communities and biodiversity as measured by scientific standards.

With the assistance of an Inter-Agency Team (representatives of state and federal agencies), the scope of work for this study was refined and field data were collected over a five-month period from March 2009 through July 2009. In addition to these field data, literature reviews, data from previous studies (including studies for this project and other independent studies), and available resource data were used to define the stream baseline conditions and evaluate the proposed instream flow regime.

Bois d'Arc Creek is a highly channelized stream system. This has been identified and documented in previous studies as well as in this instream flow study. The altered nature of the stream system is important because the channelization plays a significant role in the current behavior and processes occurring in the stream system. The straightened and channelized sections of Bois d'Arc Creek contribute to the flashy nature of the creek, substantial erosion of the stream bed and banks, lack of habitat diversity in channelized sections, and minimal lateral migration of the stream.

The frequent large flow pulses that occur in response to rain events in the watershed are contributing to continuing erosion, including channel downcutting and bank mass failures. This

results in negative impacts to aquatic habitats by mass wasting and high current velocities that scour established habitats. This study found that large flows are not necessary to move sediment along the creek bed. The sediment transport analyses determined that flows less than 1 cfs can transport fine sediments and that gravel transport begins at 25 cfs.

While the Texas Commission on Environmental Quality (TCEQ) classifies Bois d'Arc Creek as perennial, this instream flow study documented extended periods with little to no flows. During these dry times, the aquatic species must migrate from runs and riffle areas and seek refuge in deeper pools. There were 42 species of fish collected and identified as part of this study. Most of these species are generalist species, with red shiner accounting for 50 percent of the relative abundance and longear sunfish accounting for 13.7 percent. Generalist species are more adapted for survival than obligate stream species in the widely varying hydraulic conditions documented in Bois d'Arc Creek, with flows ranging from 0 to greater than 10,000 cfs. The quality of the existing fish communities, as measured by the fish Index of Biological Integrity (IBI), was found to be generally in the High Aquatic Life Use category. Aquatic habitats are dominated by pools (70 to 80% of the weighted useable area) and runs (14 to 28% WUA). Habitat modeling found that flows as low as 2 to 3 cfs provide connectivity between the mesohabitats in the modeled reaches. When evaluating the relationship of habitats with the identified species, there are no statistically significant species-habitat associations. These findings are consistent with the stream hydraulics and the types of species identified in the creek.

Of the fish species identified, most reproduce from spring to early summer. The reproductive cues appear to be largely temperature dependent. The conditions of Bois d'Arc Creek tend to favor the generalist species. The little to no flow conditions observed during the summer months are unfavorable spawning conditions for fluvial specialists.

A total of 2,621 macroinvertebrates, consisting of 103 identified genus and 46 families, were collected as part of this study. The macroinvertebrates were used to define the tropic structure of Bois d'Arc Creek and assess the aquatic life use. Using the Rapid Bioassessment Protocol, the analyses found the overall biological integrity of the macroinvertebrate community at the instream flow sampling sites to be at the higher end of the intermediate range. This is consistent with previous studies on Bois d'Arc Creek and the nearby North Sulphur River.

Water quality data collected during this study and from others (USGS, TCEQ, Red River Authority) is consistent with the High Aquatic Use classification of the stream. Measured dissolved oxygen concentrations generally ranged between 5.4 and 10.7 mg/L at all sites but the U.S. 82 site. The low dissolved oxygen concentrations at this site during limited sampling by the Red River Authority were attributed to warm temperatures and very low current velocity due to a log jam located upstream. Water quality does not appear to be a limiting factor for aquatic life in Bois d'Arc Creek. The observed data indicate that there are sufficient dissolved oxygen concentrations in the creek provided there is any flow in the stream. However, even during

extreme drought conditions, there apparently is adequate dissolved oxygen in pools to sustain aquatic life.

Hydrologic and geomorphic analyses indicate that the Bois d'Arc Creek is currently in disequilibrium. Downcutting and streambank erosion have increased, and lateral migration of the stream (i.e., meander creation) has slowed. Channelization has increased the "flashy" nature of flows in the watershed, with rapid rise and fall in flow in response to rainfall events. This likely has reduced base flows in the watershed as well. Instream habitats continually vary, as high flows scour gravel bars and dislodge large woody debris or low flows reduce connectivity along the stream. The frequency of extreme flow events, both high and low, has resulted in an environment that favors generalist species. Although water quality in the watershed is generally good, Bois d'Arc Creek is not able to support a large variety of aquatic life because the relatively few habitat features in the watershed are frequently washed away by high flow events. The apparent lack of reliable subsistence or baseflow hydrology from year to year may also be a limiting factor for fish and other aquatic species. With no changes in the watershed, Bois d'Arc Creek is expected to continue to downcut and erode, enlarging the existing channel. This will further reduce longitudinal connectivity at low flows and continue to constrain aquatic species to specific habitats that contain water (i.e., pools).

To provide a sound ecological environment in Bois d'Arc Creek, it is necessary to reduce the frequent highly erosive flows and provide sufficient flows to maintain water quality, provide connectivity between habitats, and foster aquatic species reproduction and habitat maintenance. Consistent with the Texas Instream Flow Program, it is proposed that the following instream flow regime as measured at the USGS gage located at FM 409 would provide a sound ecological environment for Bois d'Arc Creek downstream of the proposed reservoir:

- **Subsistence flow: 1 cfs** . This would provide flow to maintain water quality during extreme drought. Water would be released through the dam when the Lower Bois d'Arc Creek Reservoir is less than 40 percent full. Based on modeling studies, this occurs 9 percent of the time.
- **Base Flow (July to March)**: **3 cfs**. This flow would provide connectivity of mesohabitats and is capable of moving sediment through the channel. Releases of 3 cfs are proposed to occur from July through March.
- **Base Flow (April to June): 10 cfs**. These higher base flows are proposed during the primary spawning months of the dominant fish species to encourage and support reproductive activities.
- **Pulse Flow: 50 cfs.** It is proposed that two deliberate pulse flows would be released annually if such flows do not occur naturally. One pulse flow of 50 cfs would be released on June 1 if one did not occur in the previous April or May. Another pulse release would occur on October 1 if one did not occur in the previous September. These pulse releases

would provide the necessary stream power to move larger sediment particles (gravel) and maintain habitats.

Flows greater than 50 cfs would not be released from the reservoir to minimize erosional processes, channel downcutting and habitat destruction. There still would be naturally occurring larger flow events associated with runoff from the watershed downstream of the dam, spills from the Lower Bois d'Arc Creek Reservoir, and spills from existing downstream reservoirs (Coffee Mill and Crockett Lake). This reduction in the number and volume of large erosive flow events would also allow vegetation to become established along the stream banks and help restore the downstream riparian corridor.

The proposed flow regime is expected to allow the establishment of and preservation of relatively long-lived habitats while less frequently occurring larger events would perform the maintenance that is needed from time to time for habitat sustainability.

With the dam in place and the proposed environmental flow releases, there would be

- Higher median flows during low flow periods;
- Fewer erosive high flow events;
- Improved water quality during typically low flow summer months;
- Sustainable aquatic habitats;
- Increased stability of stream banks; and
- Increased potential for aquatic diversity and migration with higher median low flows.

1 INTRODUCTION

The North Texas Municipal Water District (NTMWD) is projected to need an additional 318,000 acre-feet per year of water in the next 50 years to meet the water supply needs of its growing customer base (FNI, 2008). The NTMWD is actively pursuing conservation, water purchases and the development of new water supplies to help meet its growing demands. One of the new supply sources is the proposed Lower Bois d'Arc Creek Reservoir project. This project is located approximately 15 miles northeast of the City of Bonham in Fannin County and would provide about 126,200 acre-feet per year of additional supply (Figure 1.1).

The NTMWD is currently seeking the necessary permits for the Lower Bois d'Arc Creek Reservoir project. An application for a State of Texas water right was submitted to the Texas Commission on Environmental Quality (TCEQ) on December 29, 2006, and declared administratively complete on June 26, 2007. The application for a Section 404 permit was submitted to the Tulsa District of the U.S. Army Corps of Engineers (USACE) on June 3, 2008, and supplemented with an *Environmental Report* on July 1, 2008.

This instream flow study report was prepared in support of these permitting activities and requests for additional information from the permitting agencies. It includes:

- an assessment of the current instream flow conditions in Bois d'Arc Creek,
- a discussion of expected conditions in the reservoir pool after the reservoir is built,
- an evaluation of the instream flow needs for a sound ecological environment downstream of the dam,
- an assessment of downstream conditions with the proposed dam and recommended operation,
- a reservoir operation plan with recommended instream flow releases, and
- a proposed monitoring and adaptive management plan.

1.1 Purpose of the Instream Flow Study

The primary purpose of this instream flow study is to characterize baseline stream conditions within the proposed reservoir site and downstream, develop predictions of conditions in the reservoir pool, and develop a proposed instream flow regime to maintain a sound ecological environment downstream of the dam. The instream flow regime considers the four technical components described in the *Texas Instream Flow Studies: Technical Overview* (Texas Water Development Board (TWDB), 2008): fluvial geomorphology, hydrology and hydraulics, water quality and biology. The report is intended to provide information on instream flows sought in a TCEQ Request for Information dated February 22, 2007 (the "RFI").

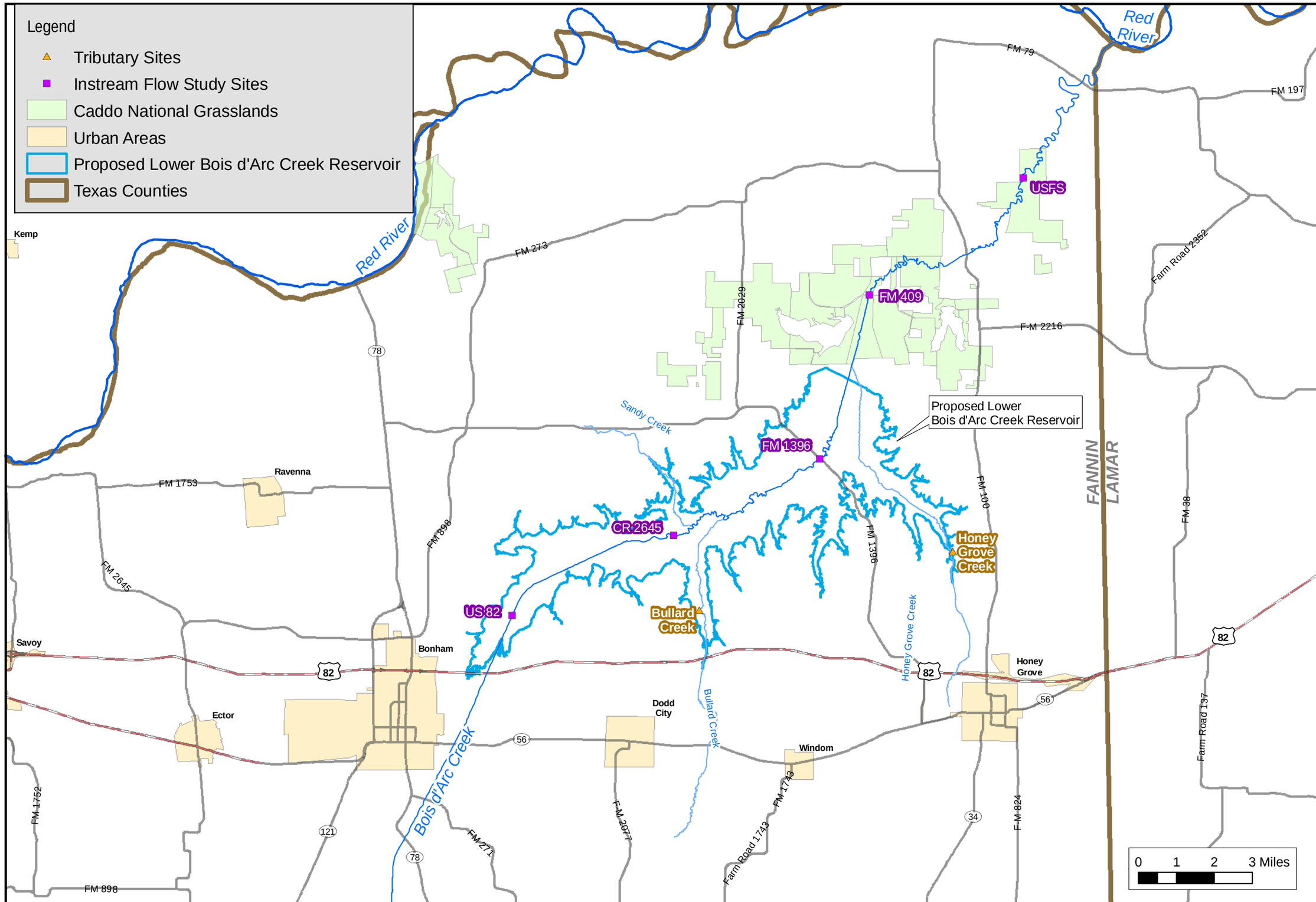

Figure 1.1

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North Texas Municipal Water District
Proposed Lower Bois d'Arc Creek Reservoir

Instream Study Sites

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1.2 Participants in Instream Flow Study

The TIFP is a relatively new approach to assessing instream flow needs. The State developed guidelines for assessing instream flows in 2008. To date, most, if not all, of the instream flow studies conducted with this approach have been on large river systems in Texas.

To facilitate the development of the scope of work and conduct the field studies for this study, an Inter-Agency Team was formed including representatives from the United States Fish and Wildlife Service (USFWS), United States Army Corps of Engineers (USACE), United States Environmental Protection Agency (USEPA), United States Forest Service (USFS), Texas Parks and Wildlife Department (TPWD), TCEQ, Red River Authority (RRA), NTMWD and Freese and Nichols (FNI). A list of the participants and associated role or expertise is shown in Table 1.1.

FNI conducted two scoping meetings in advance of the field data collection. At each meeting, input was solicited from the Inter-Agency Team and adjustments to the scope of work were made in response to comments received. An aerial video of the Bois d'Arc Creek, from upstream of the reservoir site to the Red River, was shown to all Inter-Agency Team members to orient the team members on the issues specific to the watershed and the stream.

All team members were invited to participate in the field data collection. Representatives from TPWD, TCEQ, USACE and NTMWD accompanied FNI in data collection from March through July 2009.

A follow-up meeting was held with the Inter-Agency Team on September 1, 2009 to present the findings of the field data collection to date. At that time, there was a request to collect an additional sampling event during the 2009-2010 fall/winter time period. The NTMWD and FNI agreed to the additional sampling. However, due to an extremely wet winter, high flow conditions made it impossible to conduct this sampling safely during this period. Because of on-going El Niño conditions, the high flows in Bois d'Arc Creek were projected to continue through the spring and possibly into the summer months. In March 2010, FNI and NTMWD concluded that the available field data and analyses, combined with literature reviews, provide sufficient information to characterize baseline stream conditions and develop an environmental flow recommendation that would support a sound ecological environment as defined herein for Bois d'Arc Creek. Subsequent to this decision, the agreed upon one additional sampling episode was conducted in May 2010. The data collected from this sampling event will be analyzed and summarized in a supplemental report to this study.

Table 1.1 Inter-Agency Team

Name	Agency	Position/ Role
Doyle Mosier	TPWD	Inland Fisheries Division
David Bradsby	TPWD	Aquatic Biologist
Clint Robertson	TPWD	Aquatic Biologist
John Botros	TPWD	Aquatic Biologist
Chris Loft	TCEQ	Resource Protection, Office of Water
Dakus Geeslin	TCEQ	Instream Uses, Water rights
Louis Kindler	TCEQ	Instream Uses, Water rights
Peter Schaefer	TCEQ	Aquatic Biologist, 401 Certification
Mark Fisher	TCEQ	Aquatic Ecologist, 401 Certification
Andy Commer	USACE	Regulatory, Permits
Mark Wentzel	TWDB	Hydrologist, Modeling
Nolan Raphelt	TWDB	Geomorphologist
Henry Wied	RRA	Operations
Jim Crooks	USFS	District Ranger Caddo/LBJ National Grasslands
Dave Peterson	USFS	Fisheries Biologist
Jeanene Peckham	USEPA	Water Quality Protection
Sid Puder	USFWS	Biologist
Kathy Alexander	TCEQ	Hydrologist, Water Rights
Robert McCarthy	NTMWD	Project Manager
Mike Rickman	NTMWD	Assistant General Manager
Steve Watters	FNI	Hydrologist
Stephanie Capello	FNI	Geomorphologist
Patrick Garnett	FNI	Wildlife Biologist
Randall Howard	FNI	Aquatic Biologist
Jon Albright	FNI	Hydrologist
Simone Kiel	FNI	Project Manager
Jessica Strickland	FNI	Fisheries Biologist

1.3 Definition of a Sound Ecological Environment for Bois d'Arc Creek

Creating and maintaining a sound ecological environment is the ultimate goal of the instream flow assessment and instream flow regime development process, as prescribed by the Texas Legislature and the Texas Instream Flow Program (TIFP). The Bois d'Arc Creek watershed has been greatly altered since the early 1920s to reduce flooding in order to facilitate agricultural development, making the existing ecological environment of Bois d'Arc Creek different from original pre-settlement conditions. Based on the current conditions and history of Bois d'Arc Creek, the objectives of the TIFP, and input from the Inter-Agency Team, NTMWD proposes the

following attributes to represent a sound ecological environment for Bois d'Arc Creek downstream of the proposed Lower Bois d'Arc Creek Reservoir:

1. Geomorphology:
    a. Stream power that provides for reworking of sediment (depositional features) but not stream bed and bank erosion (downcutting and widening).
    b. Spectrum of mesohabitats – pools, runs, structures (snags, large woody debris, brush piles, other), and "riffle-like" shallows.
2. Hydrology and Hydraulics:
    a. Seasonally varying flows.
    b. Flow regime to support targeted geomorphic processes identified above, meet water quality goals, and maintain or improve existing biological communities.
    c. Hydraulic connectivity to support biological communities.
3. Water Quality:
    a. Maintain existing water quality standards as established in 30 TAC 307, including:
        i. High aquatic life use
        ii. Contact recreation – fully supporting
4. Biology:
    a. Maintain or improve existing fish and macroinvertebrate communities and biodiversity as measured by Index of Biological Integrity (IBI) and Rapid Bioassessment (RBA) metrics.
        i. Fish IBI= High
        ii. Macroinvertebrate RBA = Intermediate

1.4 Report Organization

The main body of this report is intended to provide an overview of the four technical components of the study (hydrology and hydraulics, fluvial geomorphology, biology and water quality) and information on the integration of these components that resulted in the proposed environmental flow releases. Detailed information on the four components of the study may be found in Appendices B through E.

2 BACKGROUND

The NTMWD proposes to build the Lower Bois d'Arc Creek Reservoir project on Bois d'Arc Creek and Honey Grove Creek in the Red River Basin in Fannin County, Texas (Figure 2.1). The proposed dam will cross Bois d'Arc Creek and Honey Grove Creek about 20 miles upstream of the confluence of Bois d'Arc Creek and the Red River.

BACKGROUND

Bois d'Arc Creek watershed is an altered stream system from extensive channelization.

There are periods of little or no flow in the creek.

Stream habitat is heavily influenced by geology and geomorphic processes.

Instream flow study follows TIFP technical components:

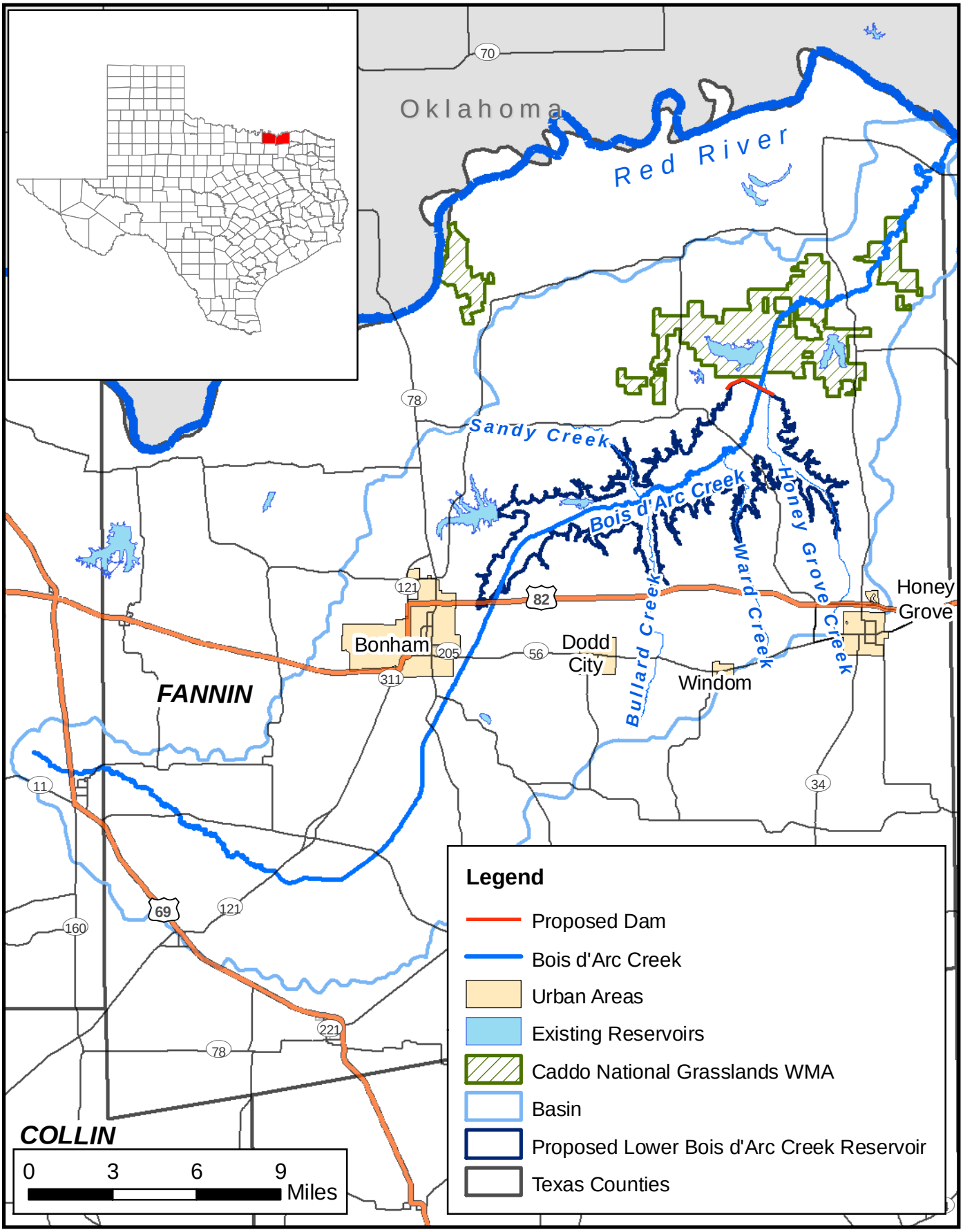
- **Hydrology**
- **Geomorphology**
- **Water Quality**
- **Biology**

Previous site-specific environmental studies and reports prepared in support of this project include:

- *Rapid Geomorphic Assessment in the Lower Bois d'Arc Creek Reservoir Site* (FNI, 2009)
- *Environmental Report*, Application for a 404 Permit for Lower Bois d'Arc Creek Reservoir, Volume II (FNI, 2008)
    - Habitat Evaluation Procedure Report for Lower Bois d'Arc Creek Reservoir
    - Archeological Potential of the Proposed Lower Bois d'Arc Creek Reservoir Project
    - Probable Maximum Flood Analysis (FNI, 2007)
- *Jurisdictional Determination Report and Application for a Section 404 Permit for Lower Bois d'Arc Creek Reservoir*, Volume I (FNI, 2008)

Streams in the project area are characterized by extensive channelization, especially along the main channel of Bois d'Arc Creek. Approximately 62 percent of the length of Bois d'Arc Creek within the project site has been channelized, as have portions of a number of tributaries. Much of the channelization was performed to reduce flooding along the creeks. These characteristics continue in the watershed downstream of the proposed dam, with long sections of straightened stream channels followed by sections of meandering channel. The hydrology of the watershed is characterized by the rapid rise and fall of stream flow in response to rain events, which is in part due to the extensive channelization in the watershed. During dry times there may be little or no flow in the creeks. The previous fluvial geomorphologic analyses indicate that the prior channelization and lack of bank stability have reduced habitat and other functions of the streams within the project area.

Additional background information is presented in Appendices B through E.



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Proposed Lower Bois d'Arc Creek Reservoir

Bois d'Arc Creek Watershed Location Map

FN JOB NO	NTD06128
FILE	Basins.mxd
DATE	February 2010
SCALE	1:300,000
DESIGNED	BME
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2.1
FIGURE

2.1 Environmental Setting

The Bois d' Arc Creek basin is located in northeastern Texas in Fannin and Grayson counties (Figure 2.1). Bois d'Arc Creek originates at the eastern border of Grayson County near Whitewright, Texas and flows in a northeasterly direction across Fannin County to its confluence with the Red River at river mile 612. The watershed has a length of about 58 miles, a maximum width of about 18 miles, and a drainage area of approximately 425 square miles.

2.1.1 Water Quality and Biology

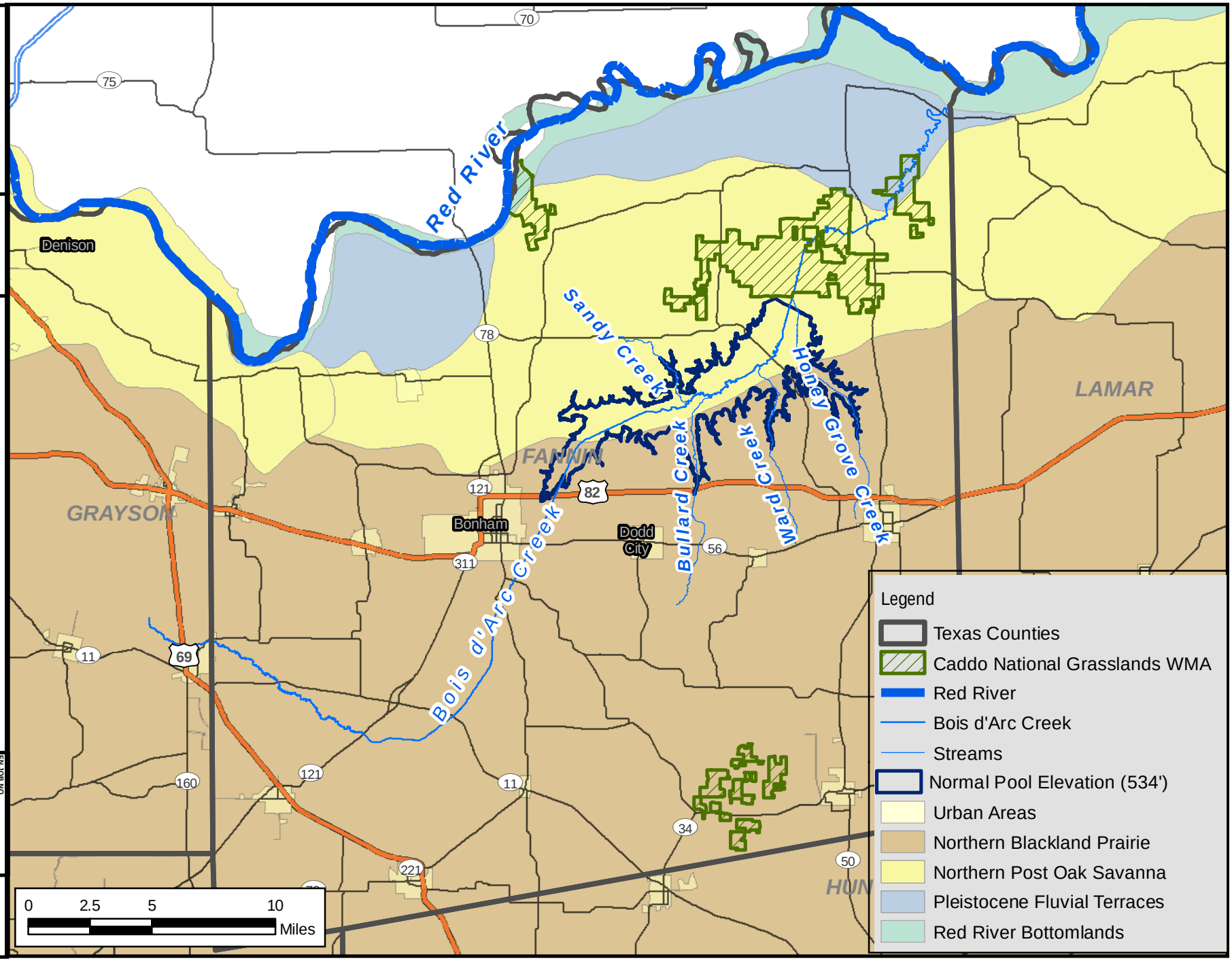
According to the TCEQ's 2008 Water Quality Inventory, Bois d'Arc Creek (Segment 0202A – unclassified water body) has perennial flow and a high aquatic life use designation from its confluence with the Red River up to its confluence with Sandy Creek within the proposed reservoir site. From the Sandy Creek confluence upstream to the confluence with Pace Creek (upstream of the reservoir site), the TCEQ categorizes the flow as perennial with an intermediate aquatic life use designation (30 TAC § 307.10(4)). Hydrologic data collected within the Bois d'Arc Creek watershed, including the recently installed gage at F.M. 1396, show extended periods of little or no flow in Bois d'Arc Creek. These data indicate that Bois d'Arc Creek might more appropriately be classified as having intermittent flow rather than perennial flow. Zero flow conditions were observed during an October 2008 site visit conducted by the U.S. Army Corps of Engineers accompanied by representatives of the USFWS, TPWD, and FNI to verify FNI's waters of U.S. determination. These zero flow conditions were also observed and documented in a video of the creek during a flyover on December 19, 2008 and recorded by the USGS gage at F.M. 1396.

Although no use assessment was conducted for the 2008 Water Quality Inventory, the TCEQ concluded that the water quality was fully supporting aquatic life and overall uses based on prior assessments.

Surveys conducted by TPWD in 1982 and by the RRA in 1998 indicate that the majority of the fish assemblage in Bois d'Arc Creek is comprised of generalist species – those able to survive in both riverine and lacustrine habitats. These results corroborate the data collected in the current study. The RRA's results yielded a calculated index of biological integrity (IDB) score of 35, indicative of low intermediate biological integrity.

2.1.2 Physiography

The Bois d'Arc Creek watershed is a smoothly dissected undulating upland plain located in four distinct ecoregions as mapped and described by Griffith et al. 2004 (Figure 2.2). In addition, there are extensive high flats, or river terraces, in the northern portion of the watershed along the Red River. The southern portion of the watershed is in the Northern



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Eco-Regions for Fannin County

FN JOB NO	NTD06128
FILE	Figure2_2.mxd
DATE	April 2010
SCALE	1:335,000
DESIGNED	BME
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FIGURE 2.2

Blackland Prairies of the Texas Blackland Prairies Ecoregion, which is dominated by a diverse assortment of grasses and forbs. The central portion of the watershed lies within the Northern Post Oak Savannah in the East Central Texas Plains Ecoregion. In both of these ecoregions the forested or wooded areas tend to be restricted to bottomlands along major rivers and streams. The most northern portion of the watershed is within the Pleistocene Fluvial Terraces of the South Central Plains Ecoregion and eventually converges with the Red River in the Red River Bottomlands of the South Central Plains Ecoregion.

Each ecoregion has unique characteristics of soils, climate, flora and fauna. With the Bois d'Arc Creek watershed crossing four ecoregions, the behavior of the stream system changes as it moves from the upper end of the watershed to the Red River. These changes tend to coincide with changes in geologic structure.

2.1.3 Geology and Soils

The stream channel patterns and characteristics of the Bois d'Arc Creek system are influenced by geologic structure and lithology occurring in Fannin County (Figure 2.3). The creeks and streams in the watershed, including Bois d'Arc Creek, generally flow in channels cut through alluvium deposited by larger streams during the Pleistocene and Holocene Epochs in the Quaternary Period (USDA 2001). Alluvial deposits along Bois d'Arc Creek reflect the Cretaceous bedrock and reworked Pleistocene deposits found in the watershed (Lokke and Brent 1966). The bedrock consists primarily of sandstone, clay, marl, chalk, and limestone (Adkins 1932; Barnes 1967). Pleistocene terraces lie across much of the northern portion of the watershed. The terraces are underlain by clastic sediments deposited by the Red River. The sediments were derived from sources extending to the Texas panhandle and northeastern New Mexico (Fyre and Leonard 1963). Holocene alluvium along Bois d'Arc Creek and its tributaries consist of sediments derived from local bedrock and reworked Pleistocene deposits (Lokke and Brent 1966). Much of the underlying geology in the Bois d'Arc Creek watershed is poorly consolidated and is easily weathered and eroded.

The Preston Anticline, the major geologic structure in the county, is a broad arch that trends northwest-southeast and plunges southeastward. It enters the county in the northwest and continues through the western part of the county (Bullard 1931). Bedrock, stream channels, and soil types are deflected southeastward in broad curves as they pass over the axis of the anticline (TDWR 1982; USDA 2001). The anticline is responsible for the change in direction of Bois d'Arc Creek from flowing in a southeast direction at the headwaters to a northeast direction in the rest of the watershed.

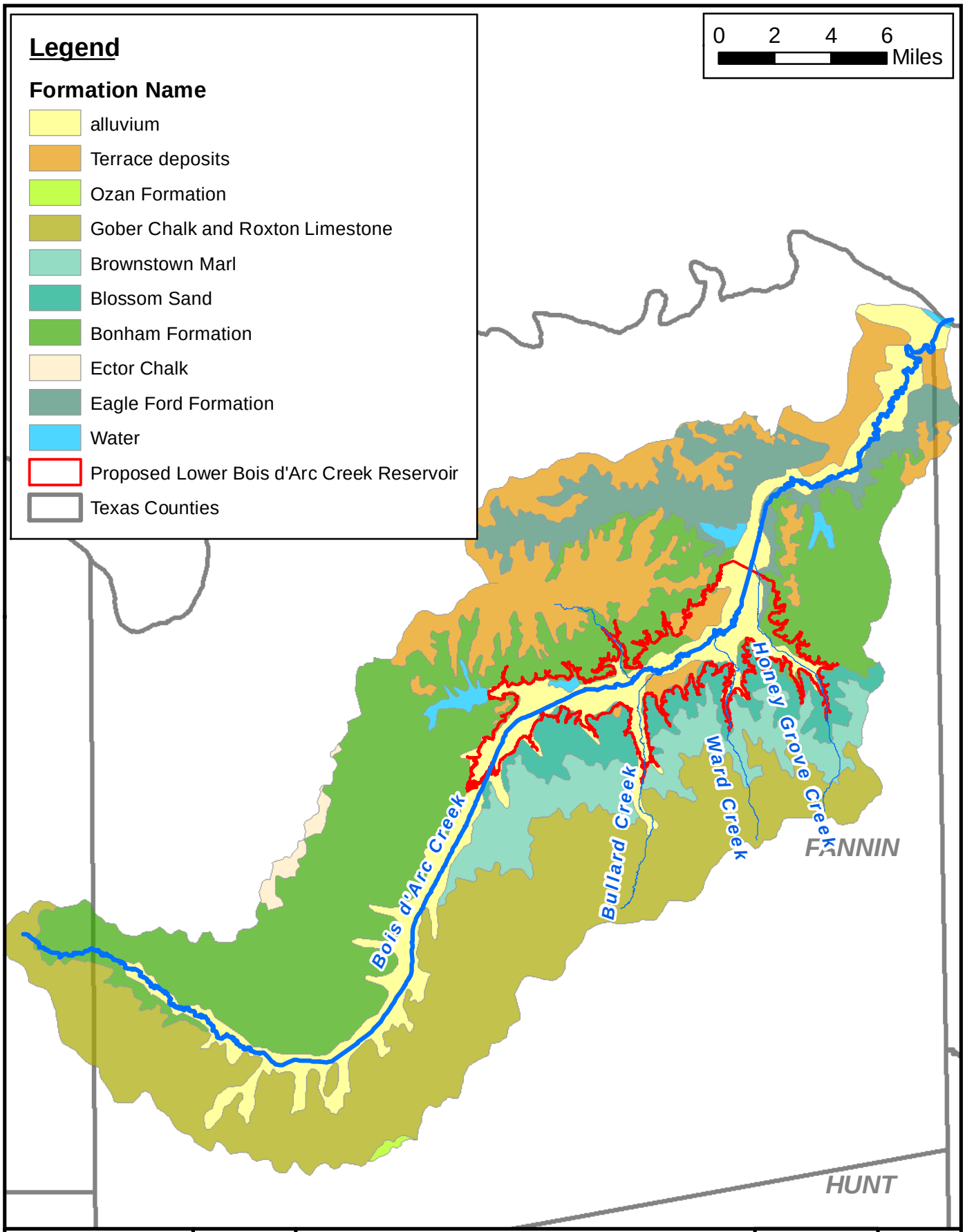
There is a close correspondence between surface geology and soils (Barnes, 1967). The soils were formed in Cretaceous bedrock residuum, Pleistocene fluvial sediment, and Holocene alluvium (Figure 2.4). Pleistocene terraces lie across much of the northern

portion of the watershed. The terraces consist of very strongly acidic to neutral, very deep, loamy soils. The soils have a moderate to high available water capacity and moderate to very slow permeability. All of the soils have a deep rooting depth and low shrink swell potential in the surface soils, but higher potential in the subsoils. The soils may have a water table that ranges between 2 to 3.5 feet during December through May, but some soils show no water table within 6 feet of the surface.

The mainstem of Bois d'Arc Creek from upstream of Bonham and downstream to about three miles above the confluence with the Red River traverses the Tinn and Frioton soil series. These soils are moderately alkaline, very deep, well drained loamy soils on floodplains. The soils have a high available water capacity, slow permeability, a very deep root zone, no water table within a depth of 6 feet, and a high shrink swell potential.

Soils found within the proposed Lower Bois d'Arc Creek Reservoir range from clay-based soils to loam-based soils. According to the General Soil Map of Fannin County Texas, there are three soil associations underlying the proposed reservoir. These soil associations are the Normangee-Wilson-Bonham Association, the Whakana-Porum-Freestone Association, and the Ellis-Crocket Association (USDA, 2001). These soil associations consist of loamy and clayey, moderately acidic to neutral soils. These soils have a high available water capacity, slow to very slow permeability, and a very deep rooting depth. The soils have a moderate to high shrink swell potential, which is influenced by soil moisture. The water table depth varies between soil types, where some are at a depth between 2.5 to 3.5 feet; others may show no water table within a depth of 6 feet.

The south side of Bois d'Arc Creek and the remaining drainages in the headwaters of the watershed consist of slightly acidic to moderately alkaline loamy and clayey soils. They are moderately to very deep and have the potential for shrinking and swelling with changes in moisture and a shallow or moderate depth to bedrock. The soils vary between low to high for available water capacity. All the soils have a deep rooting depth and show no water table within a depth of 6 feet.



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Geology of the Bois d'Arc Creek Watershed

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FILE	Figure2.3.mxd
DATE	April 2010
SCALE	1:300,000
DESIGNED	BME
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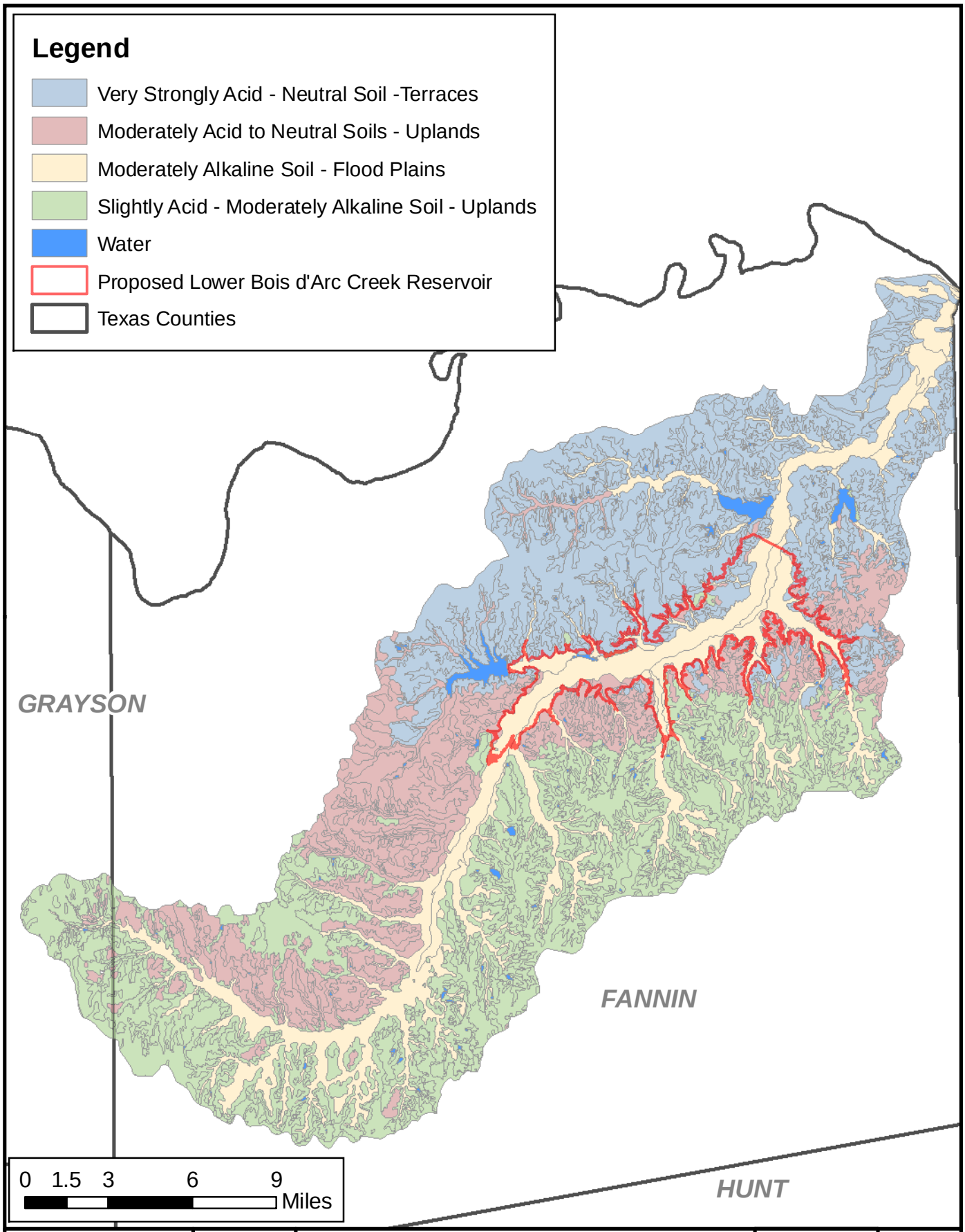
2.3
FIGURE



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Soils of the Bois d'Arc Creek Watershed

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FILE	Soils.mxd
DATE	March 2010
SCALE	1:300,000
DESIGNED	SVC
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2.4
FIGURE

2.1.4 Climate

The climate in the Bois d'Arc Creek watershed is warm-temperate, humid, and continental. The average annual temperature is 64 degrees Fahrenheit, and the mean annual precipitation is 44 inches (Figure 2.5). The watershed lies well within the more southerly paths of the high and low pressure systems that periodically sweep across the United States, and weather changes are pronounced. The summers are long, with hot days and warm nights; the winters are short, mild, and characterized by brief cold spells, alternating with short periods of warm sunny days (Templin et al. 1946). During the two hottest months, July and August, the average daily maximum temperature is approximately 93 degrees Fahrenheit (°F) and the average daily minimum is 71°F. During the two coldest months, December and January, the average daily maximum is approximately 52°F and the average daily minimum is 32°F. Although freezing weather is not unusual, it is of short duration. The ground is never frozen to a depth greater than six inches or for periods longer than two weeks (Templin et al. 1946). The growing season is from mid-March to mid-November, approximately 247 days.

2.1.5 Land Use

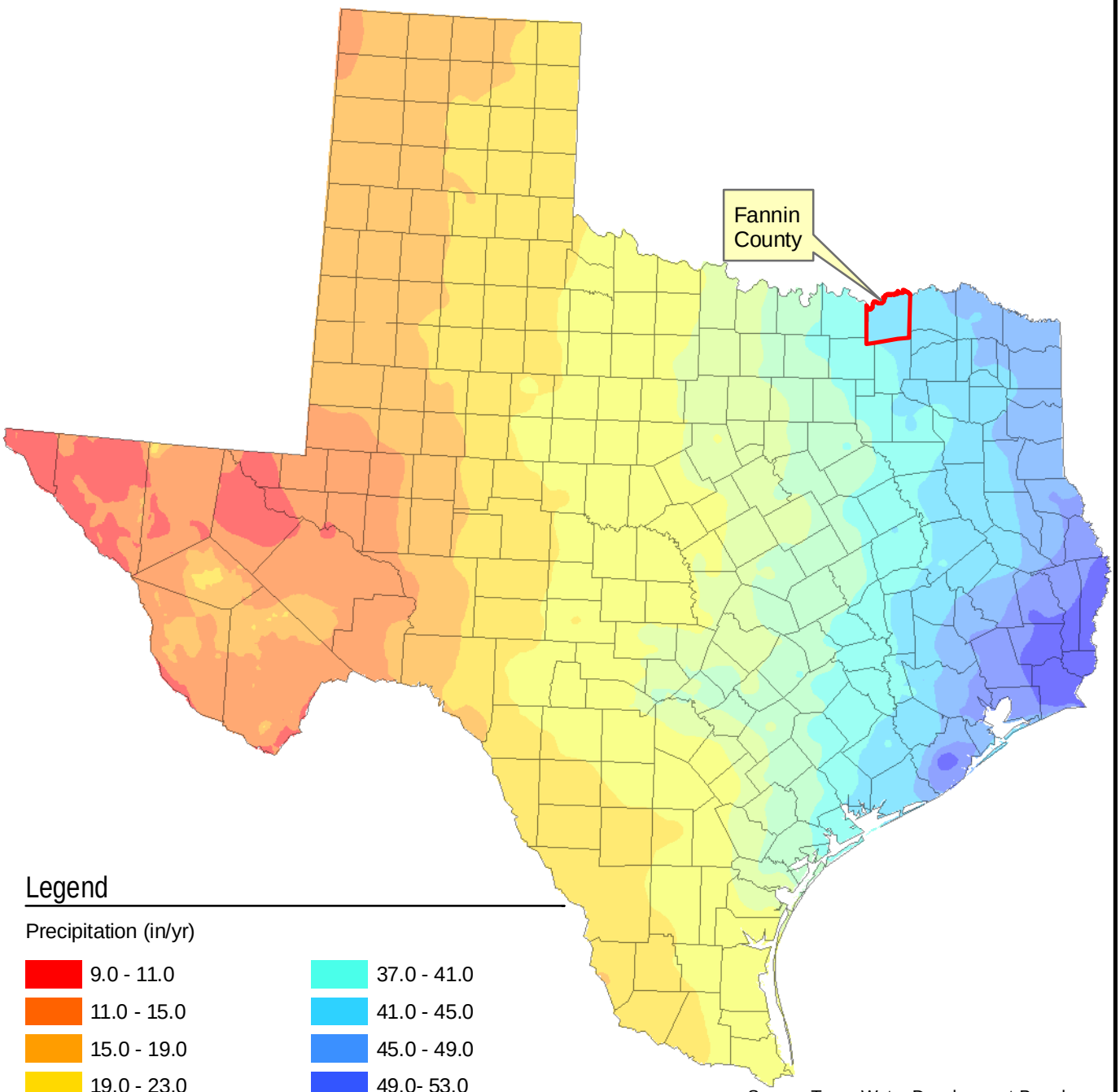
Approximately 97 percent of the Bois d'Arc Creek watershed is within Fannin County, Texas. With the exception of the City of Bonham and several small lakes, much of the watershed is rural or agricultural land.

The major land uses in Fannin County are cropland and improved pasture. In the Bois d'Arc Creek watershed, the Caddo National Grasslands comprise a significant portion of the watershed downstream of the project area. Only a portion of the designated Grasslands proclamation area is currently owned and maintained by the USFS. Much of the privately owned property in the proclamation area is undeveloped or used for timber production, livestock, crops, or hunting.

2.1.6 Channelization

Channelization is a general term covering various forms of channel modification for the purposes of flood control, drainage improvement, maintenance of navigation and erosion prevention. Flood control is of particular importance and typically involves straightening, resectioning, and levee construction, the principal aim being to speed water transport, confine floodwaters within the channel and reduce or eliminate overbank flow (Brookes 1988).

Based on historical maps and satellite photographs of the watershed, there is evidence that landowners in the Bois d'Arc Creek watershed modified the terrain by digging drainage channels through their property, bypassing and sometimes completely abandoning the natural drainage system (Figure 2.6). This drainage modification, a type



Legend

Precipitation (in/yr)

- 9.0 - 11.0
- 11.0 - 15.0
- 15.0 - 19.0
- 19.0 - 23.0
- 23.0 - 29.0
- 29.0 - 33.0
- 33.0 - 37.0
- 37.0 - 41.0
- 41.0 - 45.0
- 45.0 - 49.0
- 49.0- 53.0
- 53.0 - 59.0

Source: Texas Water Development Board
Climatological period 1961-90

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Mean Annual Precipitation

FN JOB NO	NTD06128
FILE	Texas Precipitation.mxd
DATE	January 15, 2010
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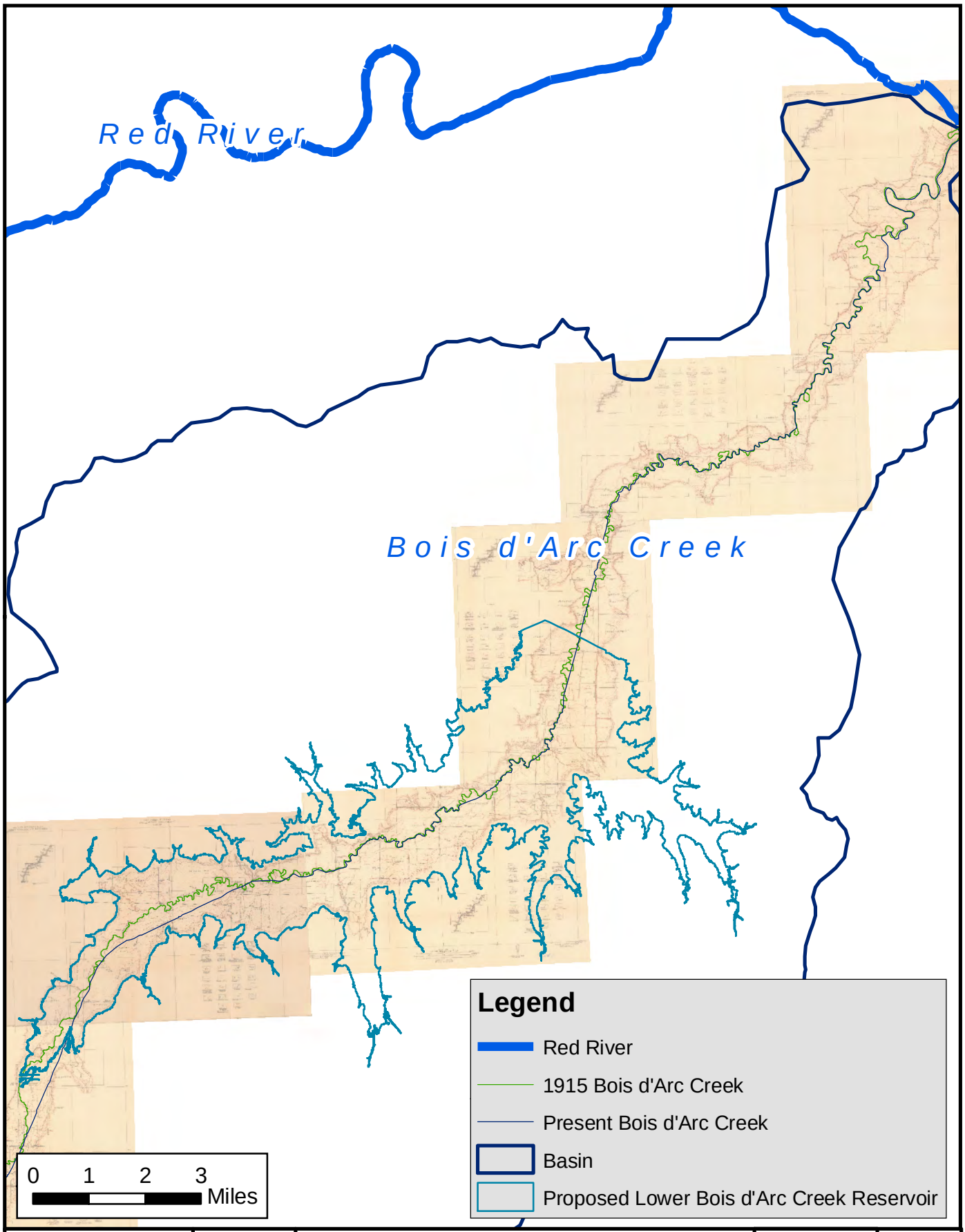
DESIGNED	BME
DRAFTED	BME

2.5
FIGURE



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Bois d'Arc Creek
Historical (1915) Channel Alignment

FN JOB NO	NTD06128
FILE	Historic.mxd
DATE	March 2010
SCALE	1:150,000
DESIGNED	SVC
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2.6
FIGURE

of channelization, started around 1920 and continued well into the 1970s in the Bois d'Arc Creek watershed. Comparison of the historical 1915 watershed map to the current stream configuration indicates that Bois d'Arc Creek has lost over 20 stream miles from the effects of channelization. While the channelization achieved a more rapid conveyance of stream flow and bed materials, the ecological attributes of the stream were fundamentally compromised. As shown in comparisons of the channelized sections of the creek to unchannelized sections, channelization appears to have caused a loss in the complexity of instream geomorphic structures and reduced the diversity of habitats. The narrowing and shortening of the stream by straightening and realignment increased the erosive potential of the flow in Bois d'Arc Creek, which resulted in incision and channel enlargement. Progressively larger flood flows have become concentrated in the channel zone as a result of downcutting into the underlying bed material.

The impacts of channelization on stream configuration, hydrology and habitats are dramatic in the nearby North Sulphur River in southwest Fannin County. In less than 90 years, the channel in the upper reaches of the North Sulpur River increased from 48 feet wide by 6 feet deep to over 300 feet wide by 40 feet deep (Mussetter Engineering, 2006). While the impacts of channelization have not been as severe in the Bois d'Arc Creek watershed, the watershed is experiencing similar consequences. Channel widening and downcutting are occurring and will most likely continue under present conditions. The likelihood of continued erosion was evaluated through an assessment of stream equilibrium as part of the current study. This is discussed in Section 4 and 5.

2.2 Technical Components of an Instream Flow Study

Instream flow refers simply to the water flowing in a stream channel (Annear et al. 2002). The goal of this instream flow study is to identify an appropriate flow regime that will support a sound ecological environment in the stream channel of Bois d'Arc Creek downstream of the proposed Lower Bois d'Arc Creek Reservoir, as defined in the introduction to this report.

Instream flow programs involve technical components for identifying appropriate flow regimes. The Texas Instream Flow Program (TIFP) addresses the riverine components of hydrology, biology, geomorphology, and water quality (TWDB 2008). In the current study, each of these technical elements requires data collection and analyses specific to the technical component; however these analyses were integrated to address the connectivity, structure, and function of the stream system. The TIFP is a method to assess instream flow needs for river basins at a relatively large scale. For small scale systems, such as Bois d'Arc Creek, all of the complexities of the TIFP may not apply or be necessary to arrive at a recommended flow regime. The following subsections provide overviews of the major elements of the Bois d'Arc Creek instream flow study.

2.2.1 Hydrology and Hydraulics

Hydrology is the component that is most easily measured and plays a major role in biological, geomorphic and water quality functions. The TIFP identifies a flow regime that consists of a set of four flow components: subsistence flows, base flows, high flow pulses, and overbank flows. However, not all of these flows necessarily occur in every river or even in every reach of a river (NRC 2005), nor are all of these flows always required to achieve a sound ecological environment.

Subsistence flow is the minimum streamflow needed to maintain tolerable water quality conditions and to provide minimal habitat for the survival of aquatic organisms. Subsistence flows are expected to occur infrequently, most likely during extreme drought conditions. Base flow is the "normal" flow condition occurring between storm events. Base flows sustain habitat and maintain soil moisture and suitable water quality. High flow pulses are short-duration, high flows within the stream channel resulting from a storm event. High flow pulses flush fine sediment deposits, restore water quality following extended low flows, and offer longitudinal connectivity for organism migration. Overbank flows are high flow events that overtop the riverbanks. These flows provide lateral connectivity of a stream to the active floodplain and serve to maintain riparian habitat.

Hydraulics refers to the motion and action of water and other liquids. For this application, hydraulics is the distribution of water velocities across the width and depth resulting from the channel morphology and discharge through the channel. Hydraulic conditions are important for describing instream habitat since aquatic organisms prefer habitats with particular combinations of velocities and depths (TWDB 2008).

2.2.2 Fluvial Geomorphology and Physical Processes

Fluvial geomorphology is the study of the interactions between stream channel forms and processes at various ranges of space and time scales. These include the physical processes that form and maintain stream channels, floodplains, and habitat, flush fine sediment and transport sediment loads (TWDB 2008). Rivers and streams are continuously changing ecosystems that interact with the surrounding climatic and hydrological factors, biotic factors, and terrestrial and geological factors. As a result, geomorphic processes vary between and within basins and sub-basins (Brierley and Fryirs 2005).

The form of a stream channel results from interactions among discharge, sediment supply, sediment size, channel width, depth, velocity, slope, and roughness of channel materials (Lane 1955; Leopold et al. 1964; Knighton 1998). The magnitude, frequency, timing, and duration of flows are major factors in the geomorphic structure of a channel. Sediment transport and deposition also influence the morphology of a stream. Stream

channels react to changes in sediment dynamics and will degrade or aggrade along the longitudinal gradient in response to the sediment load.

Many researchers have recognized and emphasized the importance of geomorphic features, and the processes that form them, when considering the affects of instream flows on riverine ecology (Brierley and Fryirs 2005; Benda et al. 2004a; Torgersen et al. 2008; Phillips 2007). The type and quality of aquatic and riparian habitats are directly related to specific landforms and geomorphic processes (Hupp and Osterkamp 1996; Scott et al. 1996; Robertson and Augspurger 1999; Johnson et al. 2001; Gumbricht et al. 2004; Moret et al. 2006). Human modification, such as channelization and bank fortification influence the channel form and the resulting habitat.

2.2.3 Water Quality

Water quality is important to growth, survival, and reproduction of aquatic organisms (TWDB 2008), and it determines whether or not desired uses of a water body can be maintained. Water quality characteristics directly reflect the influence of the watershed geology, soils, land use, and climate. The primary water quality parameters that indicate the ability of a stream to support aquatic life include dissolved oxygen (DO) and temperature. Consistently depressed DO concentrations will favor a biological community typically less diverse than a system with higher DO levels.

Streams that are subject to temperature extremes will exhibit limited biological diversity as well, either directly due to species temperature intolerance, or indirectly by limiting the capacity of the stream to maintain adequate DO or by encouraging other adverse water chemistry condition. Factors that influence temperature include flow, channel width and depth, riparian shading, thermal inputs, turbulence, and current velocity (Armour 1991; TWDB 2008).

Other water quality constituents, such as turbidity, suspended solids, pH, dissolved solids, nutrients and other inorganic and organic compounds, can also affect the ability of a stream to support a sound ecological environment. The degree of influence of these constituents is often related to human activities, or the lack thereof, within a watershed. The greater the population density, or the more intensive the agriculture activities in rural watersheds, the more likely that particular water quality constituents will become unbalanced in a receiving stream due to point or nonpoint source contributions and thus impair or degrade desired water uses. While these other constituents can have an important role in maintenance of a sound ecological stream environment, they typically are assessed as secondary parameters to the primary constituents of DO and temperature in instream flow studies unless previously identified as constituents of concern.

2.2.4 Biology

The biological component of the instream flow studies reflects the integration of the hydrology/hydraulics, geomorphology and water quality aspects of the stream. These three components (hydrology/hydraulics, geomorphology, and water quality) directly impact aquatic habitats, biological migration, reproduction and overall aquatic life viability. Understanding these relationships provides a mechanism to create and maintain a sound ecological environment.

To characterize the baseline conditions of the stream, the biological component of instream flow studies includes developing relationships among aquatic communities, life histories, and habitats (TIFP 2008). This element considers the physical processes that create and maintain the habitat, water quality, and hydrology (Bovee et al. 1998; Annear et al. 2002; TWDB 2008). Flow regimes affect the quality and quantity of available habitat (Bunn and Arthington 2002). Habitat conditions are generally characterized in terms of water velocity, depth, substrate composition, and instream cover and are a key component of any instream flow prescription. Flow regimes also manipulate the geomorphic structure of a channel and affect water quality conditions in streams, in turn influencing the biological processes.

3 OVERVIEW OF METHODS

3.1 Instream Flow Study Plan Development

The instream flow study was developed with input from the Inter-Agency Team (Table 1.1), incorporating the key instream flow study components as identified in the TIFP: hydrology and hydraulics, water quality, fluvial geomorphology and biology. For each study component baseline conditions of the Bois d'Arc Creek study area were described using existing data supplemented by field data collected by the Inter-Agency Team. The future conditions of each study component were predicted using computer modeling or other appropriate techniques described in this report with the assumption that the proposed reservoir is in place and operating at full water supply demand. The baseline and predicted future conditions were used to evaluate the following:

- Effects of the proposed reservoir on Bois d'Arc Creek within the reservoir pool and the reach between the dam and FM 409
- Ability of the proposed flow regime to support a sound ecological environment between the proposed dam site and the FM 409

A series of inter-agency coordination meetings were held to describe the proposed instream flow study, seek input from regulatory agencies, and solicit participation in field studies. The following summarizes the relevant decisions made by the group with regard to sampling and data analysis protocols:

- The biological sampling effort would be conducted following the protocols of the TCEQ Surface Water Quality Monitoring (SWQM) guidelines.
- The protocols used for assessing biological quality would be the Index of Biotic Integrity (IBI) and benthic macroinvertebrate Rapid Bioassessment (RBA). This would be used for both the baseline biology and predicted future biology.
- During sampling, fish species would be identified and information collected to determine the mesohabitats from which they are caught. Additionally, information on flow and substrate would be recorded.
- Sampling efforts would not be restricted to the "critical period" and would be allowed flexibility based on field/sampling conditions.
- Fish species collected during sampling efforts may be grouped using a guild approach for data analysis. In addition, data would be collected on flow sensitive species and species of concern if discovered during sampling efforts.
- In addition to fish and macroinvertebrates, mussels would be collected (or identified in the field) at sampling sites when present for additional data.
- Sampling sites would be located in the vicinity of the proposed reservoir and downstream of the proposed dam. Locations would be finalized pending access. In addition to these sampling sites, up to four additional biological sampling sites along Honey Grove Creek,

Sandy Creek, Bullard Creek, and Pig Branch may be sampled opportunistically to characterize the biota. Sampling sites may be modified, if needed, to adapt to field conditions and land access.

- Field sampling and data collection would not be conducted during "high flow" events due to safety issues. Data collection for "high flows" could be completed two weeks after these events. Hydrology and water quality data were collected continuously at the USGS gage at FM 1396 and FM 409, including high flow events.
- It was agreed that the classification of hydrologic conditions (i.e., low/medium/high flows) for biological data collection and analyses should be different from flows used for the hydrology analyses. For biological purposes, it was suggested that only median flows and below be considered as the flow range for biological sampling.
- Stream geomorphology would be characterized only at the study reaches. FNI would extrapolate stream geomorphology for the downstream corridor with the use of aerial photography and the helicopter flyover. FNI staff would field check geomorphology at the additional cross-sections surveyed at intermediate locations between the study reaches for the HEC-RAS model (visual observation only).
- The following sections briefly describe the methods used for data collection. More detailed information on methods is presented with the study results in later chapters and in Appendices B through E.

3.2 Instream Flow Study Data Collection and Methods

The primary sampling sites for the instream flow study were located on the mainstem of Bois d'Arc Creek above and below the proposed reservoir at U.S. 82, CR 2645, FM 1396, FM 409,and USFS property located downstream of FM 100 (Figure 3.1). In addition to these primary sites, two representative tributary sites (i.e., Bullard and Honey Grove Creeks) were sampled for biota. Representatives from the Inter-Agency Team (TCEQ, TPWD, and TWDB) assisted with the site and reach selection. The reach length was determined by using 40 times the average stream width (USEPA 2000; TCEQ 2007). Two of the four sites (FM 1396 and FM 409) were selected to measure detailed transects (Figure 3.2 and Figure 3.3). The Inter-Agency Team also collaborated in the placement of the transect locations.

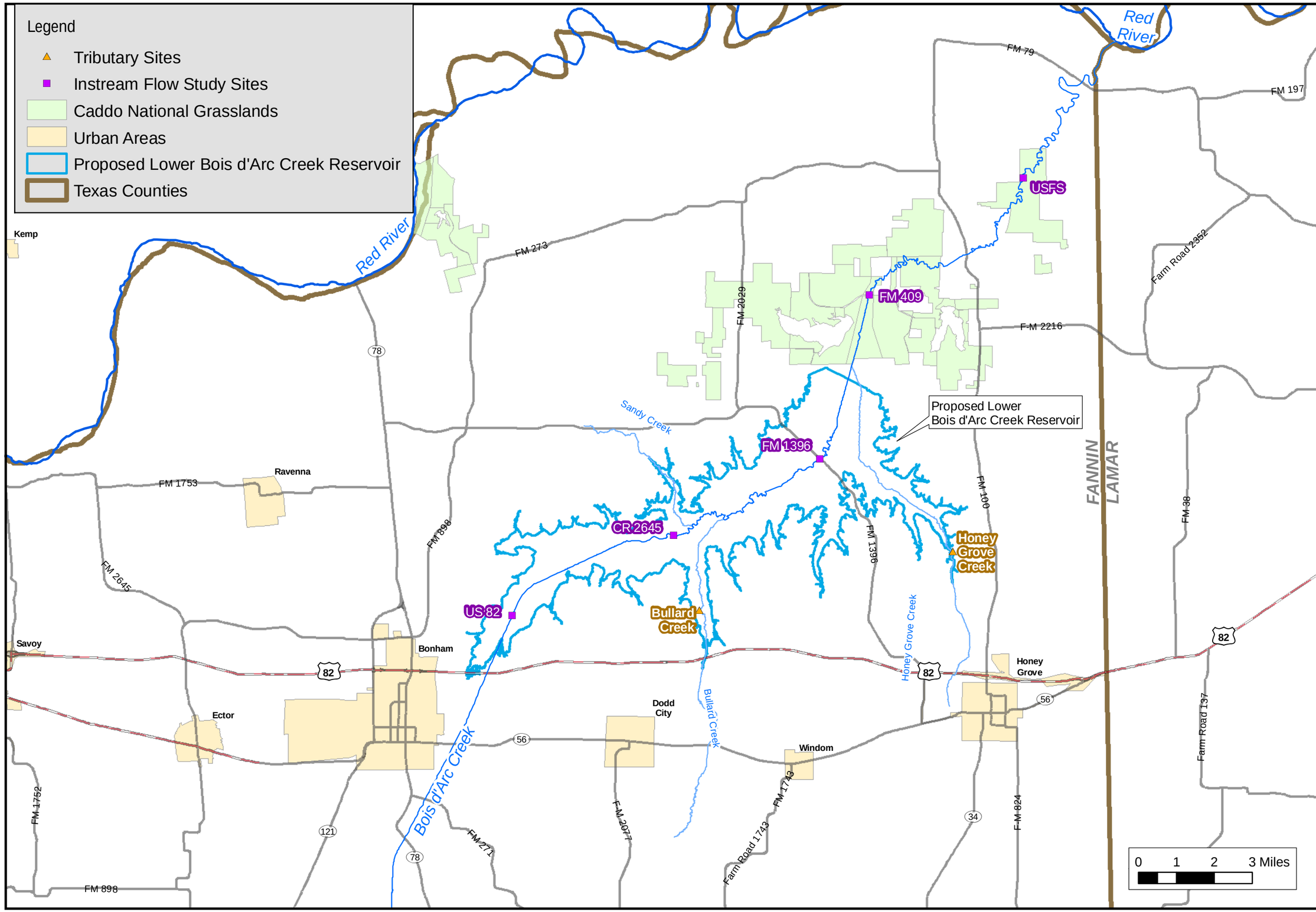

Figure 3.1

FN JOB NO	NTD06128
FILE	Figure3.1.mxd
DATE	April 2010
SCALE	1:149,333
DESIGNED	BME
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Proposed Lower Bois d'Arc Creek Reservoir

Instream Study Sites

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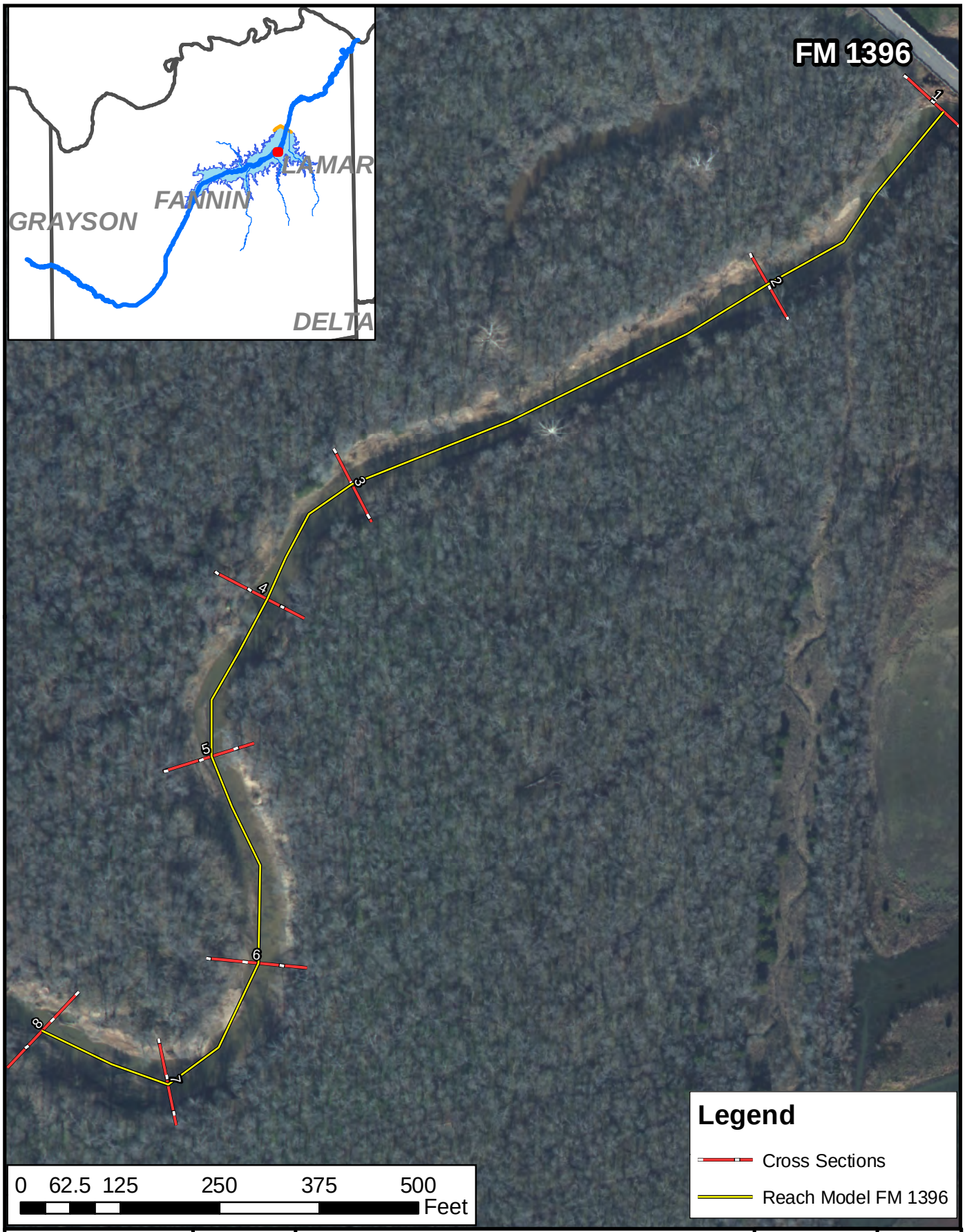
817-735-7300



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Transects at Bois d'Arc Creek Study Reach near FM 1396

FN JOB NO	NTD06128
FILE	Historic.mxd
DATE	March 2010
SCALE	1:2,000
DESIGNED	SVC
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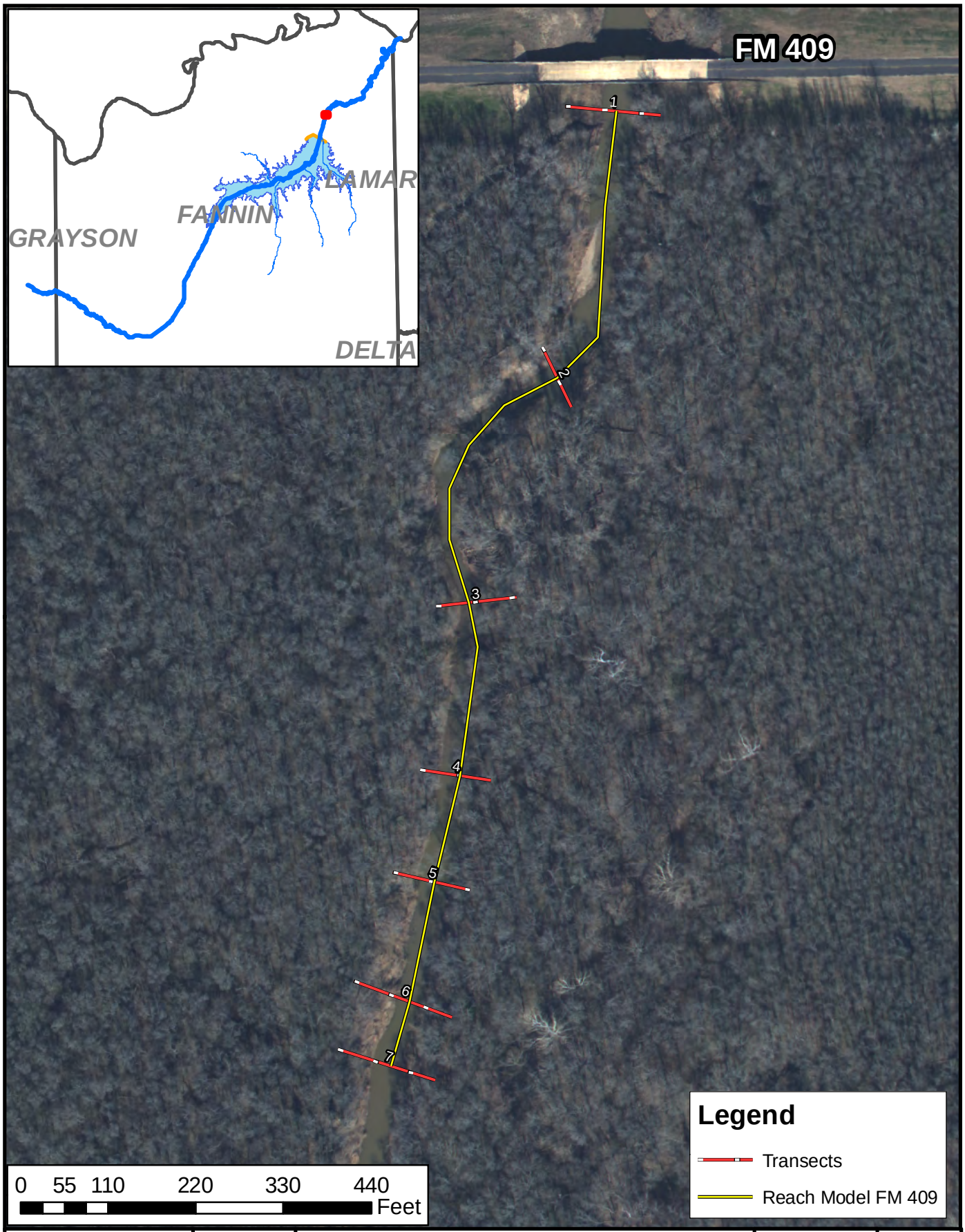
3.2
FIGURE



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Transects at Bois d'Arc Creek Study Reach near FM 409

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FILE	Historic.mxd
DATE	March 2010
SCALE	1:2,000
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3.3
FIGURE

The sampling events were conducted in March 2009, June 2009 and July 2009. All biological collections were made at a minimum of 14 days after storm pulse events to allow for species recolonization (per Inter-Agency Team recommendations). Each instream flow technical component had specific field methods (Table 3.1) which were utilized at the instream flow study sites (Table 3.2).

Table 3.1 Field Methods Utilized for the Bois d'Arc Creek Instream Flow Study

Technical Component	Field Methods
Hydrology/ Hydraulics	(1) Measure transects (2) High flow measurements: Discharge (3) Low flow measurements: Discharge Velocity (at habitat) Depth (at habitat)
Geomorphology	(4) Geomorphic mapping (habitat) (5) Bulk sediment sample: Surface sample Subsurface sample (6) Erosion pins
Water Quality	(7) Measure and record water quality parameters – DO, temperature, pH, conductivity, turbidity
Biology	(8) Macroinvertebrate sampling: Kicknet Live pick and preserve on site (9) Fish sampling: Backpack electrofishers Seine

Table 3.2 Field Methods Utilized at Each Instream Flow Study Site

Site	Field Method[1]
US 82	3,4,7,8,9
CR 2645	3,4,7,8,9
FM 1396	1,2,3,4,5,6,7,8,9
FM 409	1,2,3,4,5,6,7,8,9
USFS	3,7,8,9
Bullard Creek	3,7,8,9
Honey Grove Creek	3,7,8,9

[1]Refer to Table 3.1 for Field Method Identification

3.1.1 Hydrology and Hydraulics

The hydrology and hydraulic component of the proposed Lower Bois d'Arc Creek Reservoir Instream Flow Study consisted of four major activities:

- Evaluating historical and current flow data for Bois d'Arc Creek using USGS stream gage data;
- Surveying transects within the instream flow study reaches and making flow and water surface elevation measurements at the transects;
- Developing a hydraulic model to determine rating curves that relate water depth to flow rates using the Hydrologic Engineering Center's River Analysis System (HEC-RAS); and
- Developing a long-term hydrologic model to evaluate the historical streamflow response in the watershed.

The hydrology and hydraulic data and analyses generated from these activities were used to describe the current and future flow conditions in the Bois d'Arc Creek watershed and in the analyses of the other technical components of this study. The hydraulic model was used as data input with the habitat analyses for the biological evaluations. It was also used in support of the geomorphic analyses. The long-term hydrologic model evaluated long-term frequencies and provided data to assess on-going and future processes.

3.1.2 Fluvial Geomorphology

The geomorphic component of the Lower Bois d'Arc Creek Reservoir Instream Flow Study included:

- Conducting a geomorphic characterization of the stream system of the Bois d'Arc Creek watershed using the River Styles Framework®;
- Analyzing channel stability by comparing the lateral movement of Bois d'Arc Creek on historical maps and aerial photos and making field measurements of stream bank erosion using erosion pins; and
- Evaluating sediment transport potential within Bois d'Arc Creek by collecting and analyzing bulk sediment samples and modeling sediment transport capacity using the Stable Channel Analytical Model, Windows version (SAMWin) hydraulic design software package.

The fluvial geomorphic component of the study provided information on the stream equilibrium and fluvial processes that influence aquatic habitats and water quality. The geomorphic characterization that included mapping of aquatic habitats, sediment transport and channel stability analyses provide an assessment of the baseline stream conditions and an understanding of the processes for future conditions. These data were used in conjunction with other data components (hydrology, biology and water quality) to establish a proposed flow regime for a sound ecological environment.

3.1.3 Water Quality

The water quality component of the Bois d'Arc Creek Instream Flow Study included:

- Defining the baseline water quality of Bois d'Arc Creek by reviewing existing data collected by TCEQ and the USGS;
- Collecting dissolved oxygen, pH, temperature, and specific conductance at the study sites to identify instantaneous water quality conditions; and
- Predicting future temperature and dissolved oxygen conditions in the proposed Lower Bois d'Arc Creek Reservoir based on data from existing North Texas reservoirs and below the reservoir using the Qual-TX model.

3.1.4 Biology

Biological assessment in the study included:

- Reviewing previous biological studies that included data collected in the Bois d'Arc Creek watershed or in nearby watersheds;
- Collecting fish samples using TCEQ's 2007 Surface Water Quality Monitoring Procedures (TCEQ 2007);
- Collecting macroinvertibrates using TCEQ 2007 SWQM Rapid Bioassement Protocol (RBP);
- Characterizing habitat based on substrate composition, current velocity, and water depth;
- Categorizing fish data by relative abundance by:
    - Sampling site, flow, season, and mesohabitat, and

  - Trophic structure and reproductive guild composition to identify potentially predominant life history strategy; and
- Calculating the regionalized Index of Biotic Integrity (IBI) (TPWD 2002) and Rapid Biassessment (RBA) index for each biological sample where suitable data were collected.

The biological component of instream flow studies is the barometer for identifying and describing a sound ecological environment. The flow regime, water quality, physical habitat, and the other numerous physical and chemical constraints can affect the many types of organisms that live in streams such as macrophytes, bacteria, algae, protozoans, invertebrates, and vertebrates including amphibians, reptiles, and fish.

In this study, three groups of organisms were selected to study, sample and describe selected population and community attributes. These were benthic macroinvertebrates, mussels, and fish. Macroinvertebrates were sampled to provide data to calculate a Rapid Bioassessment (RBA) index of water quality, while mussels were observed to document presence of living species in the stream. Fish sampling included community measures (calculation of Index of Biotic Integrity scores) and mesohabitat sampling. Measurements of substrate characteristics, current velocity, water depth, and water quality were made at mesohabitat sites to provide data to correlate fish presence and abundance with hydrologic, geomorphic, and water quality variables. Habitat modeling using River2D software was used to calculate useable areas of habitats at varying flows.

3.2 Data Sources

3.2.1 Geomorphic Data

The general environmental framework of the Bois d'Arc Creek basin (geology, soils, land use and land cover) is well established. The Land Resources Map of Texas (Kier et al. 1977) and Land Use and Land Cover (LULC) for Fannin County, Texas were available, along with complete geologic mapping at 1:250,000 scale (Geologic Atlas of Texas), and full soil map coverage from the Soil Survey Geographic (SSURGO) Database.

Geologic framework and constraints were derived from 1:250,000 scale geologic maps from the Texas Bureau of Economic Geology (Geologic Atlas of Texas) from the Sherman and Texarkana sheets. The Tectonic Map of Texas (Ewing, et al. 1991) as well as a map of the structural framework of the East Texas Basin (Jackson 1982) was used to identify potential tectonic influences. Many articles, reports and bulletins published by universities and various government agencies (as cited in this report) were used to describe the geology of the Bois d'Arc Creek basin.

Soils data from the U.S. Department of Agriculture (USDA) Natural Resources Conservation Services (NRCS) were obtained for the Bois d'Arc Creek basin from the online Soil Survey Geographic (SSURGO) Database. Published surveys for Fannin and Grayson Counties were

also consulted. While the soil maps are useful in establishing the general environmental framework, their primary purpose in this study was to aid in distinguishing modern Holocene flood plains from Pleistocene alluvial terraces that occupy the river valleys and to recognize the range of soil parameters within the basin.

3.2.2 Hydrologic and Hydraulic Data

Discharge and river stage data from the U.S. Geological Survey (USGS) were used to establish hydrologic regimes. Discharge and velocity measurements were also collected in the field with the use of the SonTek ® River Surveyor M9 and Flow Tracker Handheld-ADV® (Acoustic Doppler Velocimeter). The River Surveyor was used during times of higher flows (>100 cfs) when the stream was not wadable. Discharge and velocity measurements were obtained at various locations within study reaches. The FlowTracker Handheld-ADV® was used when the stream was wadable and the velocity less than 2.5 ft/sec.

Long-term hydrologic data were developed from historical USGS gage stream flow records and evaporation data obtained from the Texas Water Development Board. Since there are limited historical stream gage data in the Bois d'Arc Creek watershed, data were also obtained from the USGS gage at the North Sulphur River near Cooper, TX (USGS 07343000). This gage is located in an adjacent watershed with similar characteristics to Bois d'Arc Creek. Historical flows from the North Sulfur River were compared to the flows recorded in Bois d'Arc Creek to confirm applicability for this study.

3.2.3 Mapping Data

Digital map and aerial photographic data were obtained primarily from the Texas Natural Resources Information Systems (TNRIS) Geographic Information Systems (GIS). U.S. Geological Survey 1:24,000 topographic maps were obtained in Digital Raster Graphics (DRG) form. The topographic maps used in the study were originally surveyed in the 1964–1984 time frame and have not been revised. Digital Elevation Model (DEM) data at 30 m resolution were obtained for the entire Bois d'Arc Creek basin. The topographic maps and DEMs were used to evaluate the elevation of the terrain and location and shape of landscape units. General visualization of the geomorphic features were discerned from 1-meter resolution digital orthophoto quarter quads (DOQQ) obtained from TNRIS. A map of the Bois d'Arc Creek system dating from circa 1915 was used along with aerial photographs from 1950, 1969, 1970, 1976, 1996, 2007 to evaluate changes in stream patterns, land use practices, and riparian vegetation. Changes that impacted or influenced the channel pattern and profile were evaluated and documented. The morphometric and spatial distribution parameters of the Bois d'Arc Creek basin were evaluated in the GIS environment, using ArcInfo 9.3.

3.2.4 Water Quality Data

Water quality data in Bois d'Arc Creek were collected by the TCEQ, RRA, NTMWD and USGS. Most of the stream data is from 1997 to the present. There are currently four water

quality sampling stations in Bois d'Arc Creek: 1) at FM 100, downstream of the proposed reservoir site, 2) at FM 409, downsteam of the proposed reservoir site, 3) at FM 78, just upstream of the proposed reservoir site, and 4) at FM 1396 within the proposed reservoir site. The two sites at FM 100 and FM 78 are sampled by the RRA and TCEQ as part of the Clean Rivers Program. Data from the TCEQ sampling sites extend from October 1997 to July 2007, and include a variety of parameters. Two USGS, real-time data gages are located on the mainstem of Bois d'Arc Creek: 1) at FM 1396 near Honey Grove (water quality data beginning in September 2006), and 2) at FM 409 (June 2009) also near Honey Grove. The gages are separated by approximately five stream miles. In addition to collecting gage height and discharge measurements, the gages also collect water temperature, specific conductance, pH, and dissolved oxygen.

USGS water quality profile data from multiple North Texas Lakes were examined to estimate water temperature and dissolved oxygen concentrations at different depths within the proposed reservoir. Jim Chapman Lake (also known as Cooper Lake), located northwest of Sulphur Springs, TX, is located in close proximity to the proposed Lower Bois d'Arc Creek Reservoir and has similar size, depth, and geology. For the months of April, October, November, and December, Jim Chapman Lake USGS data were not available. Consequently, USGS data from other lakes in North Texas, including Lake Texoma, Lake Whitney, Lewisville Lake, and Benbrook Lake were used to estimate water temperature and dissolved oxygen concentrations for these months.

In addition to the existing and current collection of water quality data, dissolved oxygen, pH, temperature, specific conductance, and turbidity were measured and recorded during each biological sampling event. The water quality parameters were measured using a calibrated Horiba U-22 Multiparameter Sonde. Instantaneous field measurements were taken at each site specific habitat location also including profiles in deeper areas as the water column is often stratified due to the temperature and salinity. The water quality measurements taken during the biological sampling events were compared to the existing data as well as the gage data.

3.2.5 Biological Data

The biological data included the review and incorporation of data from previous studies in the watershed as well as data collected as part of this instream flow study. There is little baseline data on the fish or macroinvertebrates of Bois d'Arc Creek. Data sources include fish and macroinvertebrates collected by the Red River Authority (RRA, 1999), and a species list for Bois d'Arc Creek from the Texas Natural History Collection(TNHC) Ichthyology archives; however, the TNHC list did not identify collection location, date, or numerical species accounts. Other existing data sources included personal sightings and recordings and broader studies in the Red River basin in Texas and Oklahoma.

Biological sampling conducted as part of this study included three groups of organisms: benthic macroinvertebrates, mussels, and fish. Collections were made at each of the five study reaches on Bois d'Arc Creek and two tributaries as described in Table 3.2.

4 BASELINE CONDITIONS

This chapter is an overview of current conditions in the Bois d'Arc Creek watershed based on historical data, data collected as part of this study, and modeled data. Data are grouped by the four main components of the study: hydrology and hydraulics, fluvial geomorphology, biology and water quality. More detailed information on these components may be found in the appendices of this report.

4.1 Hydrology and Hydraulics

This portion of the study examines the current hydrologic conditions in Bois d'Arc Creek. The study used a combination of measured historical data and modeled hydrology. These data are essential to understand current geomorphic and biological conditions observed in the Bois d'Arc Creek watershed. This section gives a brief overview of the baseline hydrologic conditions. More detailed information may be found in Appendix B.

HYDROLOGY

Stream flows are characterized by rapid rise and fall in response to rainfall events.

Limited historical flow data are available in watershed. Long-term hydrologic data are determined using models.

Overbank flows occur frequently, with a return period of less than 1 year.

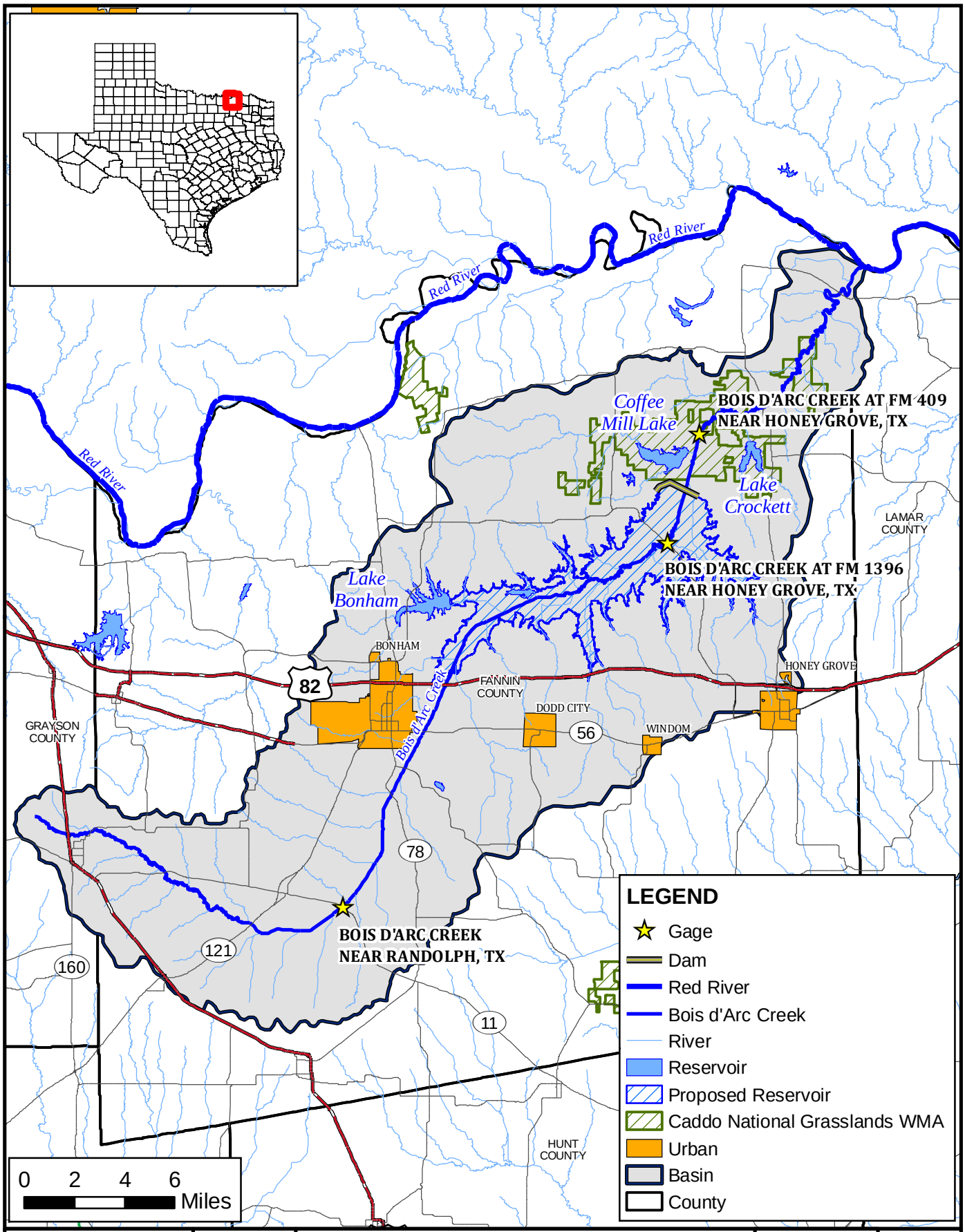
Long-term median flow is <10 cfs. Many months have no flow.

4.1.1 Gage Records

There are limited historical gage data in the Bois d'Arc Creek watershed (Table 4.1). The Randolph gage has the longest period of record (23 years), but only measured flow from 22 percent of the watershed. The FM 1396 gage has published data from July 2006 to September 2009. In addition, provisional flow data are available at the FM 409 gage (beginning in September 2009). Based on previous analyses by FNI, the North Sulphur River at Cooper appears to be the best surrogate for flows near the proposed Lower Bois d'Arc Creek Reservoir damsite. A comparison of these gages is included in Appendix B. The locations of these gaging stations are depicted in Figure 4.1.

Table 4.1 Relevant USGS Streamflow Records

Gauge Number	Gage Name	Start Date	End Date	Basin	County	Drainage Area (mi^2)
07332600	Bois d'Arc Ck nr Randolph, TX	Dec-62	Sep-85	Red	Fannin	72
07332620	Bois d'Arc Creek at FM 1396 nr Honey Grove, TX	June-06	Current	Red	Fannin	270
07332622	Bois d'Arc Creek at FM 409 nr Honey Grove, TX	Sep-09	Current	Red	Fannin	370
07343000	*N Sulphur Rv nr Cooper, TX*	*Oct-49*	*Current*	*Sulphur*	*Lamar*	*276*



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Map of Gage Locations

FN JOB NO	NTD06128
FILE	Figure4.1.mxd
DATE	May 2010
SCALE	1:335,000
DESIGNED	DLB
DRAFTED	BME

4.1

FIGURE

Figure 4.2 shows the historical flow data from the FM 1396 gage, plotted on both normal and logarithmic scales. The gage data show that Bois d'Arc Creek is a "flashy" watershed, characterized by a rapid rise and fall in response to rainfall events. There are extended periods of little or no flow. Low-flow periods include June 2006 to early October 2006 and July 2008 to May 2009. It is likely that the extreme flow characteristics of the watershed are exacerbated by the extensive channelization in the watershed.

One of the challenges faced by the USGS in measuring flows is the continuous horizontal and vertical movements of the channel bed at the FM 1396 and FM 409 gages. This has required several adjustments to the rating curves at these gages in the short period of time that these gages have been in operation (USGS 2010). As a result, unpublished USGS stage data are not easily converted to flows because of the constant adjustment of the rating curves. Not only has this made it difficult for the USGS to determine accurate flow data, but it has also made it difficult to correlate the reported flow data with measurements of water surface elevations. Water surface elevations at different flows were developed based on field measurements from this study. These elevations reflect conditions at the time the measurements were made and generally corresponded well with the USGS data for those dates; however, the measured elevations may not correspond to past or future rating tables from the USGS. In the future, flows will have different water surface elevations because of the on-going downcutting of the watershed.

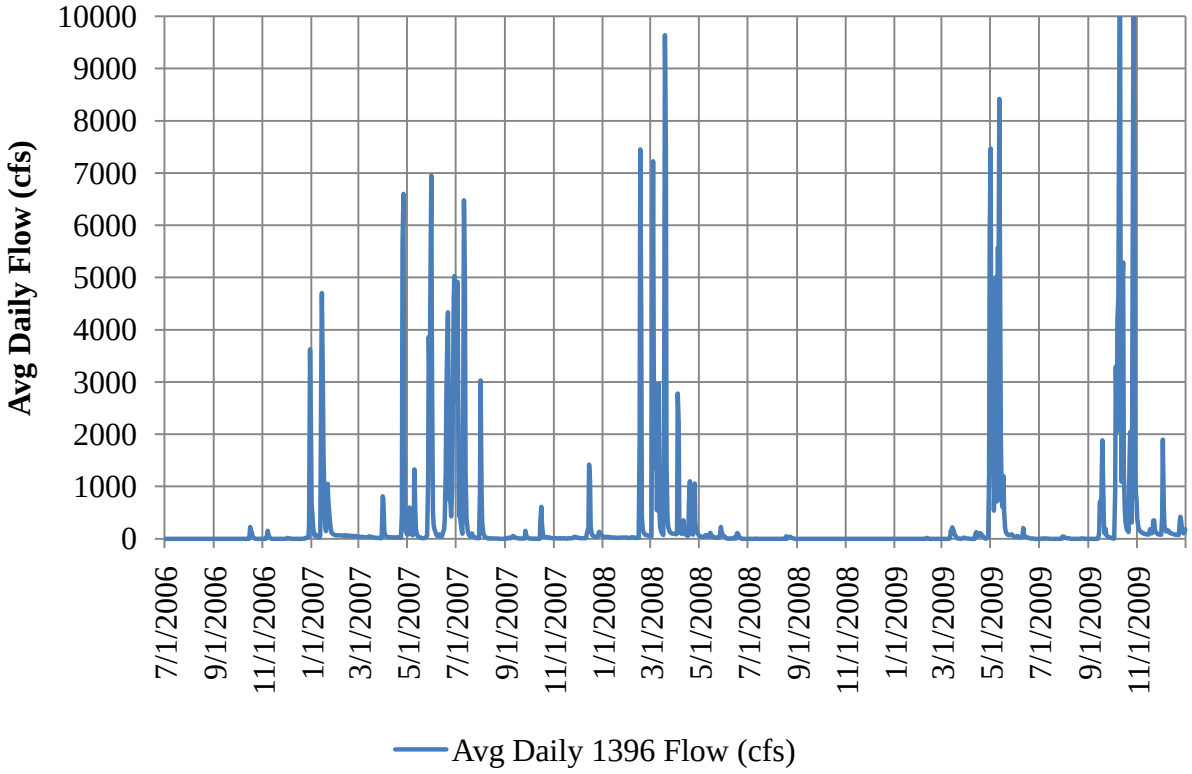
4.1.2 Modeled Flows

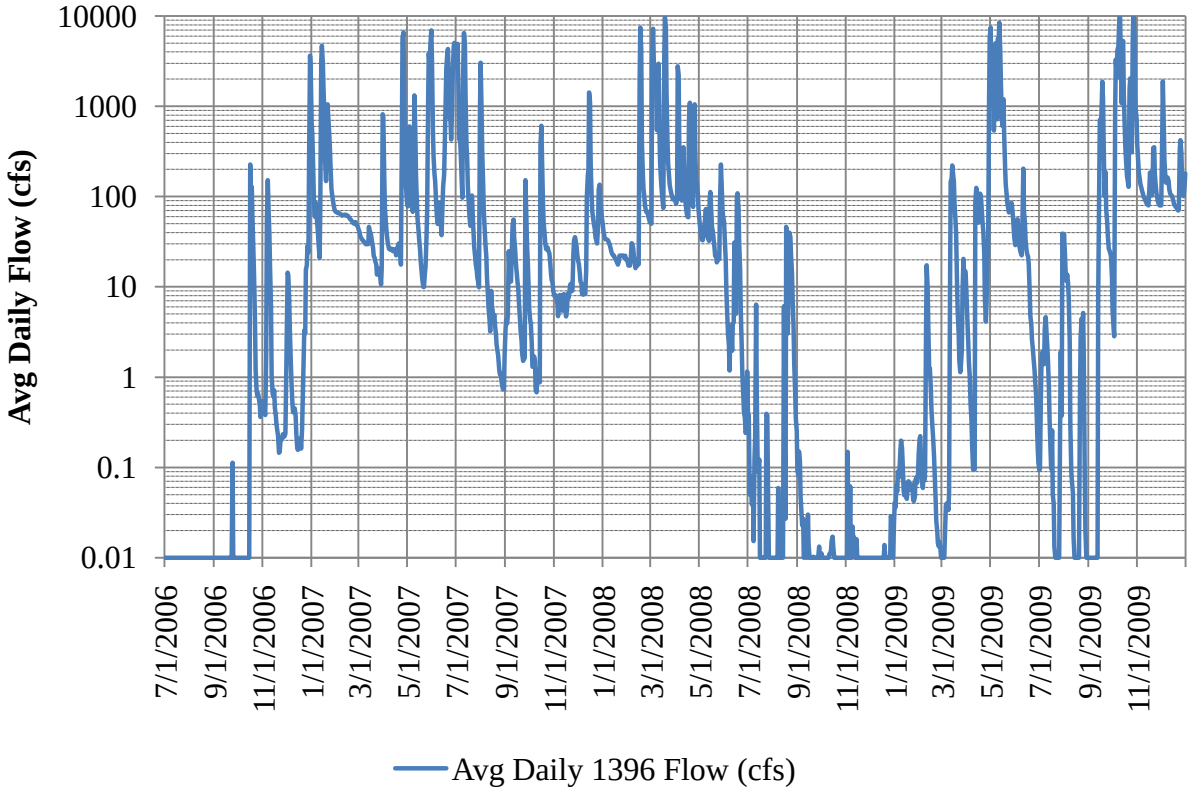
Three types of modeling were used to help characterize current hydrologic conditions:

- Modeling of overbanking storm events using a HEC-RAS model of the watershed from about 23.6 miles above the proposed Lower Bois d'Arc Creek Reservoir dam site to just above the confluence with the Red River. This model is called the *Full Model*.
- Modeling of low-flows in the FM 1396 and FM 409 study reaches, also using the HEC-RAS model. These models are referred to as the *Reach Models*.
- Modeling of the long-term hydrologic response of the watershed using RiverWare.

A brief description of these models follows. More detailed information about the modeling may be found in Appendix B.

Figure 4.2 Historical Flow Data for USGS Gage 07332620 - Bois d'Arc Creek at FM 1396





4.1.2.1 HEC-RAS Modeling of Overbanking Events

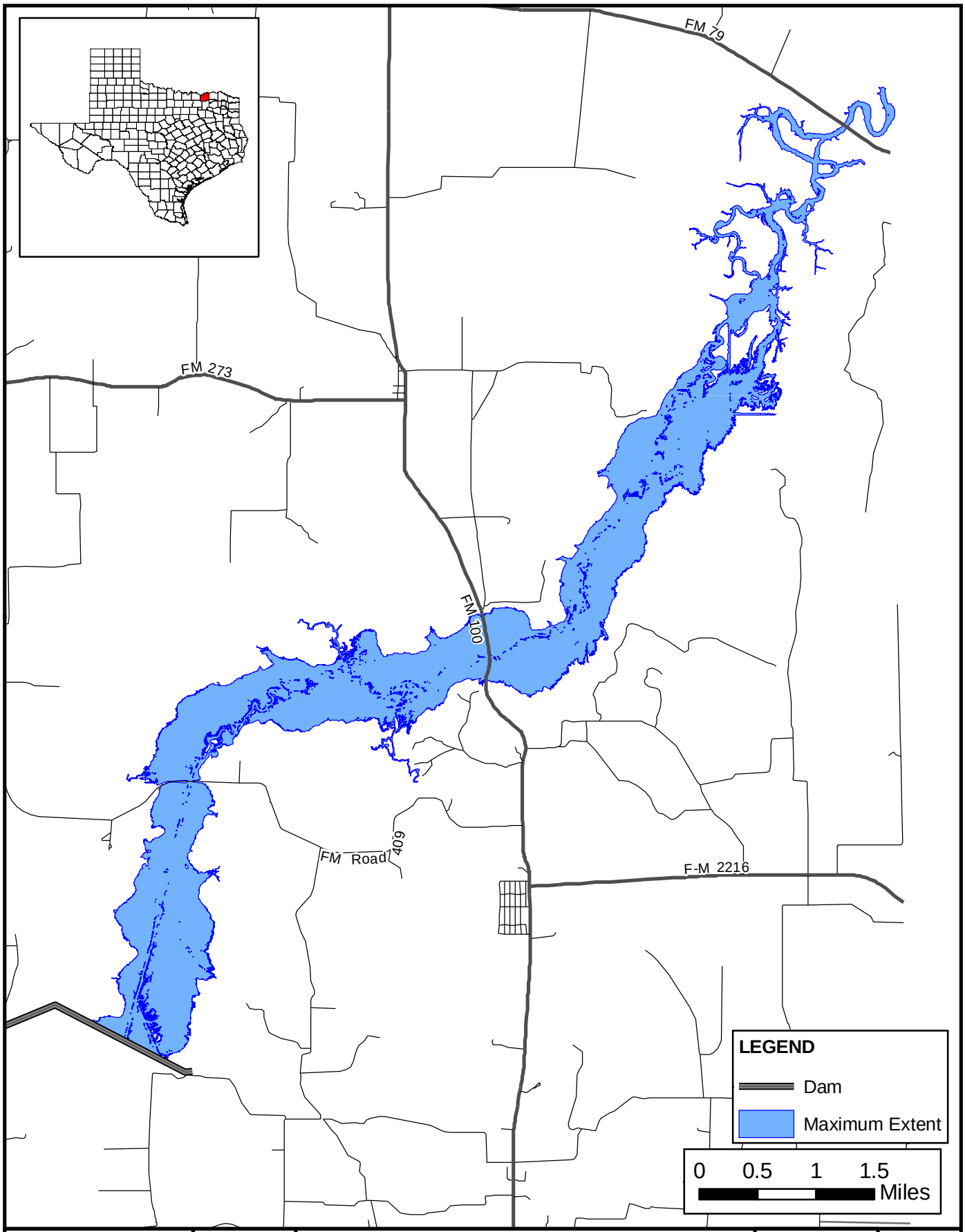
HEC-RAS is a one-dimensional hydrology and hydraulic modeling program developed by the US Army Corps of Engineers. A large scale HEC-RAS model of the watershed, called the Full Model, was used to identify the extent of overbank flooding for 1-year, 1.5-year, and 2-year storm events. Table 4.2 shows the peak flow and daily average flows for each of these events, as measured at FM 409 (model cross section 85046). Figure 4.3 through Figure 4.5 show the maximum inundation for each of these events from the proposed dam location to a point just below the FM 79 bridge, which is close to the confluence of Bois d'Arc Creek with the Red River. All three events cause similar overbank flooding from the proposed dam to a point between the FM 100 and FM 79 crossings. From that point the storm events are more confined, with inundation limited to cutoff channels and gullies. However, the Full Model does not include any backwater effects from the Red River. If flows in the Red River are high, there is potential for additional overbanking in the lower portions of Bois d'Arc Creek. These results show that under current conditions overbanking events are a relatively common occurrence in the Bois d'Arc Creek watershed and the corresponding floodplains are a relatively narrow corridor along Bois d'Arc Creek.

Table 4.2 Bois d'Arc Creek Flow Rates and Inundated Area for 1.0-Year to 2.0-Year Storm Events

	At FM 409		Dam to FM 79
Recurrence Interval	**Peak Flow (cfs)**	**24-hr Average Peak Flow (cfs)**	**Inundated Area (acres)**
1.0 Year	8,056	5,948	3,396
1.5 Year	11,095	8,814	3,709
2.0 Year	13,390	11,265	4,121

4.1.2.2 Development of Study Reach Rating Curves using HEC-RAS

Detailed HEC-RAS models were developed for the FM 1396 and FM 409 study reaches, referred to as the Reach Models. The Reach Models were calibrated using discharge and water surface data collected as part of this study and flow data collected by the USGS at the FM 1396 and FM 409 stream gages. These models were used to develop rating curves that relate water surface elevation to flow and velocity in the study reaches. These rating curves were used in habitat models described in the Biology sections of this report.



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Proposed Lower Bois d'Arc Creek Reservoir

1 Year Flood Event

FN JOB NO	NTD06128
FILE	Figure4.3.mxd
DATE	May 2010
SCALE	1:72,000
DESIGNED	BME
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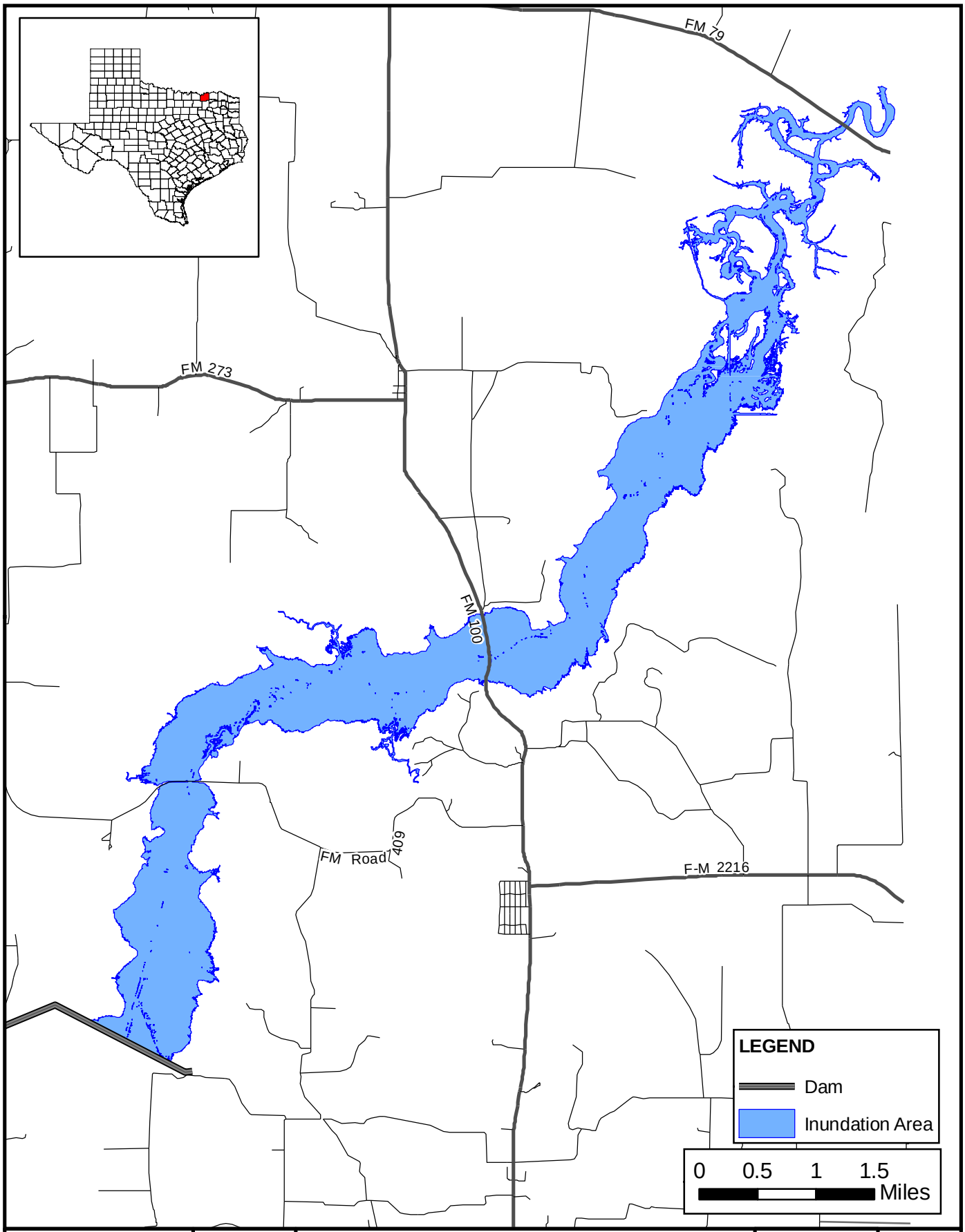
4.3
FIGURE



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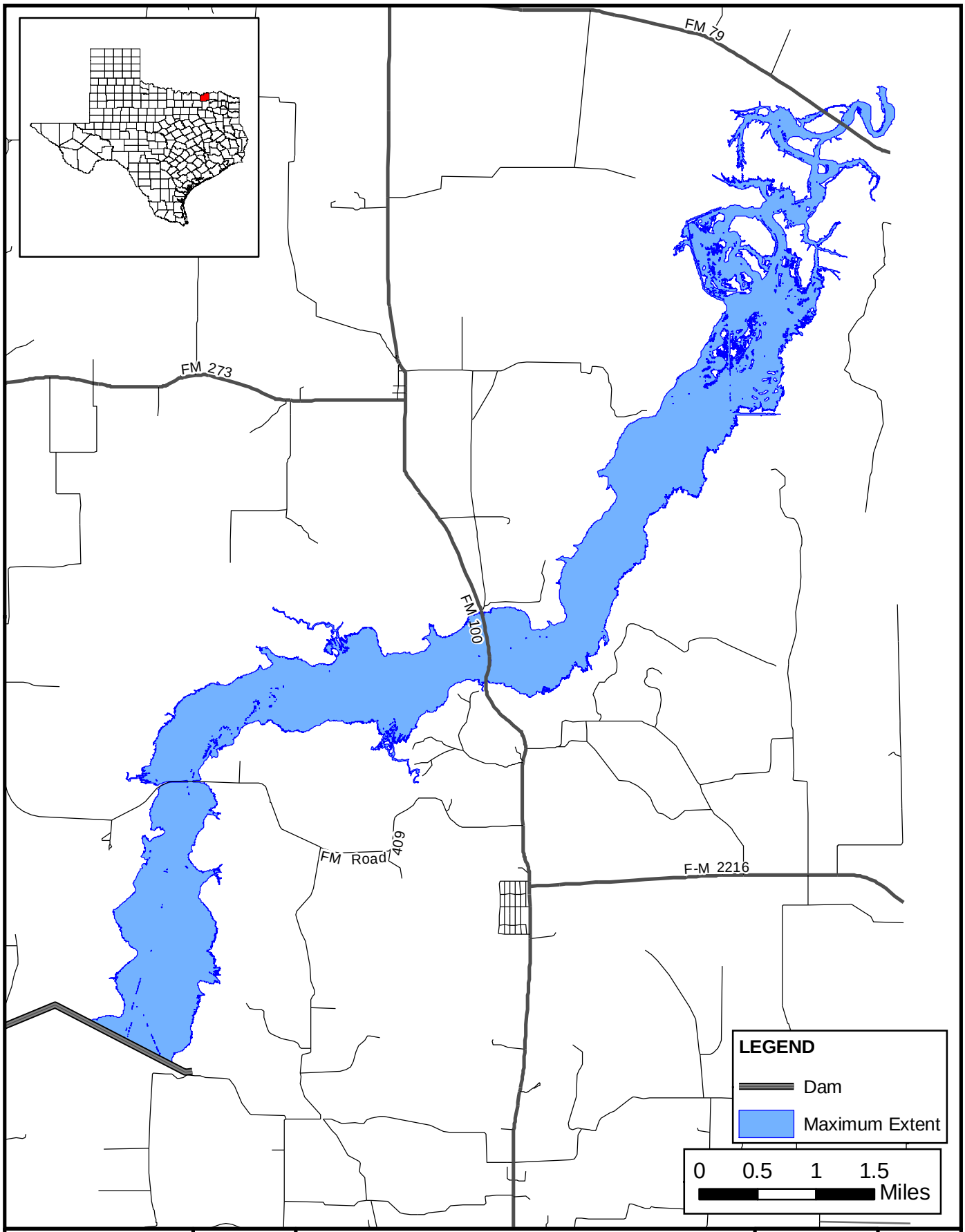
Proposed Lower Bois d'Arc Creek Reservoir

1.5 Year Flood Event

FN JOB NO	NTD06128
FILE	Figure4.4.mxd
DATE	May 2010
SCALE	1:72,000
DESIGNED	BME
DRAFTED	BME

4.4
FIGURE



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Proposed Lower Bois d'Arc Creek Reservoir

2 Year Flood Event

FN JOB NO	NTD06128
FILE	Figure4.5.mxd
DATE	May 2010
SCALE	1:72,000
DESIGNED	BME
DRAFTED	BME

4.5
FIGURE

4.1.2.3 Long-Term Hydrologic Modeling using RiverWare

The available USGS gage data at the reservoir site only show a small time window of flow conditions in Bois d'Arc Creek. A RiverWare model was developed to estimate the response of the watershed to changing stream conditions over a longer period of time. RiverWare is a hydrologic model designed to simulate management of reservoir and stream segments that was developed by the Center for Advanced Decision Support for Water and Environmental Systems (CADSWES), a division of the University of Colorado at Boulder. The model was used to assess the baseline conditions of the watershed as well as future conditions with the dam in place. Figure 4.6 shows the layout of the model. It includes explicit modeling of Lake Bonham, the FM 1396 gage (USGS 07332620), the proposed reservoir damsite, Lake Crockett, the FM 409 gage, Coffee Mill Lake, the FM 100 crossing and the reach from FM 100 to the Red River. Flows for the RiverWare model are based on data from the North Sulphur River near Cooper gage (USGS 07343000) and the TCEQ Red River Basin Water Availability Model (TCEQ WAM). The model uses a daily time step and covers the period from 1948 to 1998.

Figure 4.6 RiverWare Model Layout

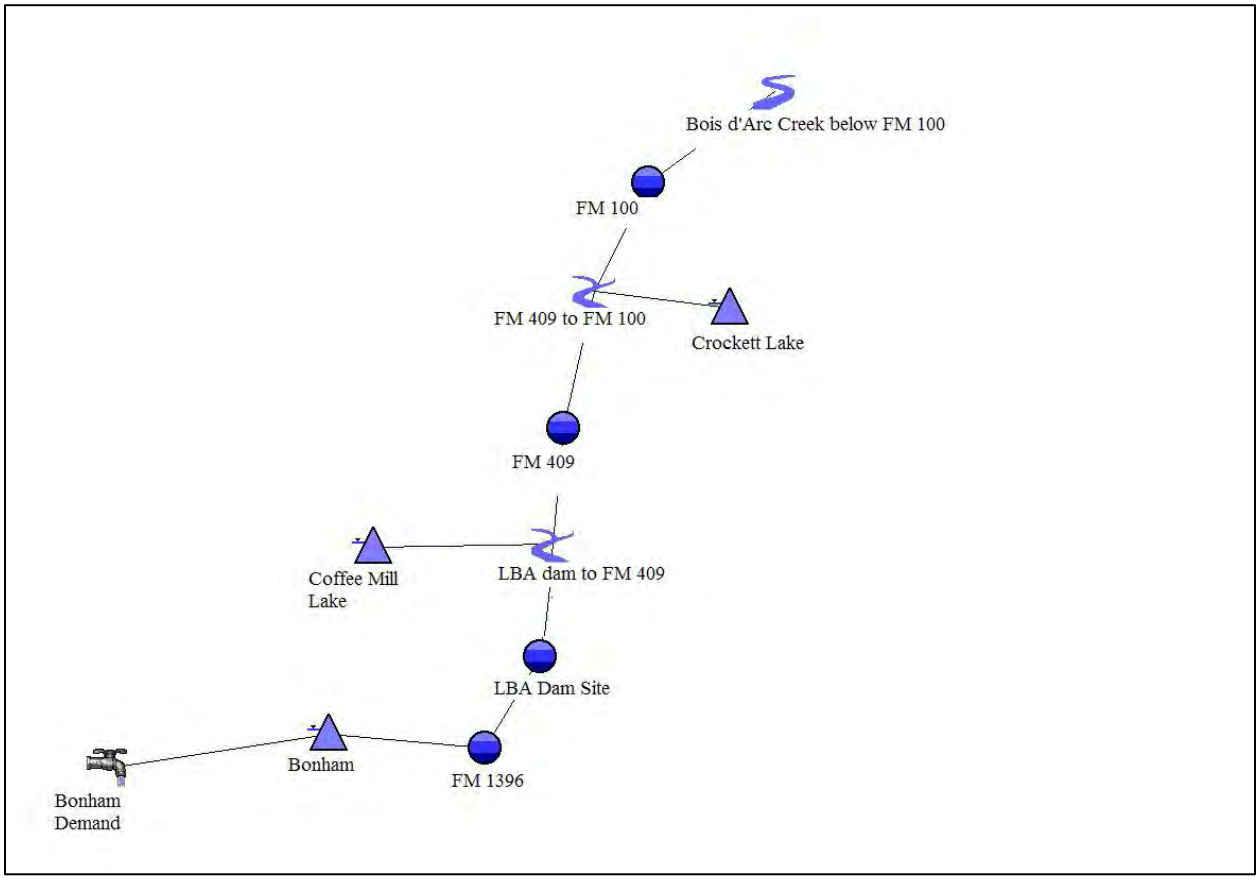


Table 4.3 is a statistical comparison of the modeled flows at FM 1396 to historical flows measured at FM 1396. In this study, we have identified three seasons based on the flow characteristics of the watershed. April, May, and June are typically high flow months associated with spring rains. July and August are typically low-flow months associated with high summer temperatures and lower rainfall, and these low flows tend to persist through September and October, which also tend to be relatively dry. November through March have variable flows, but are typically higher than the summer season. Note that in Table 4.3 the three years of historical data tend to be higher than the modeled flows for flows above the median, and tend to be lower than the modeled flows below the median. Conditions were relatively dry in the summer of 2006 and from the summer of 2008 through the winter months of 2009, and relatively wet in the other parts of the historical period. Although caution should be used when making conclusions based on such a short period of record, the results seem reasonable.

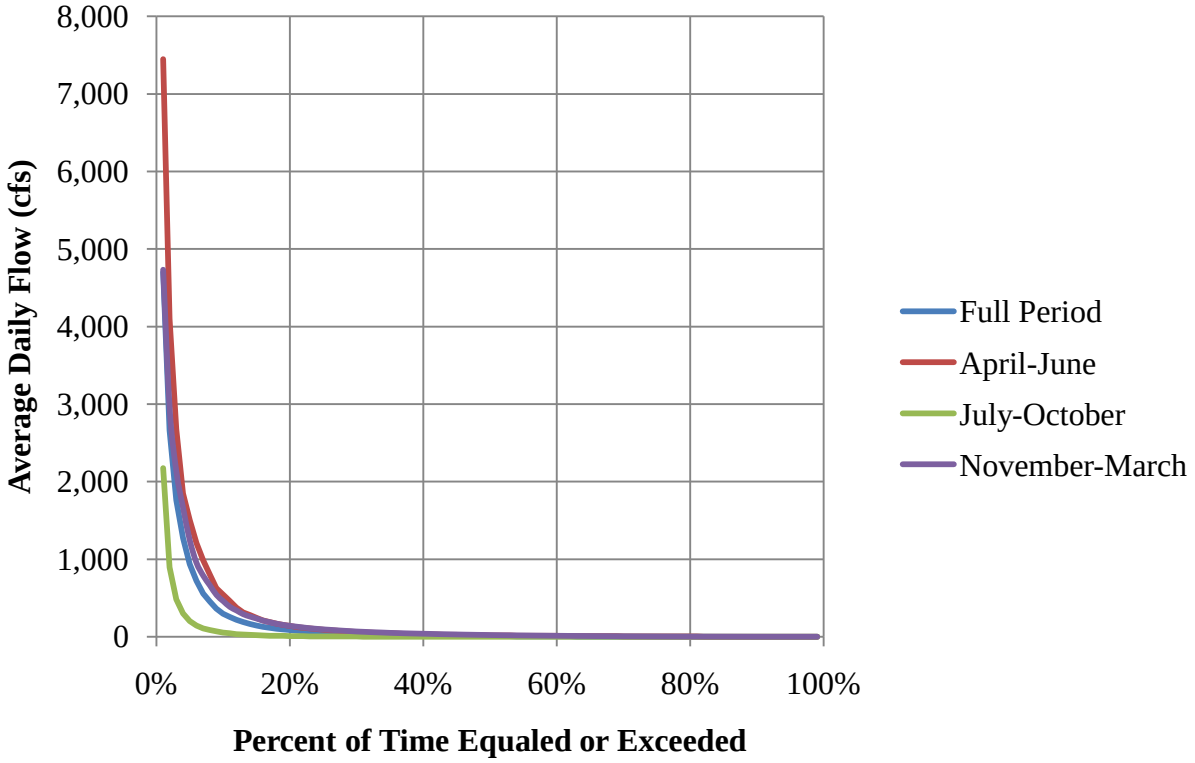
Figure 4.7 shows the exceedence frequencies for the modeled data, displayed using both linear and logarithmic scales. The median flow for an entire year is about 10 cfs. Note that the July-October flows are significantly less than the other two seasons, with flows less than 1 cfs about 60 percent of the time and less than 10 cfs about 80 percent of the time. Outside of the July-October season, flows are less than 1 cfs from 12 to 15 percent of the time and less than 10 cfs about 36 percent of the time.

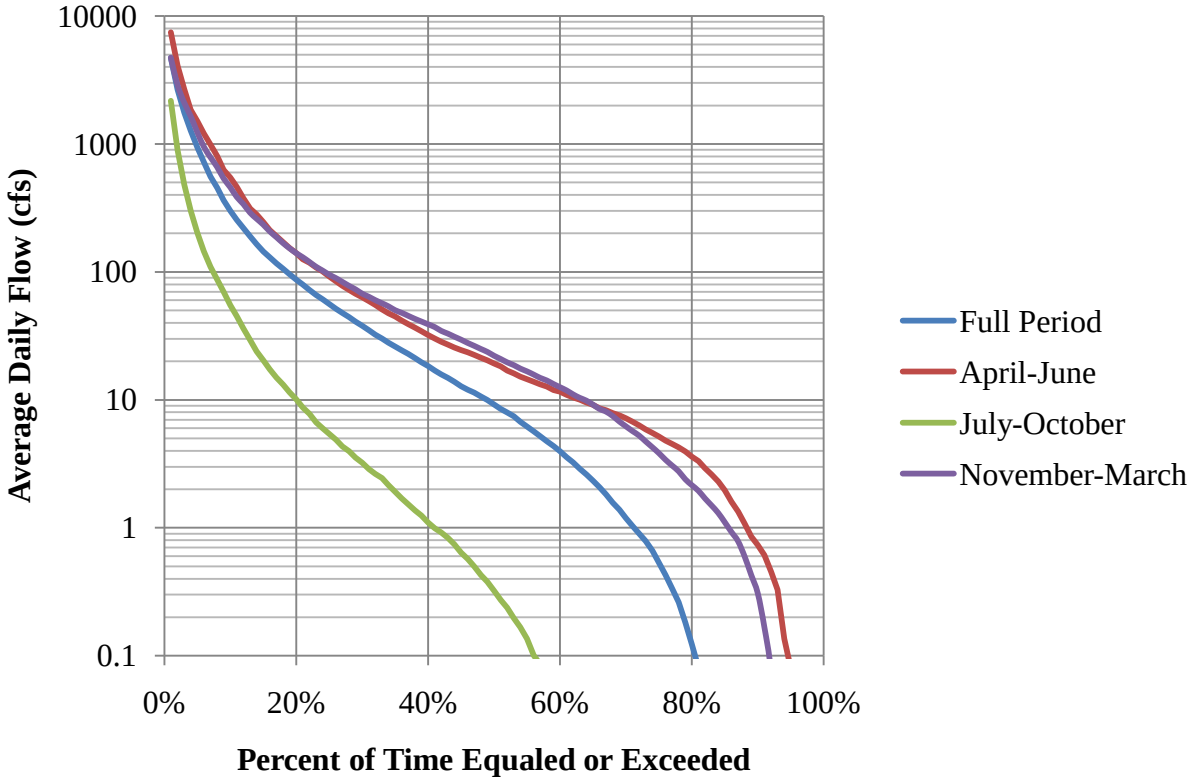
Table 4.3 Bois d'Arc Creek Flow Statistics at FM 1396

(Values in cfs)

Statistic	Modeled Flows (1948 – 1998)				Recorded Flows (July 2006 – Sept 2009)			
	Full Period	April-June	July-October	November-March	Full Period	April-June	July-October	November-March
Average	231	341	104	268	310	569	262	218
Minimum	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
15%	0.0	2.0	0.0	1.1	0.0	5.7	0.0	0.0
30%	1.2	7.2	0.0	6.2	0.2	26.0	0.0	0.5
Median	9.2	19.3	0.3	22.1	13.9	58.8	0.1	20.9
70%	38.1	63.5	3.2	67.7	57.2	128	6.4	65.5
85%	145	246	20	234	165	755	60.1	141
Maximum	34,914	34,914	30,163	28,091	11,627	8,420	11,627	9,641

Figure 4.7 Flow-Duration Curve of Modeled FM 1396 Flows





4.2 Fluvial Geomorphology

The fluvial geomorphology component of this study includes the classification and characterization of the Bois d'Arc Creek study reaches, identification and mapping of geomorphic units within study reaches, evaluation of lateral movement and erosive characteristics of the stream, and modeling of sediment transport. The results of these studies are summarized in the following section. Appendix C describes these studies in detail.

GEOMORPHOLOGY

Channelization has caused downcutting and degradation to the stream system including unchannelized reaches.

Incised channel restricts normal channel processes including floodplain migration and meandering.

Flows of less than 1 cfs can transport sediment load.

Gravel transport occurs at 25 cfs.

4.2.1 Stream Classification at the Reservoir Site

In a previous study, FNI conducted a Rapid Geomorphic Assessment on Bois d'Arc Creek and four major tributaries (Honey Grove Creek, Sandy Creek, Ward Creek, and Bullard Creek) within the inundation pool of the proposed reservoir (FNI, 2008). The study found that all of the reaches have been impacted by human activities and none of the reaches has reached a new state of dynamic equilibrium. The study classified the stream segments as "good", "fair" or "poor" pending the segment's state of equilibrium and stream stability. A "good" rating indicates a relatively stable channel with sediment transport capacity in balance with sediment supply, a "poor" rating indicates disequilibrium with unstable, eroding channel sections and degraded instream habitats, and a "fair" rating indicates moderately stable channel sections and the sediment transport and sediment transport capacity is not in balance with the sediment supply.

The 2008 geomorphic assessment classified 54 percent of Bois d'Arc Creek within the inundation pool of the proposed reservoir as "poor" with the remainder 46 percent being classified as "fair." Eighty-six percent of Honey Grove Creek was classified as "fair" with the remainder being classified as "good" (8%) or "poor" (6%). Ward Creek was classified as "fair" (84%) with the remainder of sixteen percent being classified as "poor." The majority of Bullard Creek (82%) and Sandy Creek (83%) were classified as "poor" with the remainder of 18 and 17 percent being classified as "fair," respectively.

4.2.2 Basin-Wide Stream Characterization

The River Styles™ methodology (Brierly and Fryirs, 2005) was used to characterize Bois d'Arc Creek throughout the watershed. River Styles is a geomorphic approach for characterizing stream forms and processes. In the first step of the process, the Bois d'Arc Creek watershed was divided into five landscape units based on geology, climate, soil, local relief, valley slope, and morphology. The landscape units were separated into 12 river styles defined by channel dimensions, channel planform (the layout of the stream channel on the landscape viewed from above), tributary confluences, transitions from a natural channel to channelized segments, changes in slope, changes in the underlying geology, or other features. Figure 4.9 is a map showing the landscape units and the reaches of each river style. (Although there are 13

segments, the Bois d'Arc Creek watershed has only 12 river styles. Segments 7 and 9 are classified as the same river style.)

Within each river style, geomorphic features were identified using aerial photographs and review of aerial video of Bois d'Arc Creek. This information was used when selecting the five study reaches. Table 4.4 describes the river styles for the five study reaches. A complete list of the Bois d'Arc Creek river styles may be found in Appendix C.

The geomorphic units were field mapped at four of the five instream flow study reaches (Figure 4.10 through Figure 4.13). Each of these reaches represents a different river style. Although the four study reaches do not cover every river style in the watershed, they are representative of the instream micro-habitat available for the aquatic life of Bois d'Arc Creek. These geomorphic base maps were used in habitat modeling to evaluate the amount of habitat available at different flows.

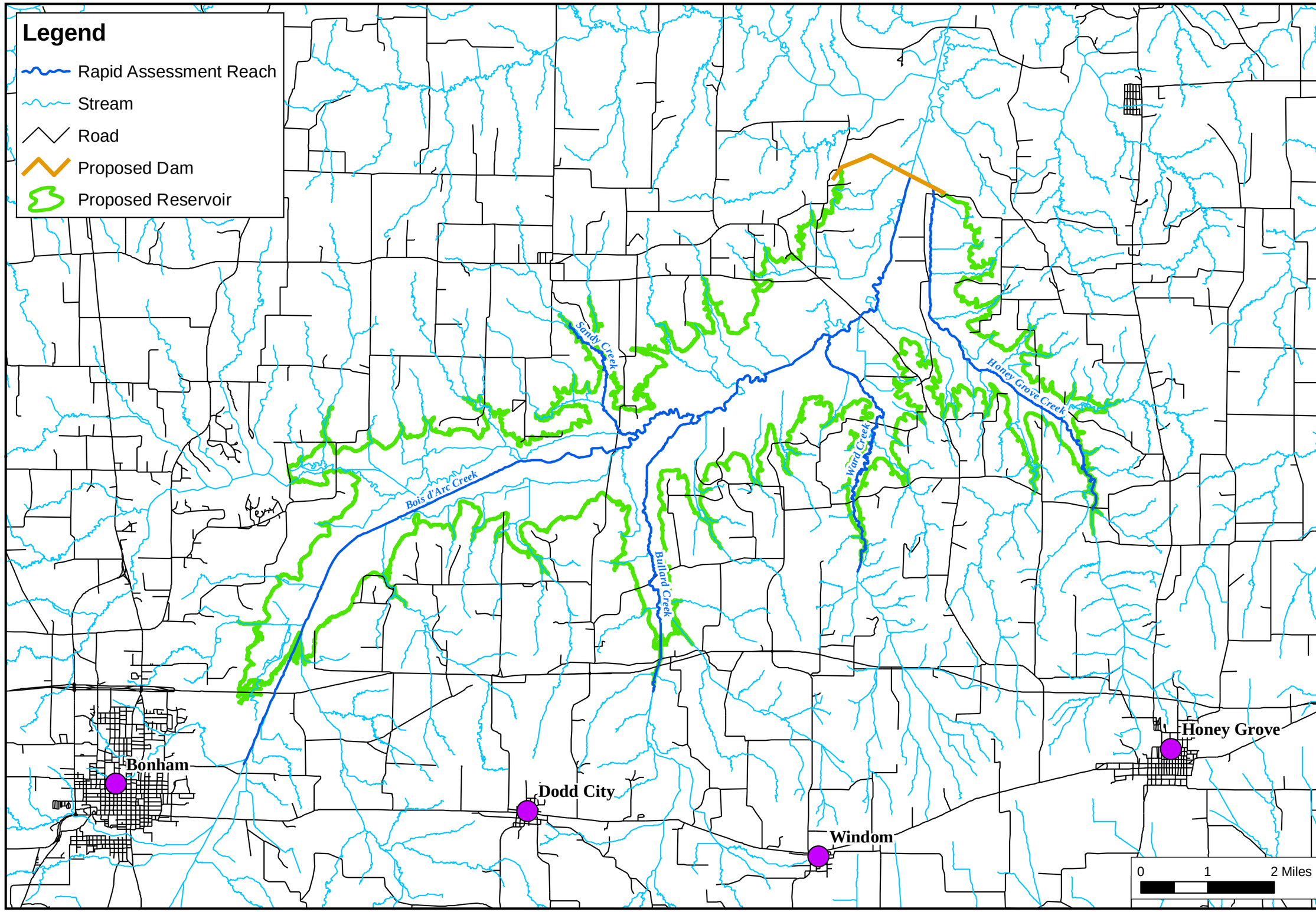


Figure 4.8

FN JOB NO	NTD06128
FILE	Figure4.8.mxd
DATE	May 2010
SCALE	1:85,000
DESIGNED	SVC
DRAFTED	BME

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Rapid Geomorphic Assessment

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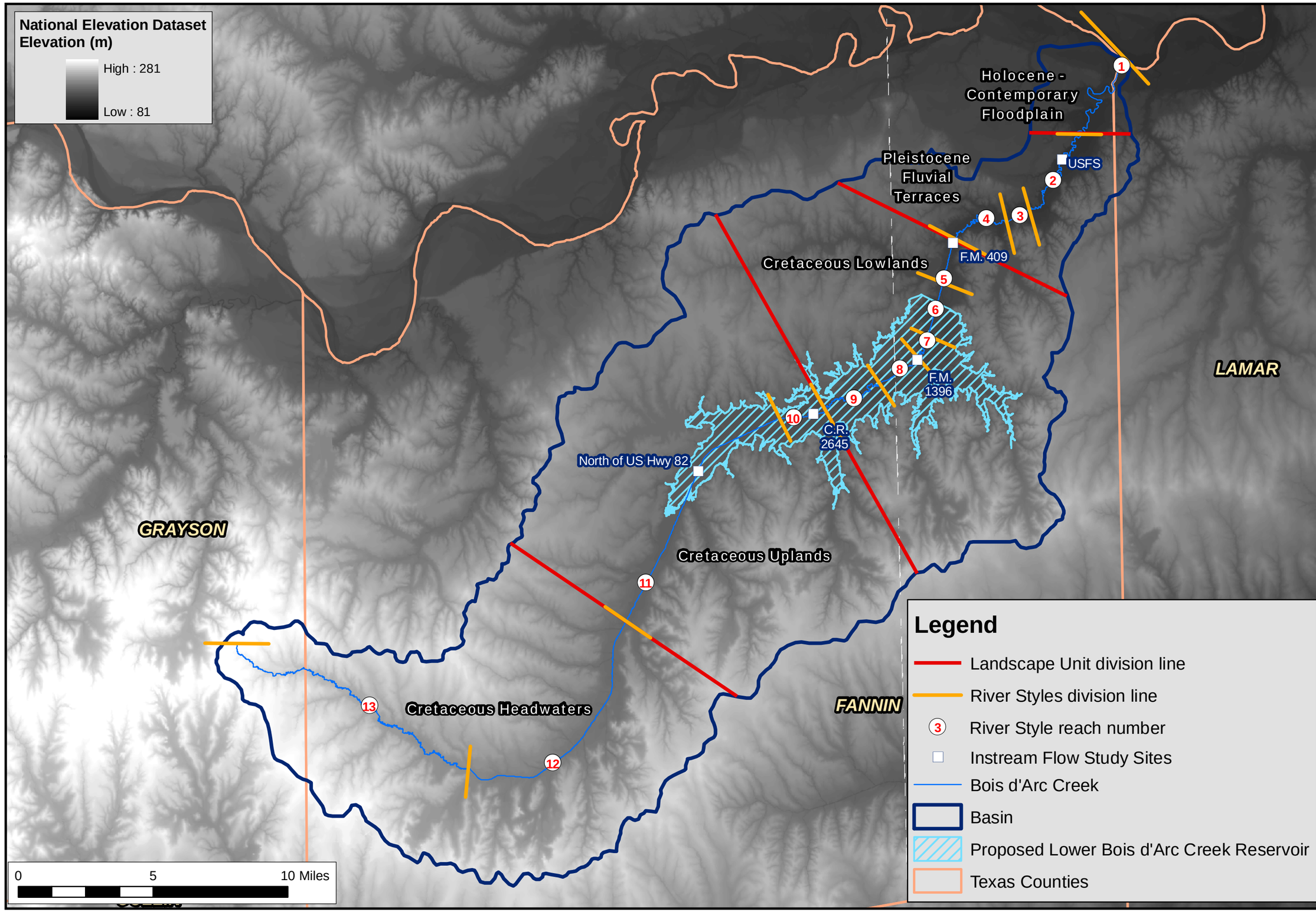

Figure 4.9

FN JOB NO	NTD06128
FILE	DEM.mxd
DATE	January 20, 2010
SCALE	1:210,000
DESIGNED	SVC
DRAFTED	SVC

North Texas Municipal Water District
Proposed Lower Bois d'Arc Creek Reservoir

Landscape Units and River Styles
for Bois d'Arc Creek

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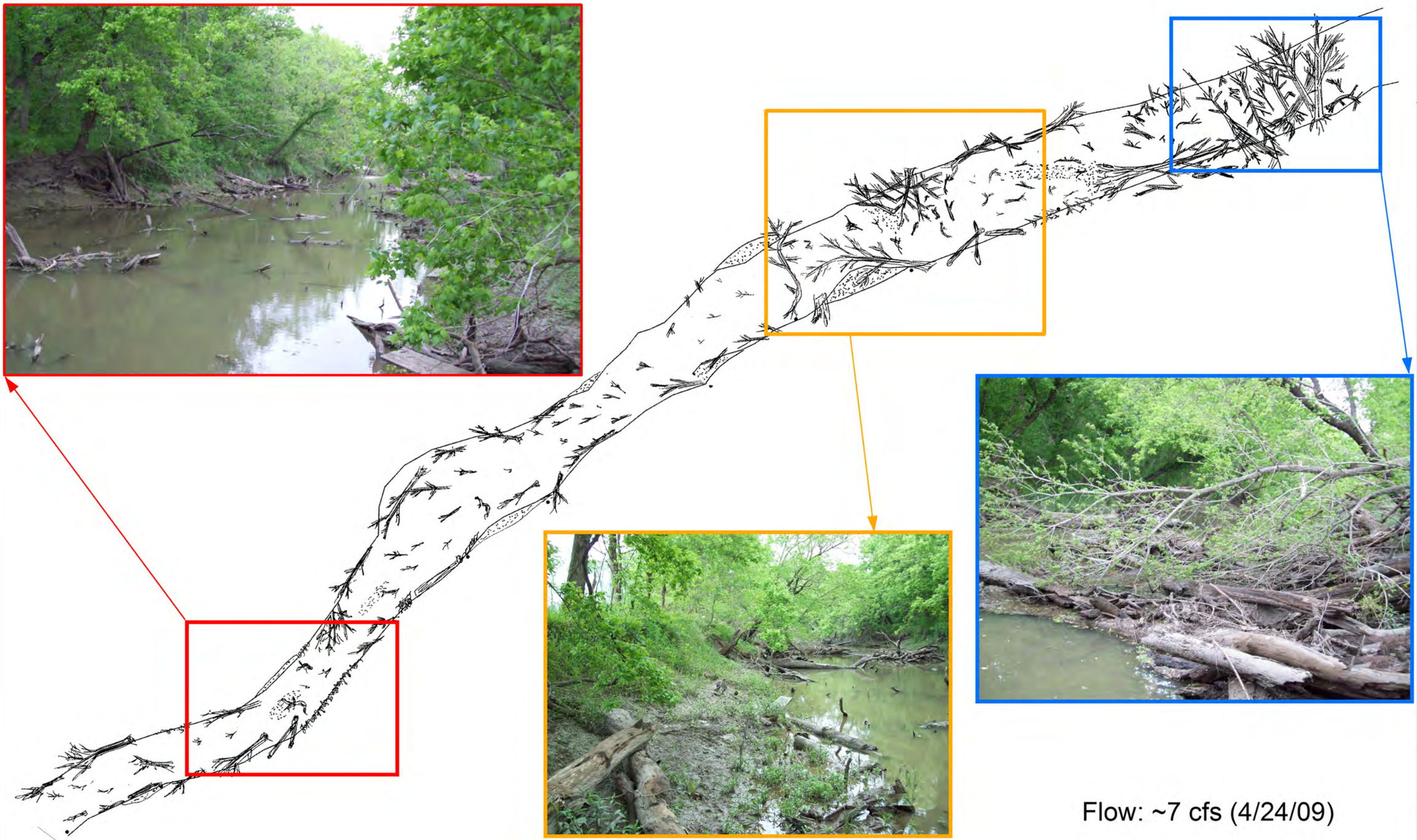
Table 4.4 River Styles at Study Reaches

Landscape Unit	River Style Reach Number	Study Reach and Location*	Valley Setting	River Style	Channel Planform	Bed Material	Geomorphic Units
Cretaceous Uplands - Rolling to nearly level plains, underlain by interbedded chalks, marls, limestones, and shales of Cretaceous age. Strongly dissected primarily on the Bonham Marl and Blossom Sand formations and intermittent streams.	11	US 82 site (Stream mile 40.4 to 30.5)	Laterally Unconfined	Unconfined Valley Moderately Entrenched Confined Channel - The channel morphology and alignment are controlled by channel incision into clay and marl. Continuous floodplain where not constricted by levee control. Channel geometry is a uniform incised channel that is laterally stable.	Straightened single thread	Bed material is weathered clay and marl with minor outcrops of limestone which are lined with silt and clay.	• Log/debris jams resulting in sediment deposition and mid-channel bars. • Elongated deep pools • Undercut banks • Tree topples/falls
	10	CR 2645 site (Stream mile 30.5 to 28.4)	Laterally Unconfined	Unconfined Valley Confined Channel and Flood Channels – The channel is controlled by incision into clay and marl. Floodplain pockets along both valley margins and flood events connect the main channel to flood channels.	Modified single-thread with low sinuosity (1.09)	Bed material is weathered clay and marl with a minor number of coarse sand and fine gravel midchannel and bank-attached lateral bars.	• Runs and shallow pools • Midchannel sand bars • Coarse gravel lateral bars • Undercut banks • Large woody debris/log jams • Floodchannels
Cretaceous Lowlands - Generally level and gently rolling, moderately dissected surface composed of Eocene and Paleocene age formations underlain by Cretaceous age formations.	8	FM 1396 (Stream mile 24.4 to 22.5)	Laterally Unconfined	Unconfined Valley Entrenched Channel - Channel morphology and alignment are controlled by incision and widening into the weathered shale. Continuous floodplain along both valley margins. Channel geometry is a trapezoidal channel with near vertical banks.	Modified single-thread with low sinuosity (1.10)	Bed material is weathered shale and marl. Slaked material from the lower bank and streambed is mixed within the coarse sand/gravel point and midchannel bars. Fine silts overlay the majority of the streambed	• Runs with long, thin scour features carved in the in the weathered bedrock. • Deep pools located in midchannel and along concave banks. • Bank-attached lateral bars and point bars • Vegetated island sand bars • Mass wasting – bank failures on curved reaches and rotational slumps on straight reaches.
	5	FM 409 site (Stream mile 19.0 to 17.2)	Partially Confined	Partially Confined Valley Straightened Channel with Abandoned Flood Flow Channel - The channel morphology and alignment are controlled by the incising and slumping processes. Continuous floodplain along both valley margins. The abandoned channel is utilized at overbanking flows. Streambank alternate concave and s-shape	Straightened single-thread	Bed material is weathered marl. Eroded bank material from the lower bank is mixed within the bedload. Midchannel bars are composed of coarse sand and fine gravels. Lateral bank-attached bars are composed of fine gravels to coarse gravels.	• Elongated runs and pools • Midchannel bars • Bank-attached lateral bars • Large woody debris with downstream sand deposition • Undercut banks • Scour pools • Vegetated rotational slumps • Chute cutoff
Pleistocene Fluvial Terraces - Located within the Pleistocene fluvial terrace deposits and Pleistocene age to Holocene age alluvial deposits. Gently rolling with low relief. Erosion has dissected the Pleistocene fluvial deposits, exposing underlying Cretaceous age formations.	2	USFS site (Stream mile 12.1 to 6.3)	Left laterally Confined	Left Laterally Confined Valley High Sinuosity Channel - The channel morphology and alignment are controlled to a significant degree by the sinuosity and the bed and bank material. The banks are concave on the outside of meanders and s-shaped on the inside on meanders. The left side on the channel is confined to the valley wall. The right side is continuous floodplain, engraved with rills and gullies.	Tortuous meandering single-thread with high sinuosity natural channel (1.70)	Bed material is sand and gravel from the fluvatile terrace deposits.	• Runs and pools • Sand sheets • Point bars • Bank-attached lateral bars • Midchannel bars • Chute cutoff • Large woody debris • Floodchannels • Floodplain pockets • Gullies

* The study reaches are only a portion of the river style reach.



Flow: ~7 cfs (4/24/09)

F&N JOB NO: NTD06128
DATE: April 2010
SCALE: 1:580
DESIGNED: SVC
DRAFTED: MJA
FILE: Figure3_12.mxd

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U.S. 82 Geomorphic Unit Base Map

N

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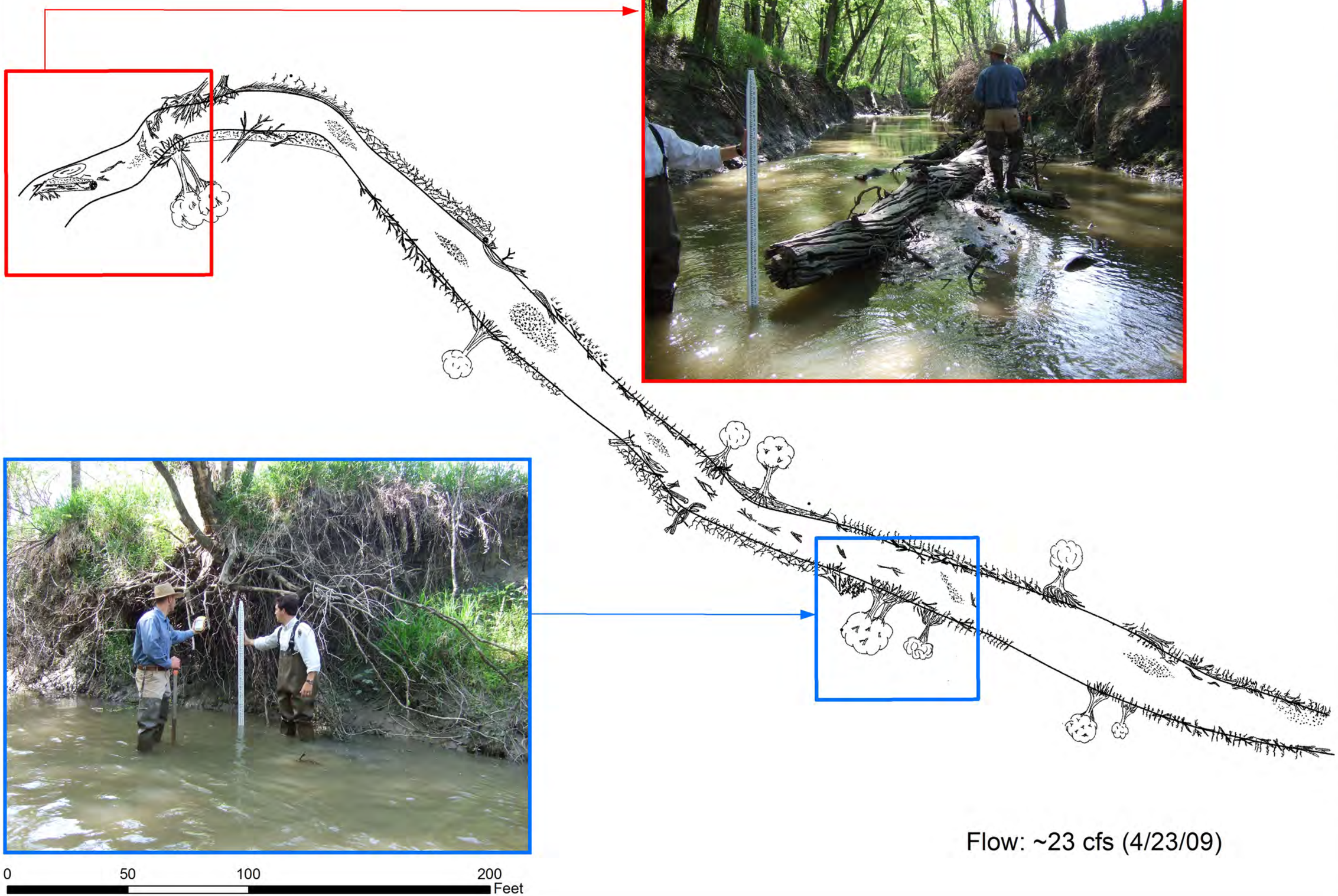
4.10

FIGURE



F&N JOB NO: NTD06128
DATE: April 2010
SCALE: 1:445
DESIGNED: SVC
DRAFTED: MJA
FILE: Figure3_13.mxd

North Texas Municipal Water District
Proposed Lower Bois d'Arc Creek Reservoir

C.R. 2645 Geomorphic Unit Base Map

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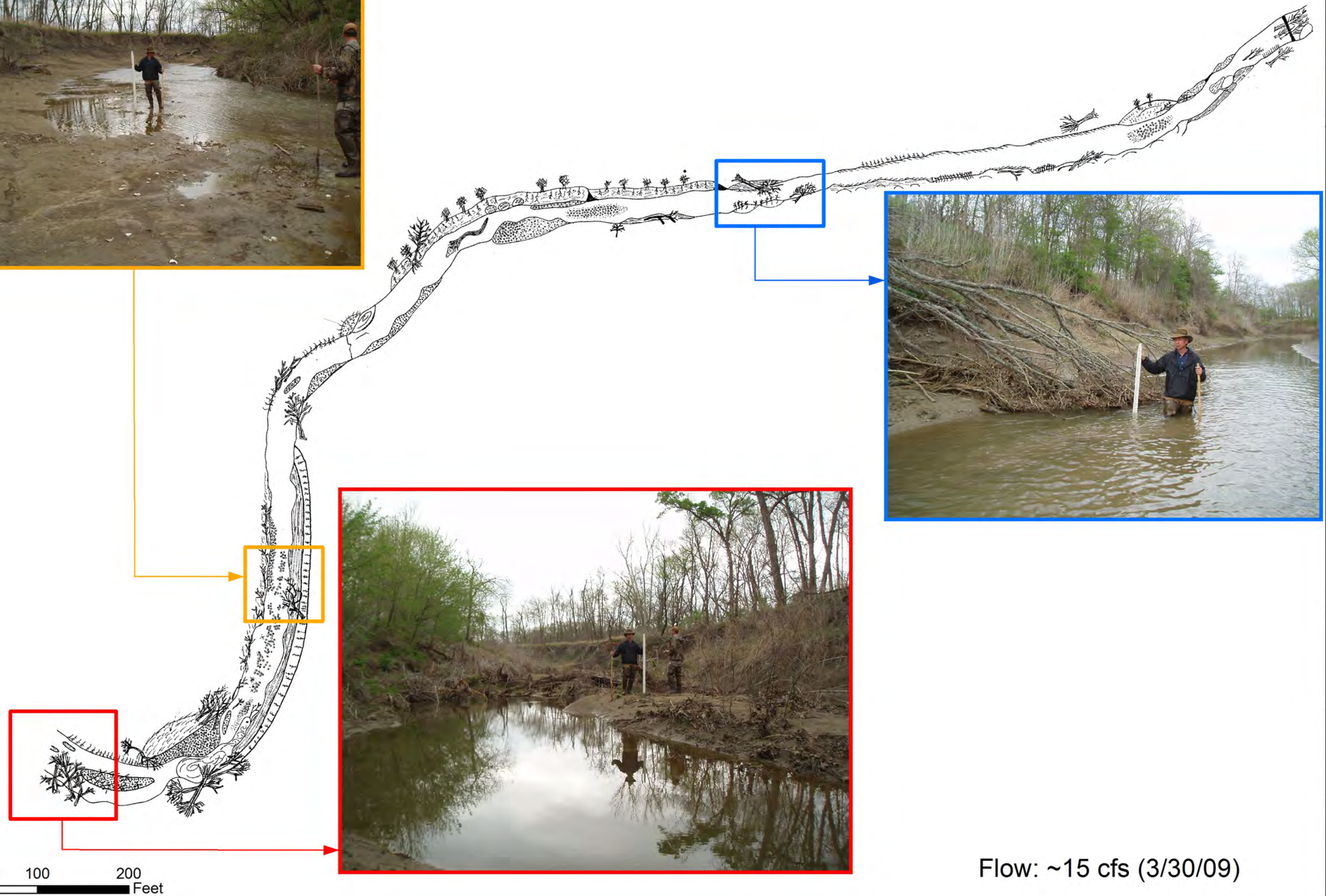
4.11

FIGURE



Flow: ~15 cfs (3/30/09)

F&N JOB NO: NTD06128
DATE: April 2010
SCALE: 1:1,200
DESIGNED: SVC
DRAFTED: MJA
FILE: Figure3_14.mxd

North Texas Municipal Water District
Proposed Lower Bois d'Arc Creek Reservoir

F.M. 1396 Geomorphic Unit Base Map

N

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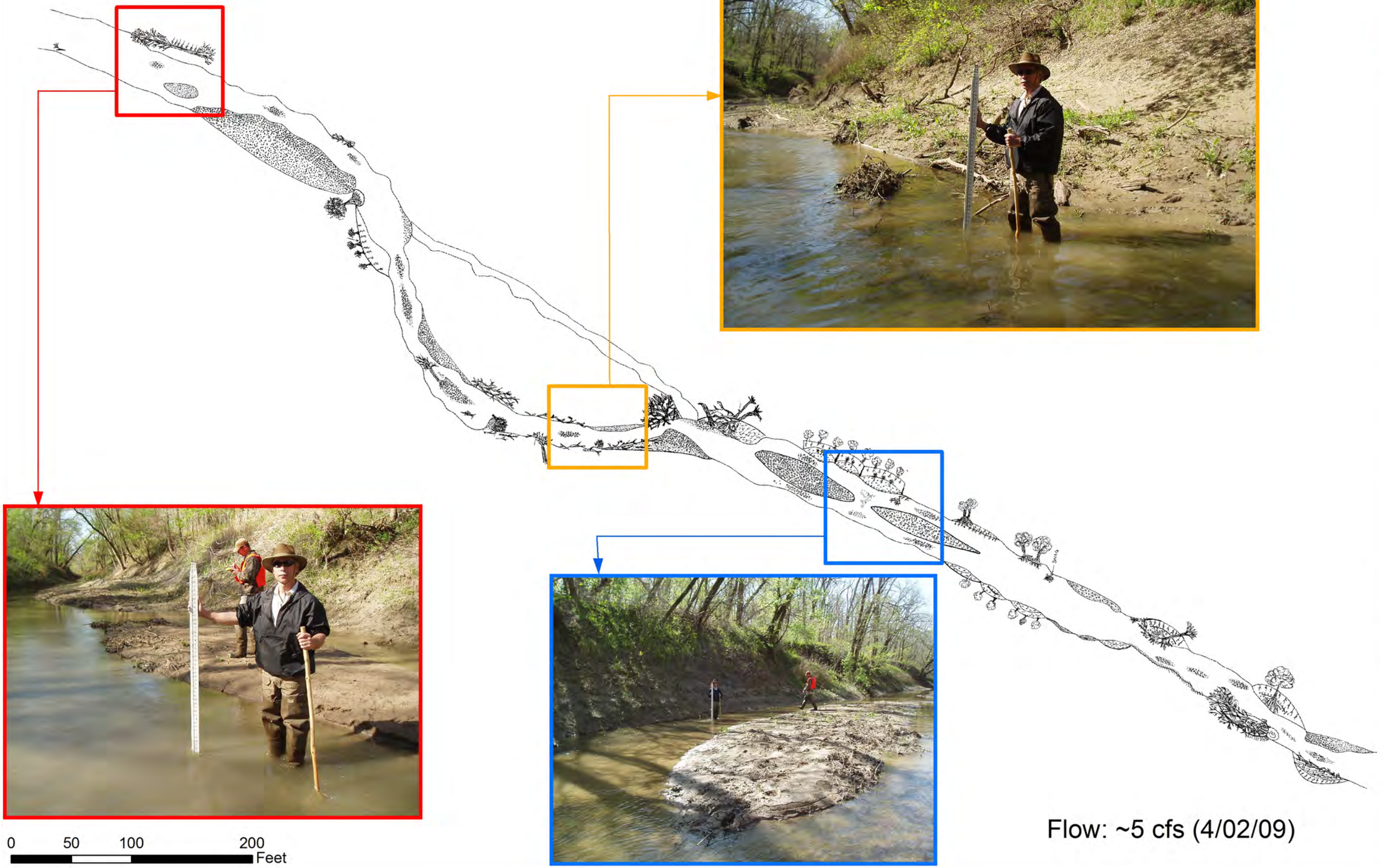
4.12

FIGURE



F&N JOB NO: NTD06128
DATE: April 2010
SCALE: 1:915
DESIGNED: SVC
DRAFTED: MJA
FILE: Figure3_15.mxd

North Texas Municipal Water District
Proposed Lower Bois d'Arc Creek Reservoir

FM 409 Geomorphic Unit Base Map

N

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4.13

FIGURE

4.2.3 Planform Stability and Erosion

Planform stability refers to the lateral movement of a stream across a floodplain, or the tendency of a stream to meander. Stream bank erosion refers to the rate at which material on the stream bank is detached and displaced or transported by water. In general, the banks of Bois d'Arc Creek are actively eroding, resulting in channel widening and limited meander migration.

Figure 4.14 to Figure 4.18 compare the historical planform view of the areas surrounding the five study reaches. The earliest information is from a series of maps made in 1915, while the later data are from aerial photographs of the watershed. Four of the study reaches (US 82, CR 2645, FM 1396, and FM 409) are located within channelized sections of Bois d'Arc Creek. The USFS study reach (Figure 4.18) is located in a relatively natural, meandering section of stream.

It can be assumed that Bois d'Arc Creek was a natural, meandering stream prior to the channelization efforts. There is evidence of meander scars that indicate that Bois d'Arc Creek historically migrated across the floodplain over time. The straightening and resectioning of the stream resulted in abandoned channels or artificial oxbows that can be seen in the figures. The four study reaches located within channelized sections no longer migrate across the floodplain. Instead they are widening from fluvial erosion, subaerial erosion, and mass wasting. Based on the historical map and aerial photograph comparison, it can be estimated that bank loss in the straightened reaches of Bois d'Arc Creek is approximately 0.5 feet per year. All stream migration in the channelized reaches is confined within the incised straightened channel. In the sinuous segments of Bois d'Arc Creek, the historical map and aerial photographs indicate approximately between 0.9 to 2.1 feet per year of meander migration over the past 95 years (Figure 4.18). The migration is a result of the same erosional processes occurring in the straight reaches. The erosion and deposition processes of a meandering stream are present, but not at a large enough scale to cause the channel to migrate across the floodplain. It is likely that the entire stream modified its structure and function to adjust to the impacts of channelization.

STREAM BANK EROSION

Erosion on Bois d'Arc Creek is causing:

- **Channel widening**
- **Limited meander migration**
- **Reduced connectivity with riparian corridor**
- **Bank failure and habitat destruction**

Although Bois d'Arc Creek does not exhibit much tendency toward lateral migration, field measurements and observations indicate that stream bank erosion and downcutting are actively occurring at a relatively high rate in the watershed. Erosion rates are higher at the FM 1396 study reach than in the FM 409 study reach. Upstream of FM 1396 the stream banks and riparian corridor of Bois d' Arc Creek are less densely vegetated and have a narrower forested riparian buffer than other reaches. As a result, the banks are subject to increased rates of drying by direct sunlight and lack the stability provided by roots. During this study numerous mass failures were observed in this study reach. Downstream of FM 1396, the channel of Bois d' Arc Creek enters USFS property where the riparian corridor has been protected from vegetation

removal. In these reaches, including the FM 409 study reach, the forested riparian corridor shades the stream banks, effectively decreasing the rate of weathering by dessication. Plant roots reinforce bank material and slow flowing water at the bank margin, reducing shear stress during high flow events. It was observed in the field that the FM 409 study reach contains active slump failures occurring on both channel banks. These slumps are slow-moving creep failures, instead of the catastrophic streambank retreat observed at the FM 1396 site.

4.2.4 Sediment Transport Analysis

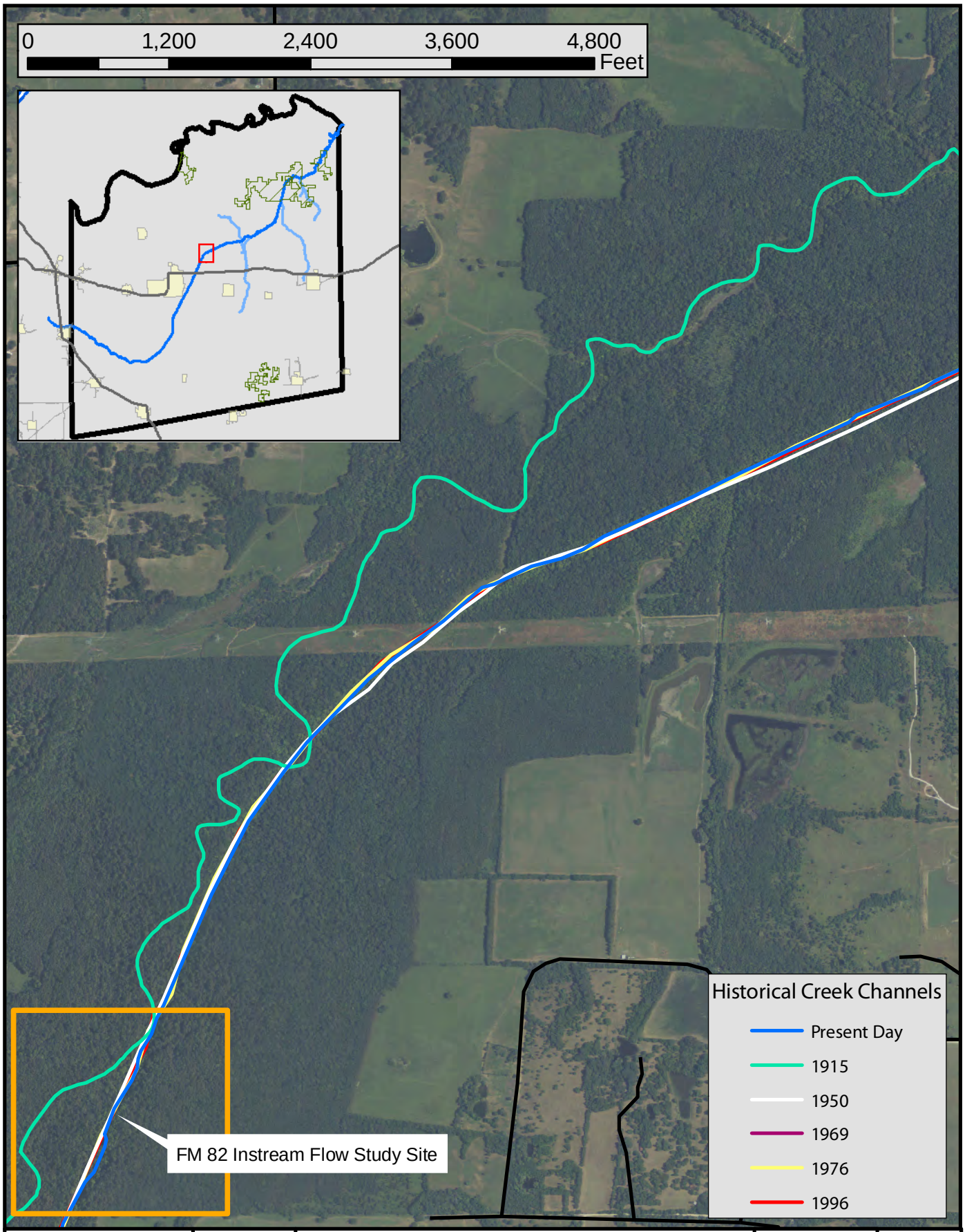
Bois d'Arc Creek is a threshold bedrock channel. The channel has incised into weathered clays, marls and shales. The Bois d'Arc Creek system has limited sources of coarse sediment. The gravel and sand material is irregularly dispersed along the creek in the form of bar deposits.

A particle size analysis quantified the bar deposit material particle size by evaluating the frequency distribution of particles sizes contained within the bar material sample. Surface and subsurface bar material was collected at representative geomorphic depositional features in the FM 1396 and FM 409 study reaches. The surface and subsurface data provide information on erosional processes and sediment transport. The surface and subsurface bar material samples at FM 1396 had a median grain size (D_{50}) on the order of 4.5 mm and 0.8 mm, respectively. Similarly, the surface and subsurface bar material samples at FM 409 had a D_{50} on the order of 4.75 mm and 0.6 mm, respectively. The surface sediment is coarser than the sediment below the surface. The difference in particle size is tied to the flow regime and the upstream sediment supply.

The particle size distribution data from the bar material samples were used in the SAMWin (Stable channel Analytical Model, Windows version) to estimate sediment entrainment and transportation potential within each reach. Interactions between flow and the channel boundary lead to adjustments in channel dimension, which result from processes of erosion, transport, and deposition.

Stream power determines the capacity of a given flow to transport sediment. The available stream power is related to the water surface slope and discharge of the channel. Identifying the flows capable of carrying sediment particles is an important part to the proper assessment of channel equilibrium slope as well as planform and vertical channel stability. A channel is in balance if the stream power is exactly sufficient to transport the sediment load, and therefore there is no net erosion or deposition along the reach.

This analysis demonstrates that even flows below 1 cfs have the potential to transport sediment. Flows between 1cfs to 10 cfs have the potential to transport approximately 0.26 ton per day to 5.3 tons per day, respectively of the fine grained particles (sand, silt and clay).



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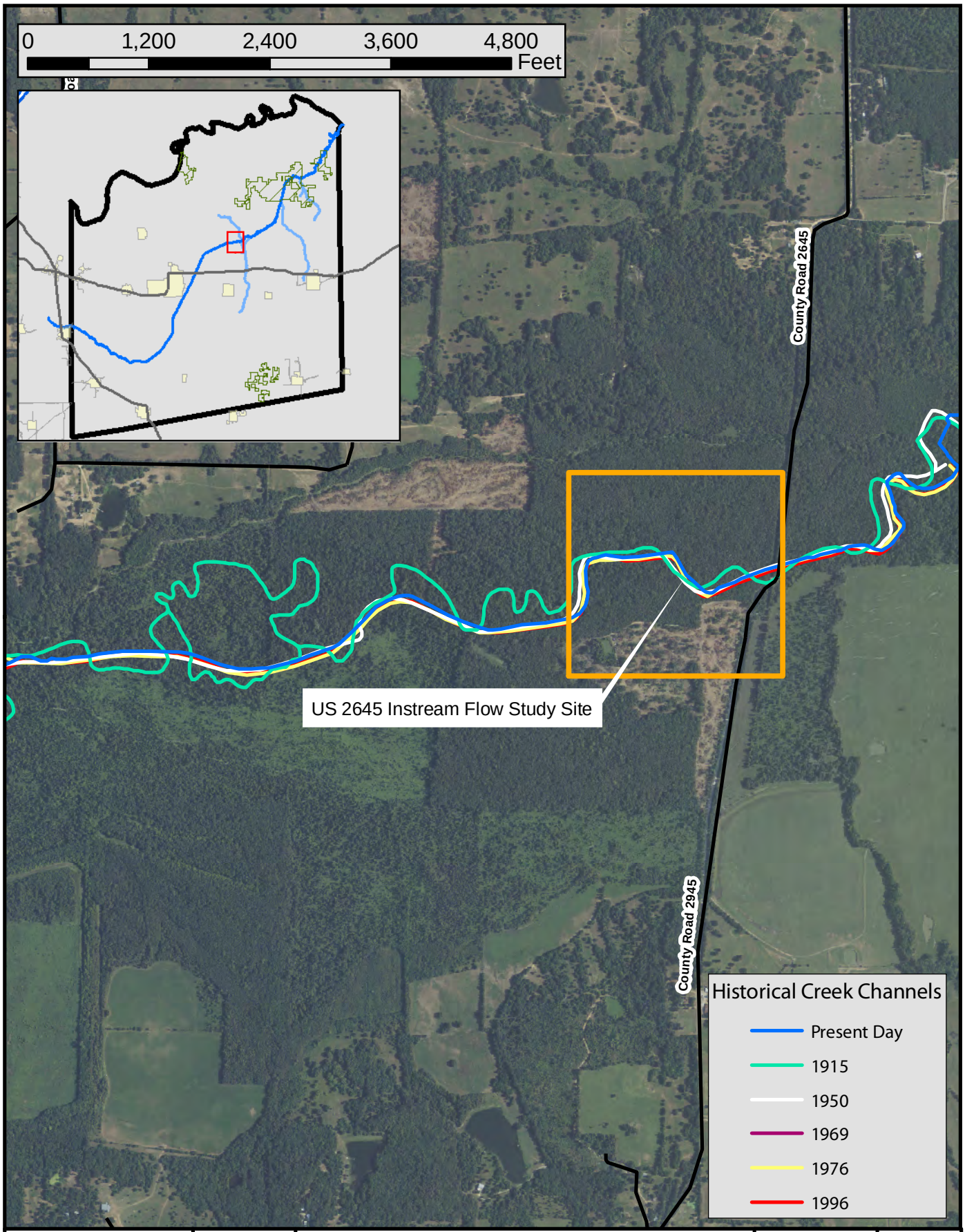
Planform View of Lower Bois d'Arc Creek near FM 82

FN JOB NO	NTD06128
FILE	Mapbook.mxd
DATE	January 22, 2010
SCALE	1:13,500
DESIGNED	SVC
DRAFTED	BME

4.14
FIGURE



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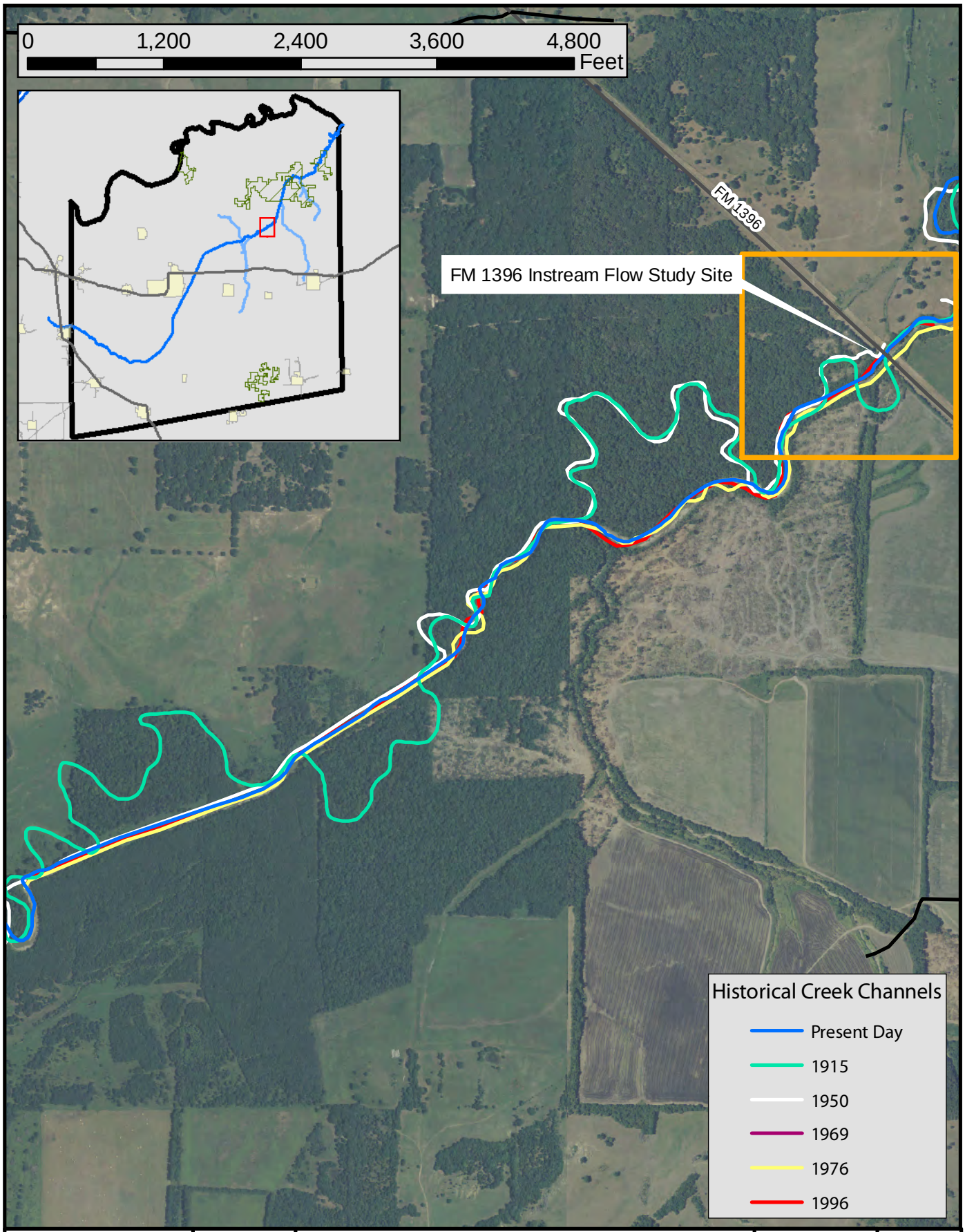
Planform View of Lower Bois d'Arc Creek near CR 2645

FN JOB NO	NTD06128
FILE	Mapbook.mxd
DATE	January 22, 2010
SCALE	1:15,800
DESIGNED	SVC
DRAFTED	BME

4.15
FIGURE



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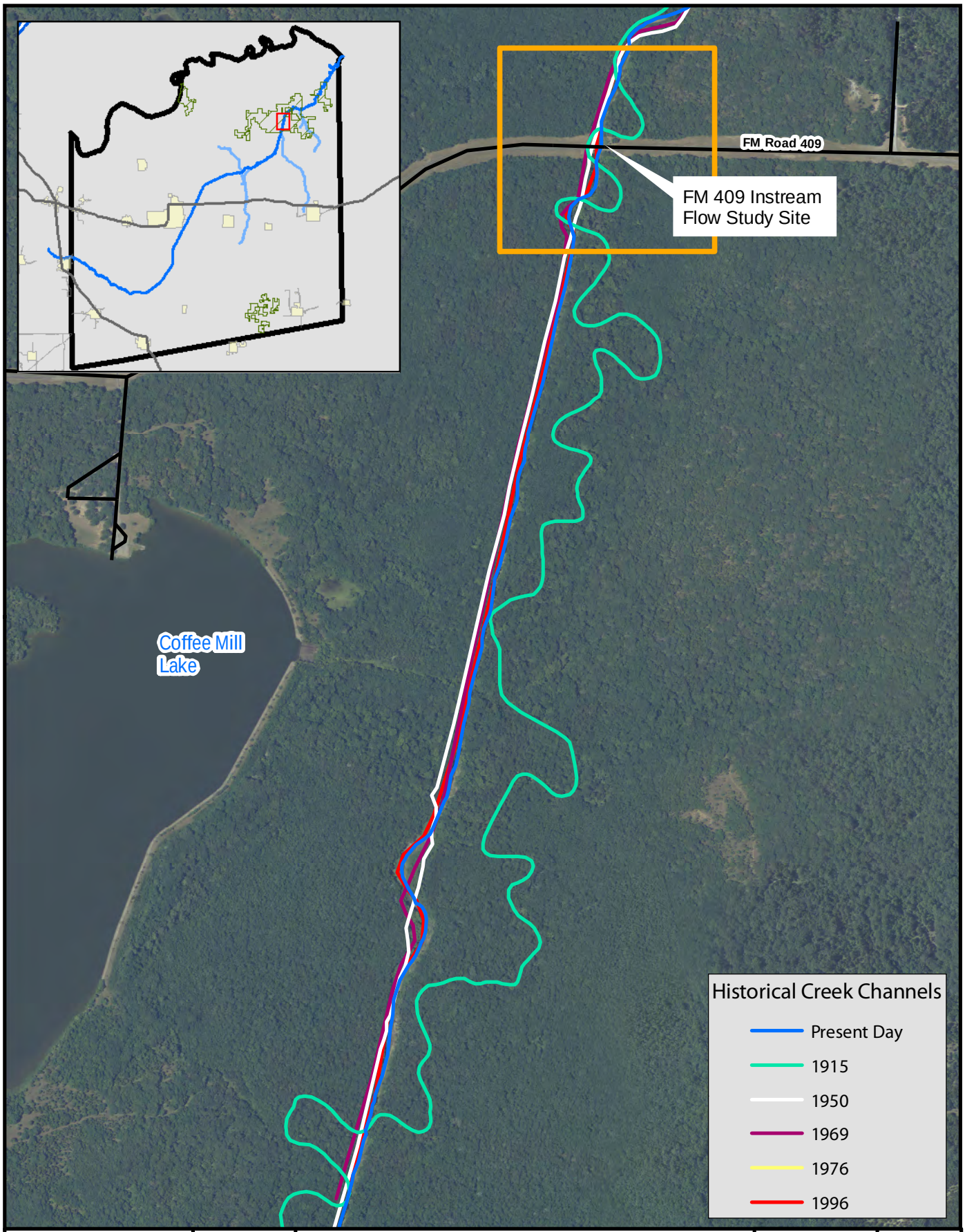
Planform View of Lower Bois d'Arc Creek near FM 1396

FN JOB NO	NTD06128
FILE	Mapbook.mxd
DATE	January 22, 2010
SCALE	1:14,000
DESIGNED	SVC
DRAFTED	BME

4.16
FIGURE



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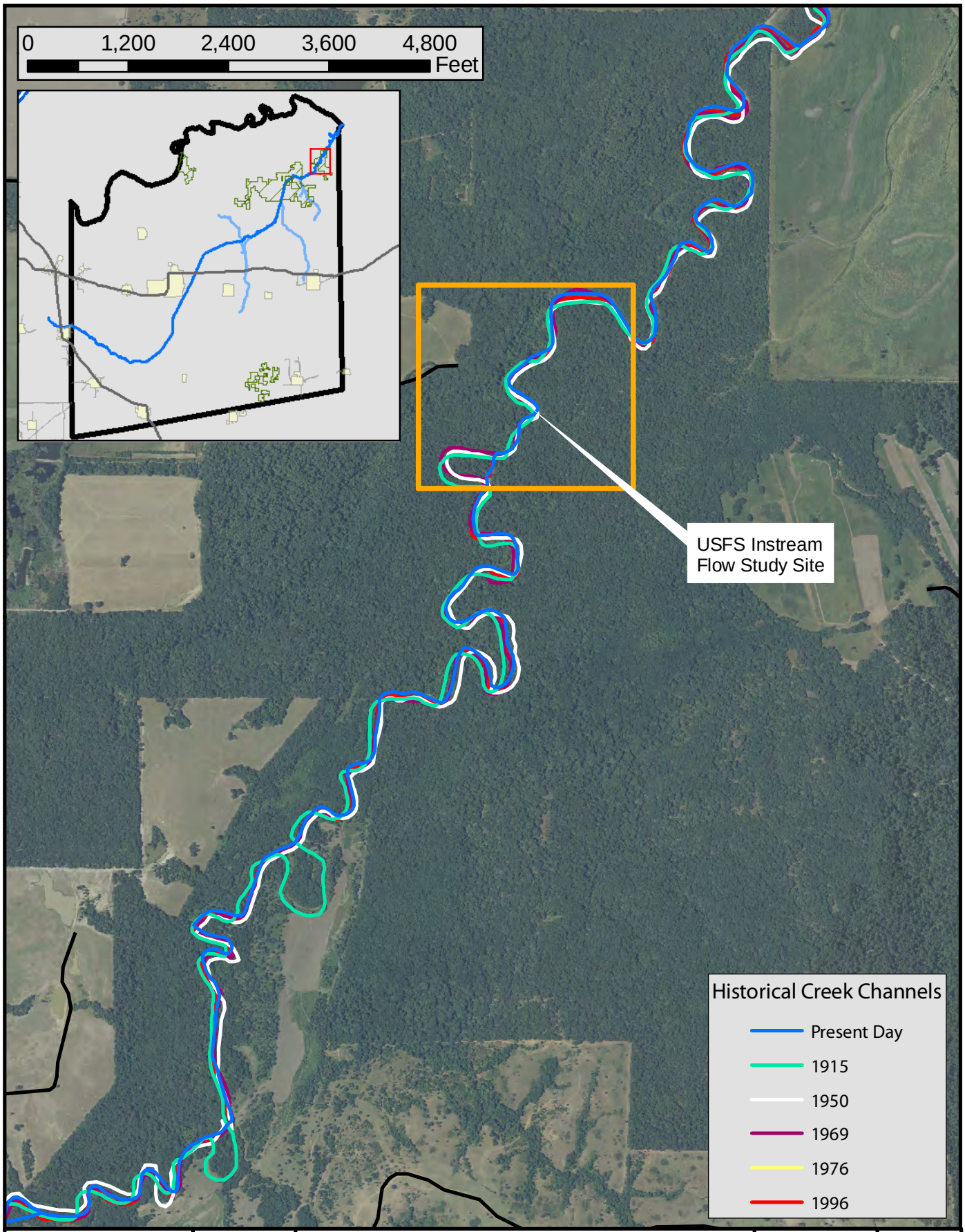
Planform View of Lower Bois d'Arc Creek near FM 409

FN JOB NO	NTD06128
FILE	Mapbook.mxd
DATE	January 22, 2010
SCALE	1:12,000
DESIGNED	SVC
DRAFTED	BME

4.17
FIGURE



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Planform View of Lower Bois d'Arc Creek on USFS Property

FN JOB NO	NTD06128
FILE	Mapbook.mxd
DATE	January 22, 2010
SCALE	1:19,000
DESIGNED	SVC
DRAFTED	BME

4.18
FIGURE

Figure 4.19 to Figure 4.22 show the results of this analysis. Four sediment transport equations appropriate for use in these study reaches were used to produce a range of values. Although the curves slightly vary depending on the transport equation used, transport regimes are similar for the two study reaches when the results from a single equation are compared.

A separate SAMWin analysis was performed on the gravel-sized portion (larger than 2 mm) of the bar material to determine flows that initiate movement of the larger sized particles. Significant gravel transport for surface and subsurface sediment (more than 1 ton/day) occurs between 20 cfs and 38 cfs, at FM 1396, and between 25 cfs and 40 cfs at FM 409, respectively.

Currently, the stream power exceeds what is needed to transport the sediment load through the reach. The excess energy has to be expended somehow, so it is used to entrain sediment from the bed and erode the banks. In this case erosion and channel degradation predominates. Detailed sediment transport modeling results are presented in Appendix C.

Figure 4.19 Sediment Rating Curve of the Surface Sediment at FM 1396

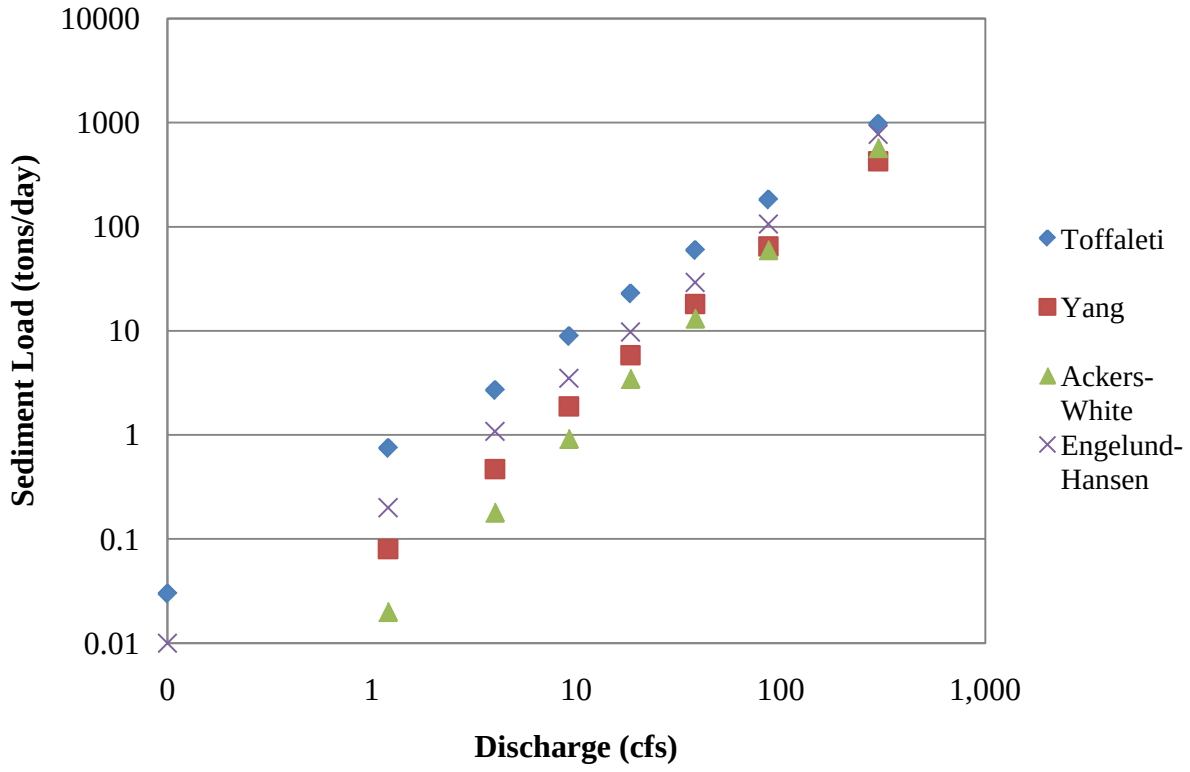


Figure 4.20 Sediment Rating Curve of the Subsurface Sediment at FM 1396

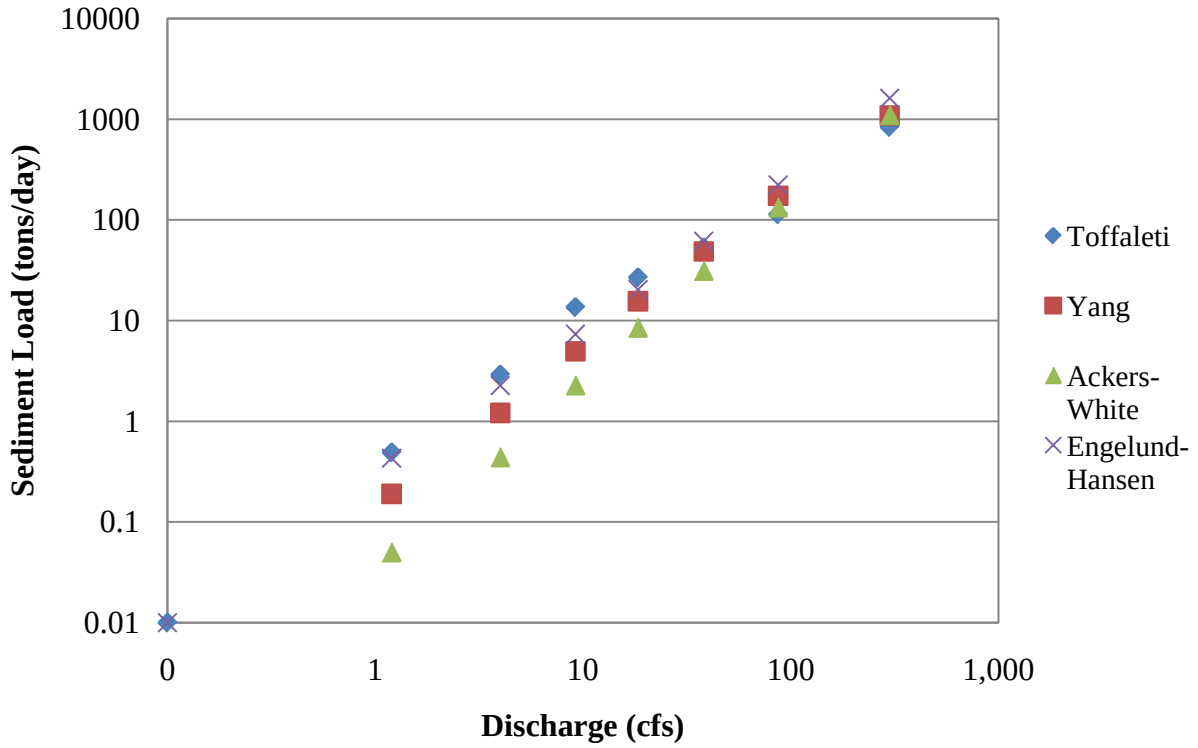


Figure 4.21 Sediment Rating Curve of the Surface Sediment at FM 409

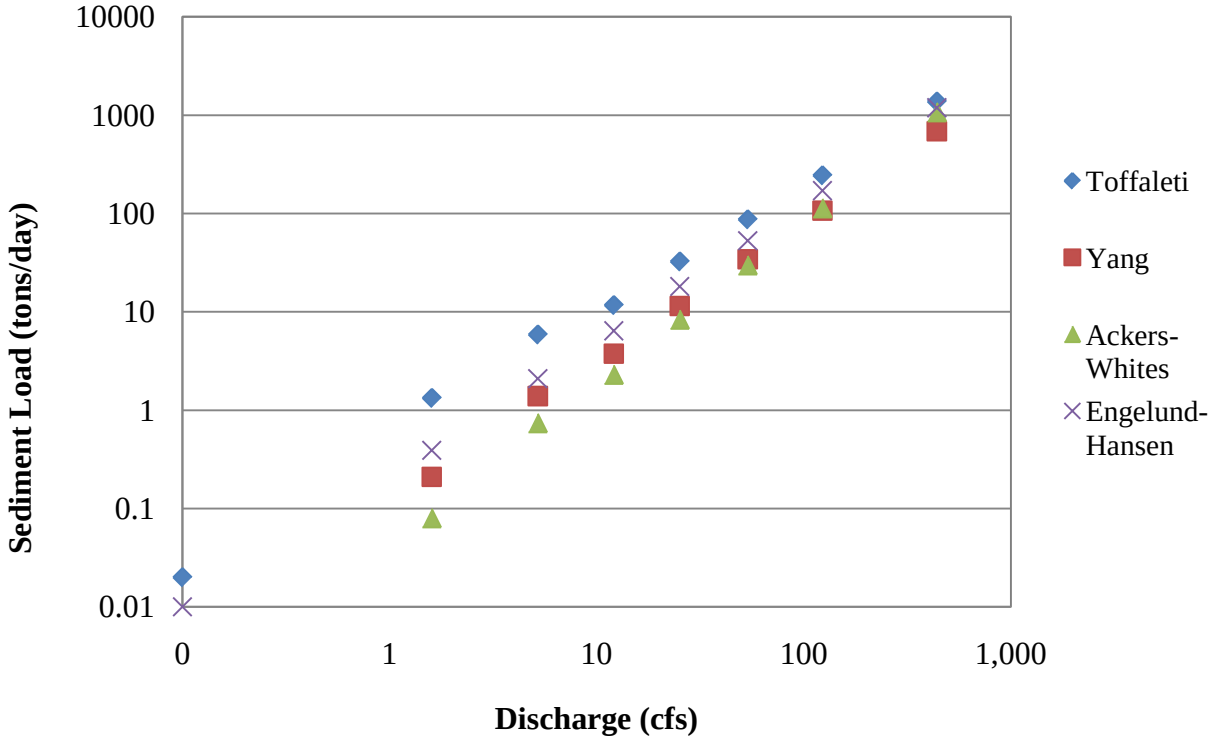
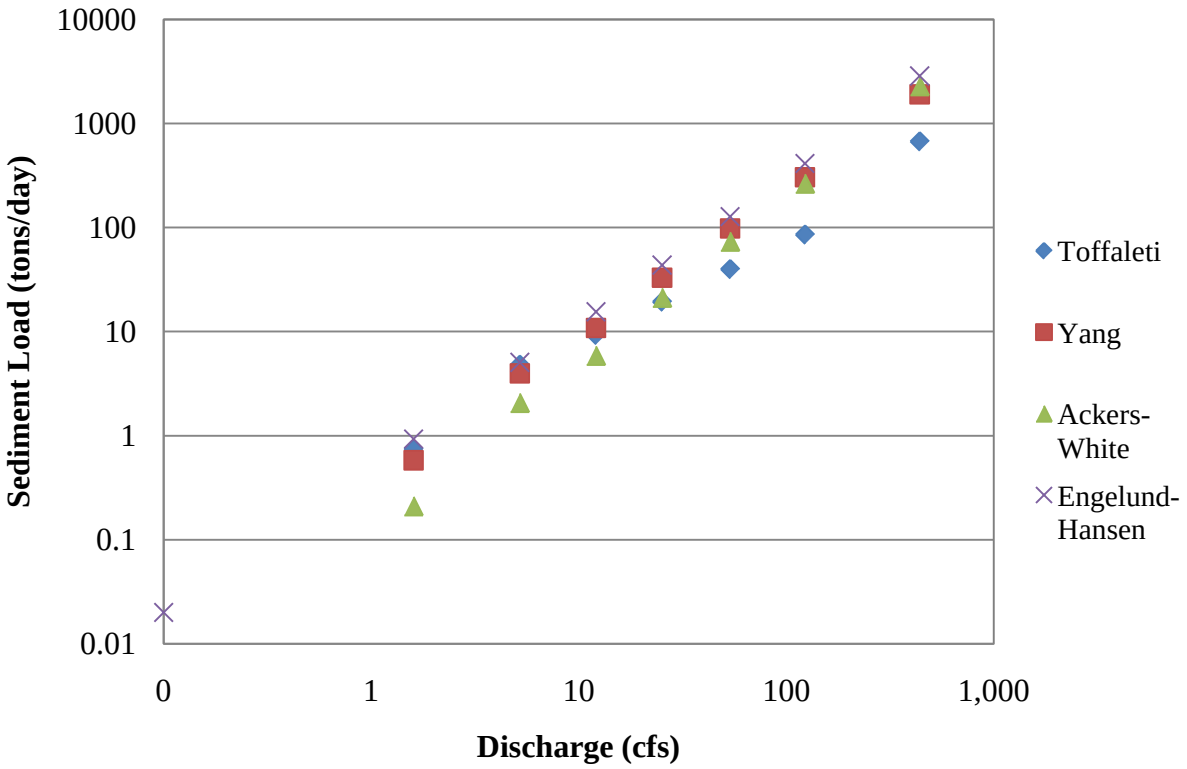


Figure 4.22 Sediment Rating Curve of the Subsurface Sediment at FM 409



4.3 Biology

BIOLOGY

42 species of fish were collected during this instream flow study.

Generalist species are dominant with red shiner most abundant.

No listed threatened or endangered species

Fish IBI scores are generally in High Aquatic Life Use category.

Biological analyses considered both field sampling data from this study and previous studies conducted within the watershed and associated ecoregions. The stream fish assemblage collected during this study is dominated by headwater colonizer species (i.e., smaller-bodied and short-lived fish). A previous study conducted by Linam et al. (2002) collected a total of 47 fish taxa from the Central Texas Plains and the Texas Blackland Prairies ecoregions. Resident species in streams similar to Bois d'Arc Creek are generally adapted to extreme environmental variation (Rahel and Hubert 1991) and illustrate rapid post-disturbance recolonization (Schlosser 1987). Prairie streams such as Bois d'Arc Creek have been described as lacking spatial heterogeneity in aquatic habitat and substrata (Osting et al. 2004), and are dominated by pools and backwater areas with silty-clay substrate. There is generally little cobble or gravel substrate in Bois d'Arc Creek, and subsequently no true riffle habitat (as defined according to standard methods; Arend 1999). Aquatic systems with these characteristics are often dominated by generalist fish taxa (Poff and Allen 1995), and recent studies conducted in neighboring watersheds have found that assemblage structure was not strongly linked to physical habitat measurements (Gelwick and Li 2002; Osting et al. 2004).

Most of the fish species (81%) collected from Bois d'Arc Creek during this instream flow study are generalist species, with only a few that are characteristically found only in flowing water or considered fluvial specialists (cential stoneroller, ribbon shiner, blackspot shiner, sand shiner, suckermouth minnow, freckled madtom, slough darter, and dusley darter).

Bois d'Arc Creek is classified as a 3rd to 4th order stream for the sampling reaches of this instream flow study. The order of a stream provides an indication of the relative size, depth and strength of specific channels within stream networks. It can also be used to understand the sediment potential in a stream segment and to determine what types of aquatic life might be present in the waterway. The 3rd and 4th order designations indicate the upper end of the overall drainage system (Red River basin). The study reaches US 82 and CR 2645 are 3rd order streams. Bois d'Arc Creek becomes a 4th order stream below the confluence with Bullard Creek. Sampling sites FM 1396, FM 409, and USFS are 4th order streams.

Field surveys identified four mesohabitats available for aquatic use. These mesohabitats were sampled for physical habitat features and fish composition, whereas macroinvertebrates were qualitatively sampled by stream reach for biotic integrity metrics. Fish species composition was found to be consistent with recorded occurrences for the Red River drainage basin (Thomas et al. 2007), as were biotic integrity scores (RRA 1999). The following is a summary of the biological analyses. Detailed descriptions of biological sampling and analyses are presented in Appendix D.

4.3.1 Mesohabitats

Four mesohabitats were found in the study reaches, including runs, riffles, structures (large woody debris, root wads, etc. that provide cover for aquatic species), and pools. Mesohabitats were sampled for fish and macroinvertebrates at discharges ranging from 1.2 to 21.5 cfs. These samples had measured current velocities ranging from 0.34 to 1.28 ft/sec and water depths ranging from 0.48 to 1.51 ft. Table 4.5 summarizes measured features of each mesohabitat. Runs and structural habitats had current velocities that were approximately double that of pool habitats (mean: 0.61, 0.67, and 0.34 ft/sec; run, structure, and pool, respectively), and riffle current mean velocity was greater than all other mesohabitats (1.28 ft/sec). Mean water depth was generally consistent across mesohabitats (slightly above 1 ft), except for riffles where mean water depth was 0.5 ft. Physicochemical measures (i.e., water temperature, pH, DO, and specific conductivity) were similar across all mesohabitats.

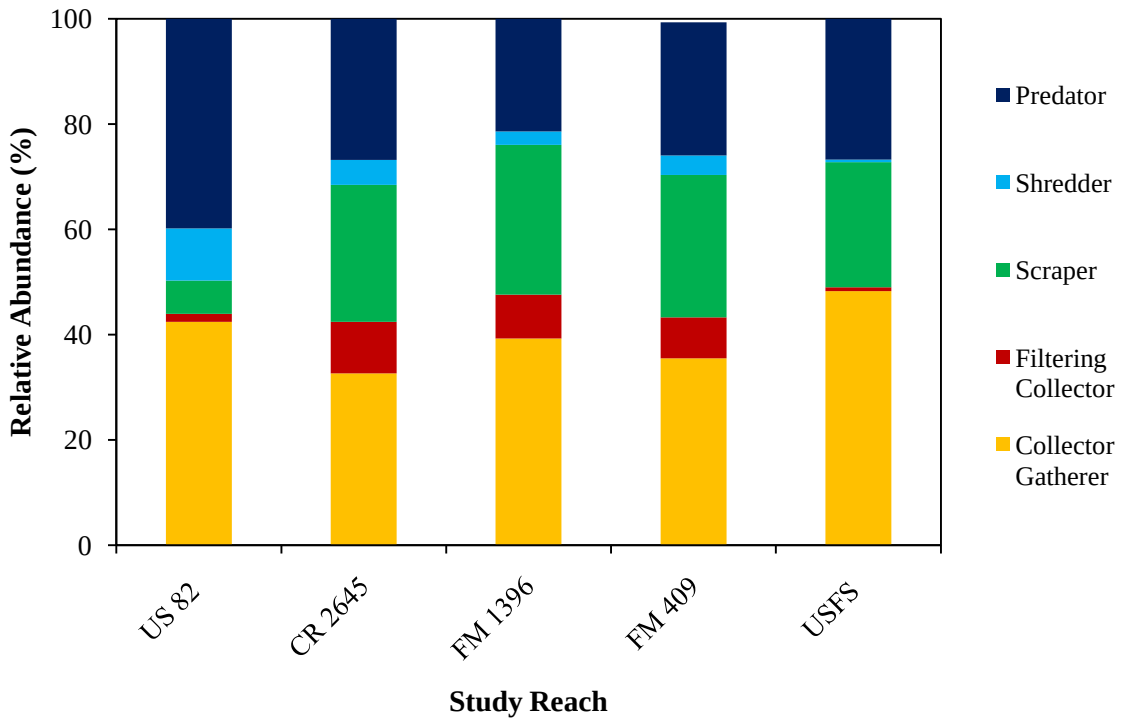
Table 4.5 Means, Standard Deviations, and Ranges for Selected Water Features by Mesohabitat.

	Run (*n* = 8)				**Pool** (*n* = 4)			
	Mean	[St Dev]	Min	Max	Mean	[St Dev]	Min	Max
Current Velocity (ft/s)	0.61	[0.55]	0.03	1.45	0.34	[0.27]	0.09	0.59
Depth (ft)	1.16	[0.50]	0.28	1.90	1.40	[0.69]	0.85	2.41
Temp (°C)	28.2	[1.79]	25.7	30.1	28.3	[1.64]	26.4	30.0
Dissolved O_2 (mg/L)	7.21	[2.52]	2.90	10.8	9.45	[1.25]	8.16	10.9
pH	7.49	[0.57]	6.26	7.98	7.98	[0.18]	7.77	8.21
Sp. Cond (uS/cm)	497	[79.5]	393	654	469	[48.5]	439	541
	Structure (*n* = 8)				**Riffle** (*n* = 2)			
	Mean	[St Dev]	Min	Max	Mean	[St Dev]	Min	Max
Current Velocity (ft/s)	0.67	[0.36]	0.11	1.17	1.28	[0.70]	0.78	1.77
Depth (ft)	1.51	[0.79]	0.63	2.80	0.48	[0.05]	0.45	0.52
Temp (°C)	29.9	[1.62]	5.27	32.0	28.5	[2.26]	26.9	30.1
Dissolved O_2 (mg/L)	7.91	[2.05]	5.27	10.5	9.55	[1.48]	8.50	10.6
pH	7.95	[0.22]	7.63	8.20	7.80	[0.13]	7.71	7.89
Sp. Cond (uS/cm)	485	[32.7]	431	520	524	[96.9]	455	592

4.3.2 Macroinvertebrates

A total of 2,621 aquatic and terrestrial insects, consisting of 103 identified genus and 46 families, were collected from March to July 2009. The relative abundance of functional feeding groups was calculated to evaluate trophic structure. Results indicated that collector-gatherers, predators, and scrapers dominated Bois d'Arc Creek (> 80%), with few filter feeding or shredder species. A high percentage (>36%) of collector-gatherers indicates degradation (TCEQ, 2007) while a low to moderate percentage (4% to 15%) of predators reflect a balanced tropic structure. The trophic structure in Bois d'Arc Creek suggests an abundance of coarse particulate organic matter (i.e., leaf litter) and a healthy prey population. There was no apparent longitudinal pattern in benthic macroinvertebrate trophic structure across mainstem sampling stations (Figure 4.23).

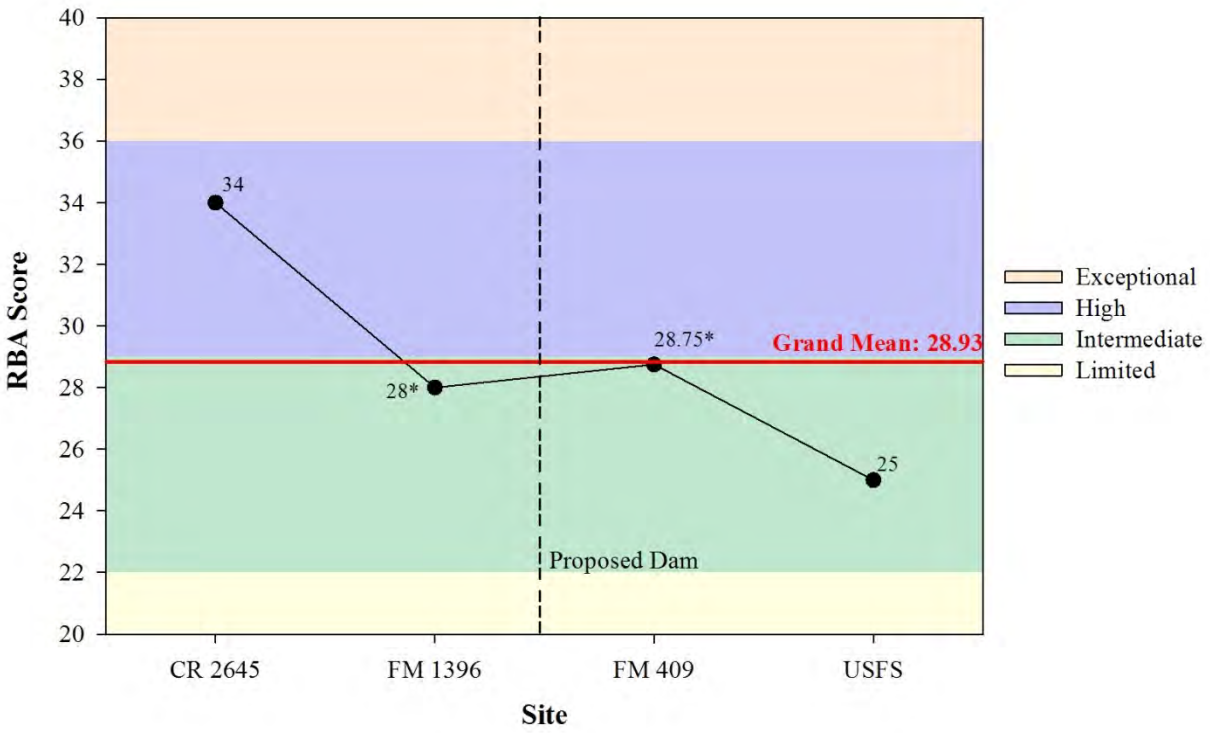
Figure 4.23 Benthic Macroinvertebrate Trophic Structure at Bois d'Arc Creek Study Sites



4.3.2.1 Macroinvertebrate Rapid Bioassessment (RBA)

Macroinvertebrates were sampled using TCEQ 2007 SWQM Rapid Bioassement Protocol (Texas RBP). Rapid bioassessments provide a standardized method for sampling and data analysis that can be used to provide a numerical value for the quality of a stream. The numerical scores determined using the Texas RBP are used to describe Aquatic Life Use categories for a stream (>36 is Exceptional, 29-36 is High, 22-29 is Intermediate, and <22 is Limited). As shown on Figure 4.24, the overall biological integrity of Bois d'Arc Creek's macroinvertebrate community was at the higher end of the intermediate range (mean: 28.9). Mainstem sampling site scores ranged from 22 (intermediate) to 37 (high)). These results are consistent with previous studies (RRA 1999, Hamilton 2009). Bois d'Arc Creek tributary scores were lower than mainstem sites, as Bullard and Honey Grove Creeks had scores of 25 and 28, respectively.

Figure 4.24 Rapid Bioassessment Results (Upstream to Downstream)



*Indicates average metric score from multiple collections (i.e., CR 2645: 31, 37; FM 1396: 31, 22, 31, 29; FM 409: 25, 31, 28, and 31).

4.3.2.2 Mussels

In accordance with the recommendations of the Inter-Agency Team, mussels were collected or photographed when they were encountered during other data collection efforts. A total of six species were collected or photographed and later identified as part of this effort Table 4.6).

According to the USFWS, no federally listed threatened or endangered mollusk species occur in Fannin County. A review of the *Texas Parks and Wildlife Department (TPWD) Annotated List of Rare Species for Fannin County* indicates that seven mollusk species are listed for Fannin County. None of these species were collected or identified in Bois d'Arc Creek during the current instream flow study. Additional information on mussels is presented in Appendix D.

4.3.3 Fish

4.3.3.1 Historical Collections

There is little baseline data on the stream fisheries of Bois d'Arc Creek. There have been several collections in the mainstem Red River, with studies in the 1950's conducted throughout the Red River basin (Bonn 1957). However, these documents give a compilation of collected species, and do not identify specific tributaries for individual collections. Only one study was found specific to Bois d'Arc Creek (i.e., RRA 1999) that documented collection location, date, and

Table 4.6 Mussel Species Collected during Instream Flow Study on Bois d'Arc Creek

Species	Habitat	Glochidia Host(s)
Bleufer *Potamilus purpuratus*	Streams, rivers, and reservoirs	freshwater drum (*Aplodinotus grunniens*)
Fragile Papershell *Leptodea fragilis*	Streams, rivers and possibly reservoirs	freshwater drum (*Aplodinotus grunniens*)
Mapleleaf *Quadrula quadrula*	Large streams, rivers, and lakes	flathead catfish (*Pylodictis olivaris*)
Pink Papershell *Potamilus ohiensis*	Large rivers and possibly reservoirs	freshwater drum (*Aplodinotus grunniens*) white crappie (*Pomoxis annularis*)
Washboard *Megalonaias nervosa*	Rivers, lakes, and reservoirs	American eel (*Anguilla rostrata*) black crappie (*Pomoxis nigromaculatus*) bluegill (*Lepomis macrochirus*) channel catfish (*Ictalurus punctatus*) flathead catfish (*Pylodictis olivaris*) freshwater drum (*Aplodinotus grunniens*) largemouth bass (*Micropterus salmoides*) sauger (*Stizostedion canadense*) white bass (*Morone chrysops*) white crappie (*P. annularis*)
Yellow Sandshell *Lampsilis teres*	Streams, rivers, and oxbow lakes*	alligator gar (*Lepisosteus spatula*) black crappie (*Pomoxis nigromaculatus*) green sunfish (*Lepomis cyanellus*) largemouth bass (*Micropterus salmoides*) longnose gar (*L. osseus*) shortnose gar (*L. platostomus*) shovelnose sturgeon (*Scaphirhynchus platorynchus*) warmouth (*L. gulosus*) white crappie (*P. annularis*)

Sources: Howells, R.G., et al. 1996. Freshwater Mussels of Texas. Texas Parks and Wildlife Press. Austin, Texas.

Roe, Kevin J. 2002. Conservation Assessment for the Yellow Sandshell (*Lampsilis teres*). USDA Forest Service, Region 9. Saint Louis, MO.

collected taxa. An additional species list for Bois d'Arc Creek was acquired from the Texas Natural History Collection (TNHC) Ichthyology archives, but the TNHC list did not identify collection location, date, or numerical species accounts.

4.3.3.2 FNI Collections and Relative Abundance Analysis

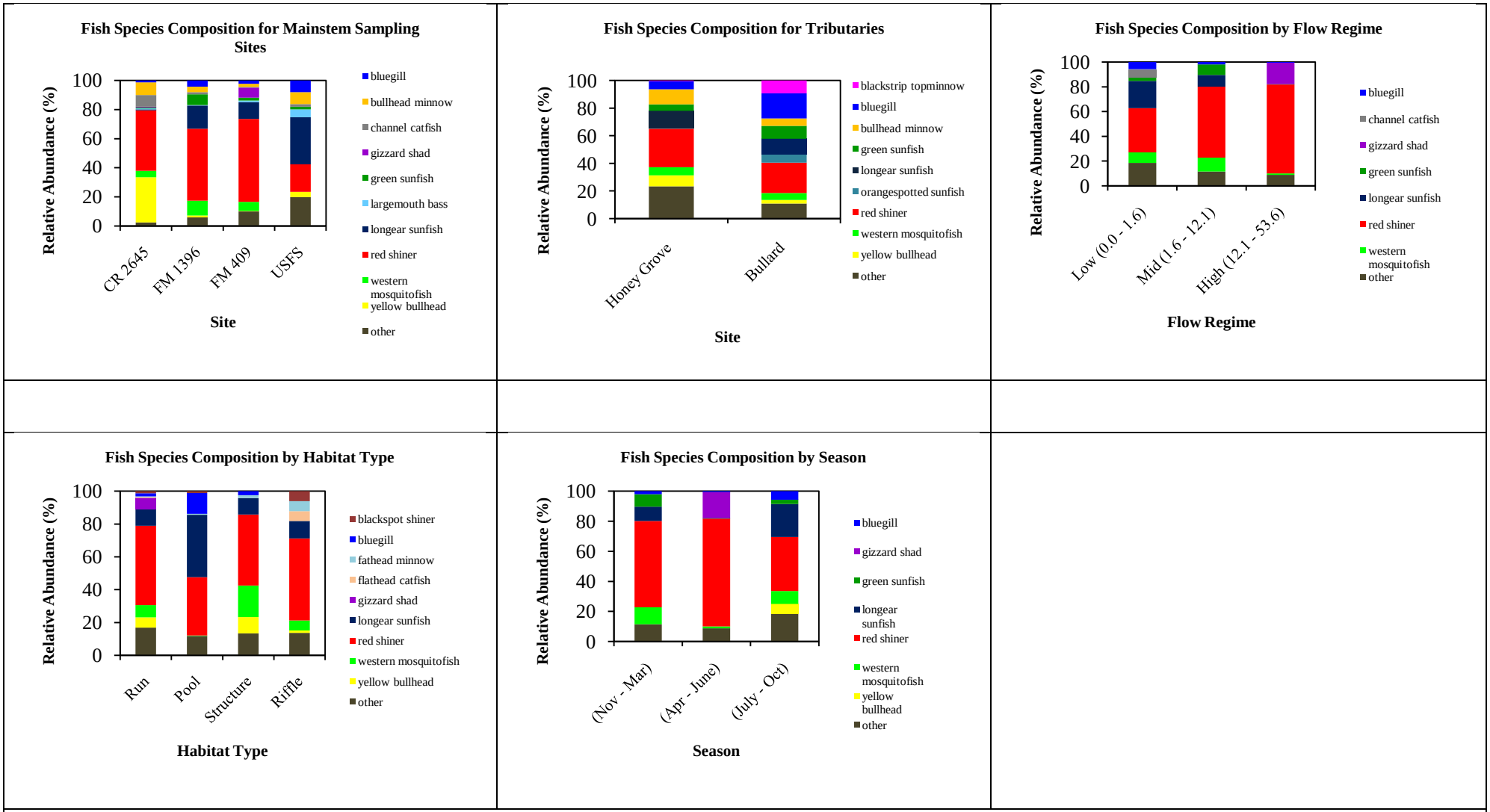
A total of 3,138 fish, consisting of 42 species and 11 families, were collected from March to July 2009 (Table 4.7). The most abundant family was Cyprinidae (59% in percent total relative abundance), followed by Centrarchidae (20%), Poeciliidae (8%), Ictaluridae (6%), and Clupeidae (3%). Complete collection data and literature-based life history accounts for dominant species are presented in Appendix D.

Species relative abundance across site, mesohabitat, flow, and season illustrated similar patterns of dominant species (Figure 4.25). Across all analyses, community composition was dominated by generalist species tolerant of a wide range of environmental conditions. In general, the two most dominant species were red shiner (50% total relative abundance) and longear sunfish (13.7%). Species composition for tributary sites was similar to the mainstem sites, although abundance scores were more evenly distributed across species. Across flow regimes, relative abundance of longear sunfish, bluegill, green sunfish, and western mosquitofish declined at higher flows, while red shiner abundance increased. There was no distinguishable seasonal pattern, except that red shiner was particularly abundant in the summer. Gizzard shad were only found during the spring sampling event, which may have been associated with migratory spawning behavior. There was no apparent pattern across mesohabitat, except that Centrarchid (sunfish) species were more abundant in pool habitats.

Table 4.7 Fish Collected During Bois d'Arc Creek Instream Flow Study

Species	Number Collected	Species	Number Collected
Lepisosteus oculatus	1	Pylodictis olivaris	10
Lepisosteus osseus	1	Labidesthes sicculus	7
Dorosoma cepedianum	69	Fundulus notatus	33
Dorosoma petenense	1	Gambusia affinis	247
Campostoma anomalum	20	Lepomis cyanellus	154
Cyprinella lutrensis	1,417	Lepomis gulosus	12
Cyprinella venusta	21	Lepomis humilis	28
Cyprinella hybrid	3	Lepomis macrochirus	151
Cyprinus carpio	0	Lepomis megalotis	421
Lythrurus fumeus	25	Lepomis microlophus	24
Notropis atrocaudalis	1	Lepomis hybrid	18
Notropis stramineus	27	Micropterus punctulatus	3
Phenacobius mirabilis	26	Micropterus salmoides	37
Pimephales vigilax	147	Pomoxis annularis	5
Carpiodes carpio	4	Pomoxis nigromaculatus	2
Ictiobus bubalus	2	Etheostoma gracile	3
Moxostoma erythrurum	1	Percina caprodes	10
Ameiurus melas	20	Percina macrolepida	1
Ameiurus natalis	112	Percina phoxocephala	1
Ictalurus punctatus	39	Percina sciera	22
Noturus gyrinus	2	Aplodinotus grunniens	1
Noturus nocturnus	9		
Total Number Collected			***3,138***
Total Taxa			***42***

Figure 4.25 Relative Abundance of Fish Taxa by Sample Site, Flow Regime, Mesohabitat, and Season.



*"Other" includes those species with a relative abundance of less than 5%

4.3.3.3 Fish Trophic Structure

Analysis of fish functional feeding groups illustrated that Bois d'Arc Creek is largely dominated by generalist species with opportunistic feeding strategies. Red shiner and sunfish species (particularly longear) mostly forage in the form of benthic grazing or water surface predation. These feeding strategies are a response to Bois d'Arc Creek's turbid waters and general lack of favorable microhabitat.

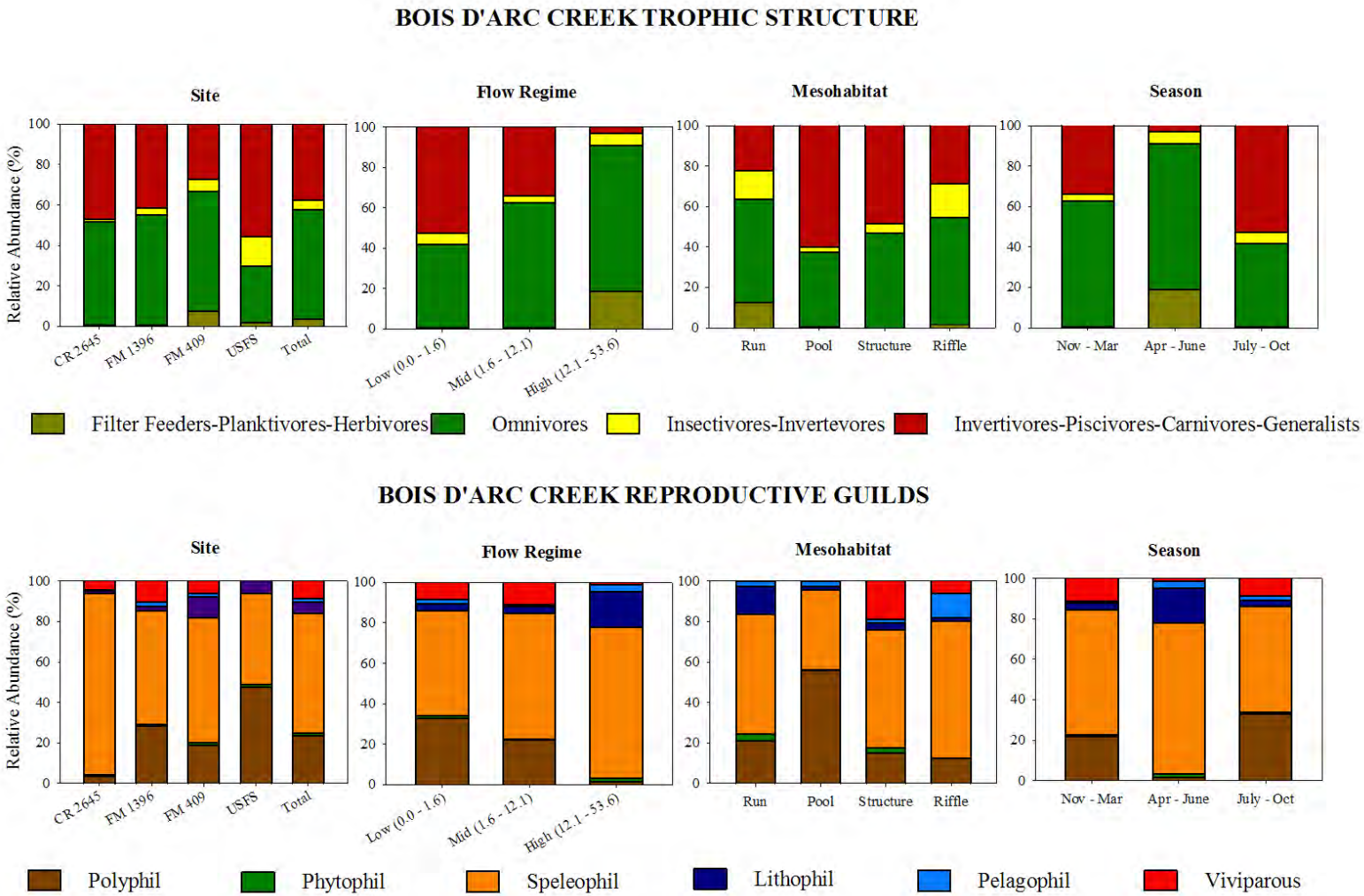
There was no clear pattern of trophic structure across sites, though there were some apparent patterns across flow, mesohabitat, and season. More top-level predators (i.e., sunfish) were collected from pools, particularly in the low flow summer sampling event. This is not surprising, as sunfish species will likely thrive under these conditions compared to fluvial specialists. The only other apparent pattern was that more filter feeders-planktivores-herbivores were collected during the spring high flow sampling event, which is likely a result of increased primary productivity and increased movement associated with spawning.

Literature review of reproductive strategies for collected fishes revealed that most of the species collected are largely opportunistic, dominated by speleophilic and polyphilic spawners. Speleophils (i.e., crevice spawners) will deposit eggs in submerged structures, but have no specific structural requirements. Polyphilic species deposit eggs directly onto stream bed substrates, and generally lack a specific substrate preference. Similar to structural patterns found with functional feeding group, sunfish species (largely polyphils) dominated pool habitats and were particularly abundant during the low flow summer sampling event. Speleophils dominated reproductive strategy across all categories, as the pervasive red shiner is a speolophilic spawner. The relative abundance of functional feeding groups and reproductive guilds by site, flow regime, mesohabitat, and season is displayed in Figure 4.26.

4.3.3.4 Fish Reproduction

Physical habitat requirements and reproductive timing for fish taxa observed in Bois d'Arc Creek were identified from published literature. Fluvial specialist species, particularly members of the families Cyprinidae and Percidae, require specific current velocities, depths, or specific substrates for reproduction. Literature review identified typically shallow depth (i.e., < 3 ft), swifter current velocities (i.e., > 1 ft/sec), and gravel or cobble substrate preference for these fluvial specialist species. However, the reproductive cues of fishes of Bois d'Arc Creek appear to be largely temperature dependent. Dominant species (as determined by the relative abundance analyses) spawn from February to October with the largest proportion in the months of May and June. The graph presented in Figure 4.27 shows the average observed temperature and flow conditions in Bois d'Arc Creek during the typical spawning periods of the dominant fishes observed in the creek. After mid-June, flow in Bois d'Arc Creek decreases to little to no flow, indicating unfavorable spawning conditions for fluvial specialists that require flowing water for spawning. However, the generalist species (or those that do not require flowing water for

Figure 4.26 Bois d'Arc Creek Trophic Structure and Reproductive Guild by Site, Flow Regime, Mesohabitat, and Season



Flow values in cfs.
Polyphil = various spawning substrates, adhesive eggs are attached singly or in clusters. Phytophil - obligatory plant spawner characterized by an adhesive egg envelope sticking to submerged plants Speleophil = cavity roof nesters and bottom burrow nesters. Lithophil - nesting, where eggs are in spherical or elliptical envelopes, always adhesive, free embryos are photophobic or with cement glands, embryos swing tail-up in respiratory motions, moderate to well-developed embryonic respiratory structures present, and many young feed first on mucus of the parent. Pelagophil = pelagic spawner with numerous buoyant eggs, not guarded. Viviparous = giving birth to active, free-swimming young.

spawning) may find suitable spawning habitat in persistent pools along Bois d'Arc Creek channel.

4.3.4 Habitat and Species Associations

Canonical correspondence analysis (Braak 2002) was used to assess correlations between fish assemblage data and habitat data (CANOCO Version 4.5; Braak and Smilauer 2002). The modeled habitat variables included: substrate (as percent bedrock, sand, silt, gravel), current velocity, depth and conductivity. To identify associations with particular habitat types, sample observations were delineated by mesohabitat. This procedure was used to identify individual species or groups of species associated with a particular mesohabitat.

According to the canonical correspondence analysis, golden redhorse, bigscale logperch, threadfin shad, and gizzard shad have an affinity for swifter water and gravel substrates. Slough darter, logperch, dusky darter, and four centrarchid species prefer slower moving or backwater areas. Freckled madtom, central stoneroller, and blacktail shiner are associated with deeper water and sandier substrates. Results indicate that the remaining 28 species can be found across a wider range of physical habitat conditions. Species-mesohabitat associations were not found.

The results from the canonical correspondence analysis did not identify clear species habitat groups or indicator species, but they reaffirmed that Bois d'Arc Creek is dominated by generalist species inhabiting a homogenized physical environment. Therefore, river modeling procedures were designed to predict physical habitat with the goal of maximizing diversity of microhabitat components (i.e., current velocity, depth, and substrate).

4.3.5 Fish Index of Biological Integrity

The regionalized Index of Biotic Integrity (IBI) (TPWD 2002) is a measure of fish communities that includes components of species composition, trophic composition, and abundance and condition (Linam et al., 2002). It is typically used by TCEQ as a water quality indicator, with higher scores indicating better water quality. In this study, IBI scores for fish community structure were intermediate to high (mean: 43.83), and increased longitudinally within the mainstem of Bois d'Arc Creek (Figure 4.28). Scores were higher than the intermediate designation reported in the 1999 RRA study. Mainstem site scores ranged from 33 (limited) to 49 (high), and tributary scores were also in the high range (i.e., 46 and 43, Honey Grove and Bullard Creek, respectively).

Figure 4.27 Reproductive Timing of Dominant Species in Bois d'Arc Creek Compared with Mean Monthly Temperature and Median Monthly Stream Discharge

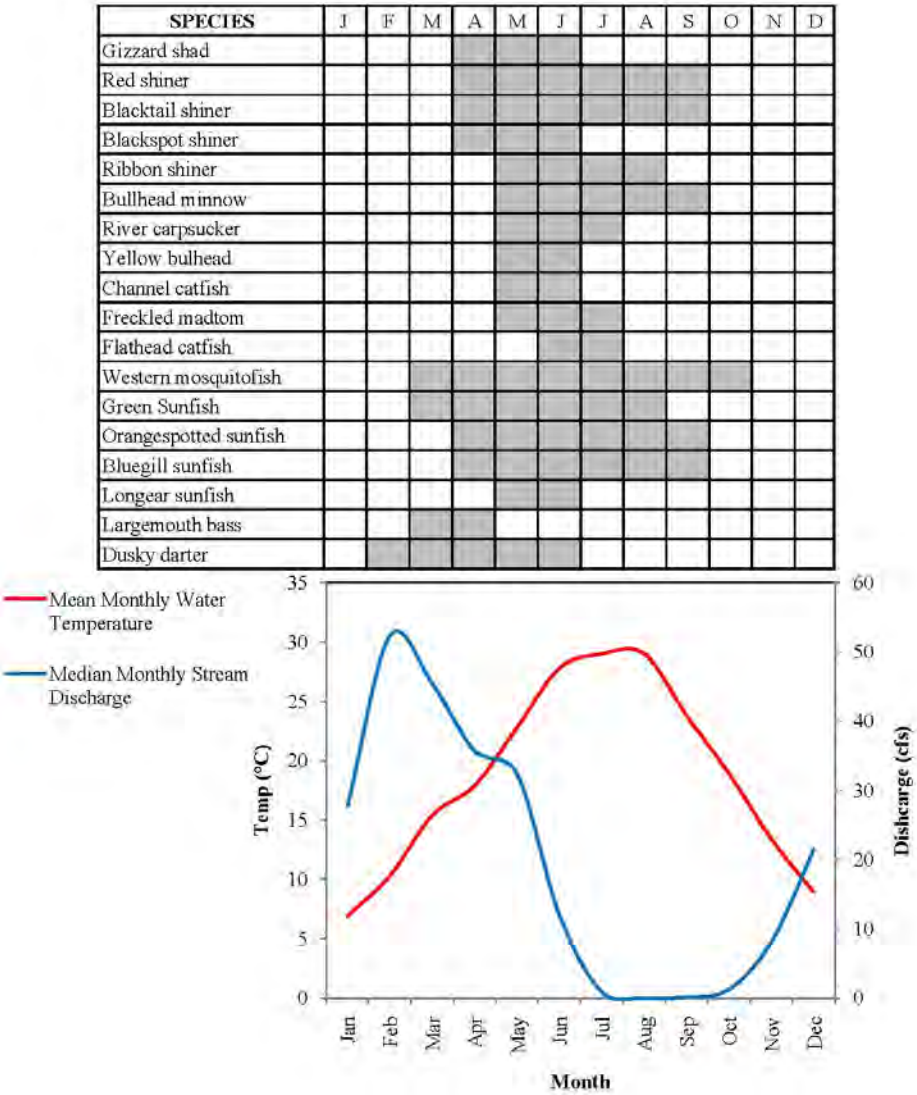
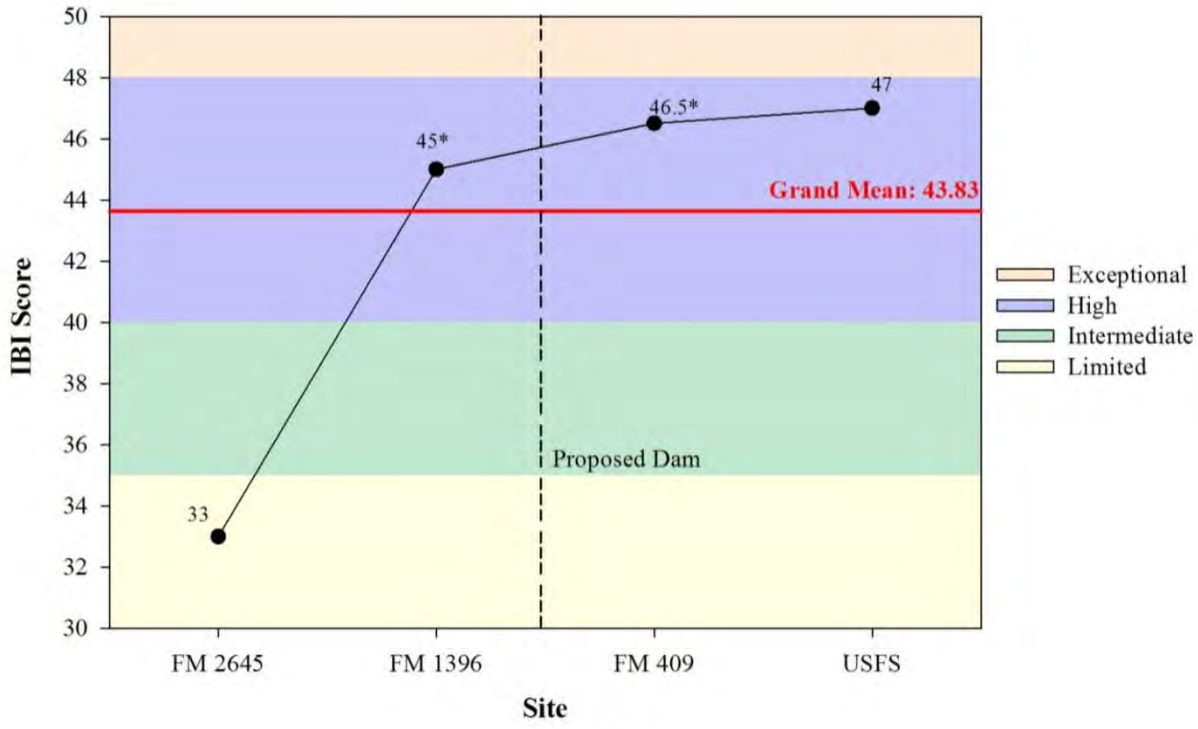


Figure 4.28 Fish Index of Biological Integrity (IBI) Results from Bois d'Arc Creek Study Reaches

(Upstream to Downstream)



* Indicates average IBI from multiple collections (i.e., FM 1396: 49, 41; FM 409: 45, 48)

4.3.6 Habitat Modeling

River 2D was used to model habitat variables (current velocity and water depth) in the FM 409 study reach, which is downstream of the proposed dam site. Habitat simulations were conducted incrementally at low discharges to evaluate stream connectivity. Higher discharges were modeled to evaluate mesohabitat abundance.

HABITATS

Mesohabitats dominated by pools (70-80% Weighted Useable Area) and runs (14-28% WUA).

No statistically significant species-habitat associations.

Longitudinal connectivity in Bois d'Arc Creek with 3 cfs flow at FM 409 study reach.

4.3.6.1 Channel Connectivity

Modeling of low discharges identified that flows between 2 and 3 cfs maintain longitudinal stream connectivity. At this discharge, modeled pool habitats remained connected by run-riffle habitats. At 3 cfs, modeled physical attributes include a maximum water depth of 2.68 ft and a mean velocity of 0.61 ft/s at FM 409 (Figure 4.29 and Figure 4.30).

In a comprehensive analysis of fish species-habitat association, Aaland (1993) found that medium-sized pool habitat maintained both the highest age-class and species diversity. He found that medium-sized pools typically ranged from 2 to 4.9 feet deep with current

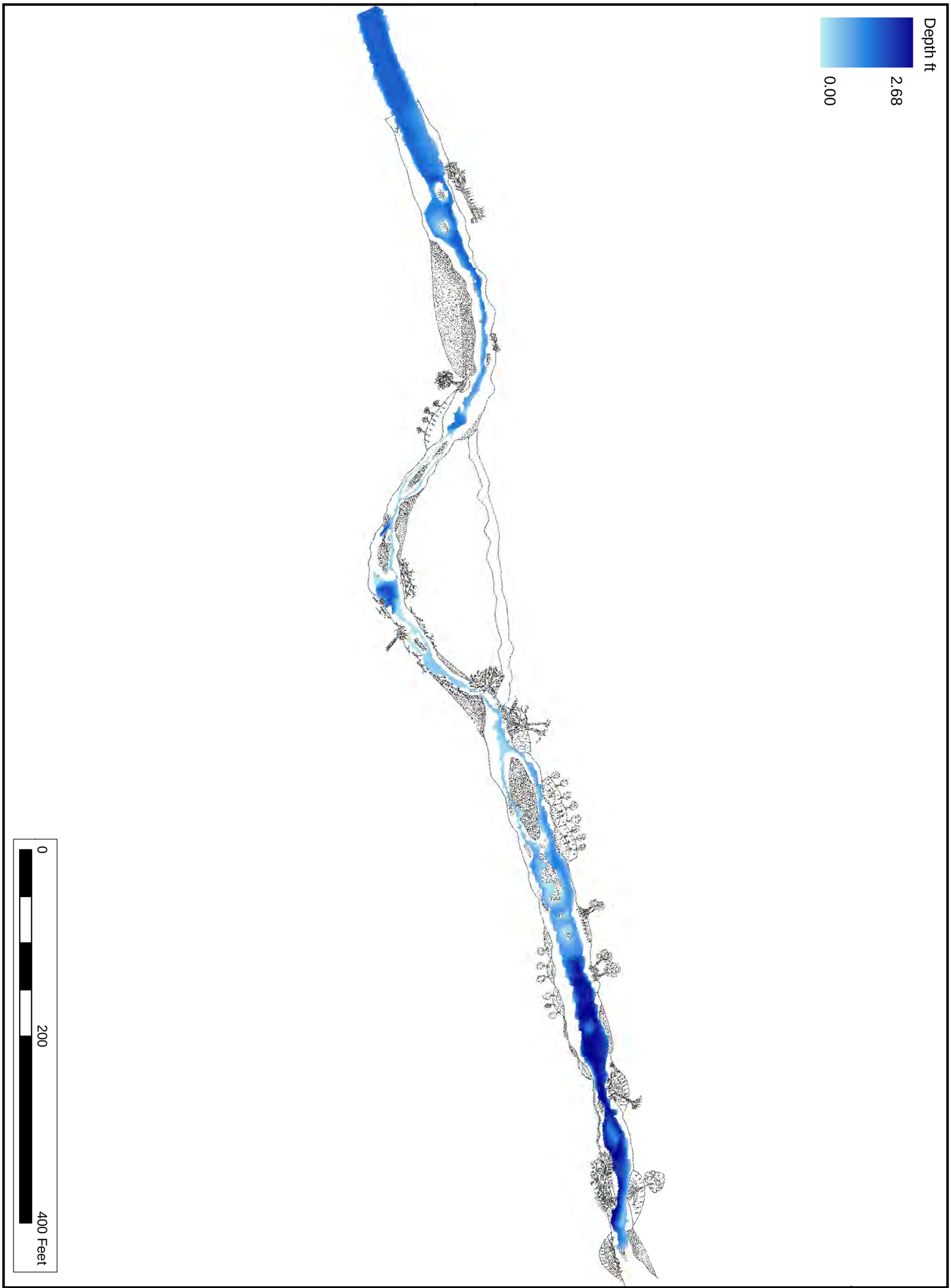
velocities of less than 0.98 ft/s (Figure 4.31). As physical habitat attributes in Bois d'Arc Creek at 3 cfs fall within this range, 3 cfs would not only maintain connectivity but also could be expected to promote biodiversity.

4.3.6.2 Mesohabitat Distribution

Weighted Usable Area (WUA) calculations from River 2D output were used to evaluate mesohabitat presence and abundance at discrete discharges. Results from WUA analyses confirmed field observations that Bois d'Arc Creek is a run-pool dominated system. Under all discharge scenarios combined run and pool habitat accounted for over 96 percent of usable area (Table 4.8).

Table 4.8 Modeled Habitat Distribution at FM 409

Discharge (cfs)	**Habitat Distribution (%)**			
	Run	**Riffle**	**Pool**	**Structure**
3	14.69	0.26	84.94	0.11
10	25.48	0.52	73.65	0.35
30	28.18	0.54	70.11	1.17
50	27.17	0.48	70.57	1.78
100	24.19	0.96	72.45	2.40
1,000	25.16	0.01	71.58	3.25
7,000	24.19	0.00	74.28	1.53



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N E S W

North Texas Municipal Water District

Proposed Lower Bois d'Arc Creek Reservoir

F.M. 409 Depth
3 CFS

FN JOB NO	NTD06128
FILE	4.30_Depth_3.mxd
DATE	April 2010
SCALE	1:1,200
DESIGNED	MJA
DRAFTED	MJA

4.29

Figure

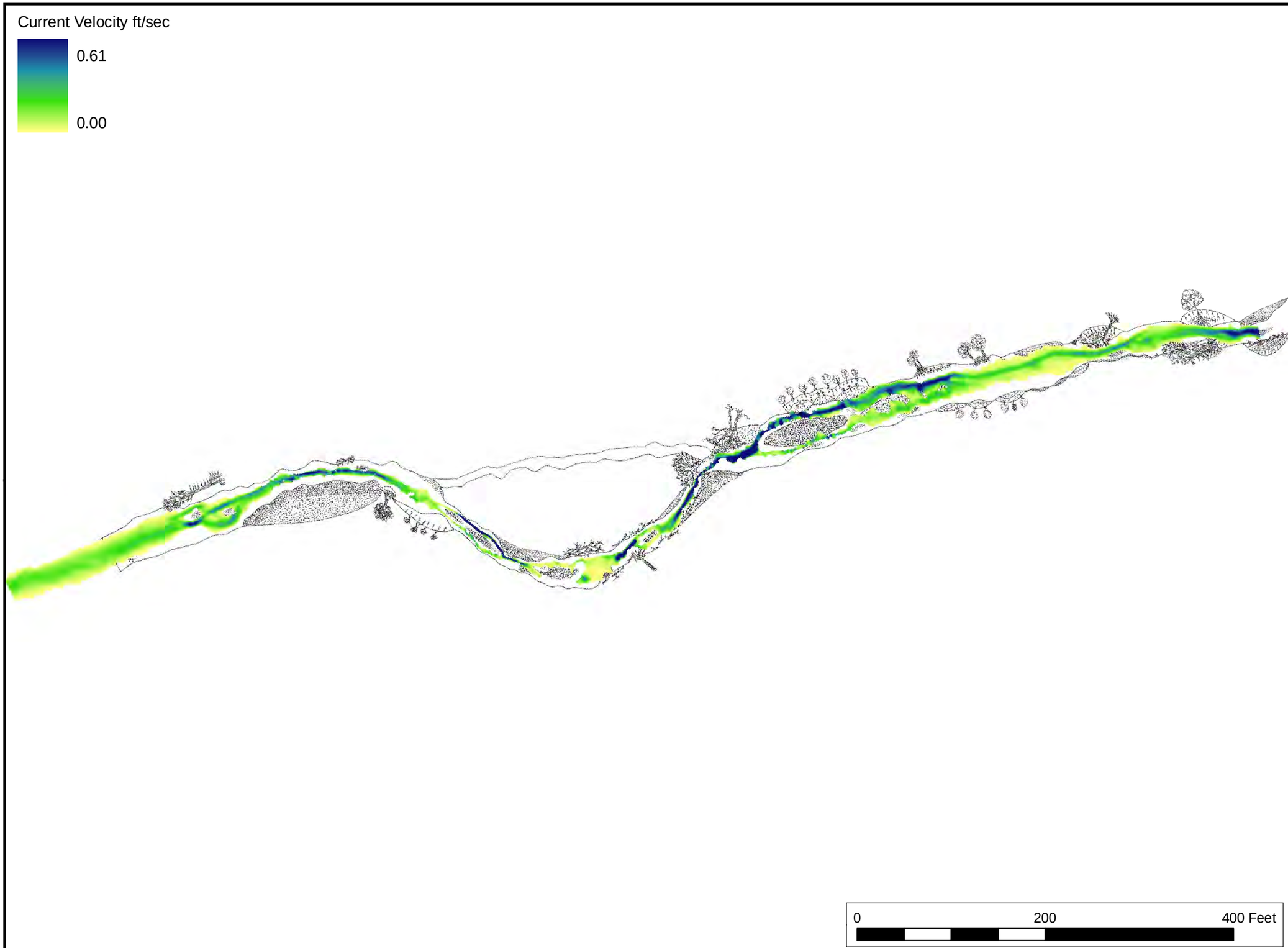

Figure 4.30

FN JOB NO	NTD06128
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DATE	April 2010
SCALE	1:1,200
DESIGNED	MJA
DRAFTED	MJA

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F.M. 409 Current Velocity 3 CFS

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FN JOB NO	NTD06128
FILE	4.32_Pool_3.mxd
DATE	April 2010
SCALE	1:1,200
DESIGNED	MJA
DRAFTED	MJA

4.31

Figure

North Texas Municipal Water District
Proposed Lower Bois d'Arc Creek Reservoir

F.M. 409 Pool Habitat Suitability
3 CFS

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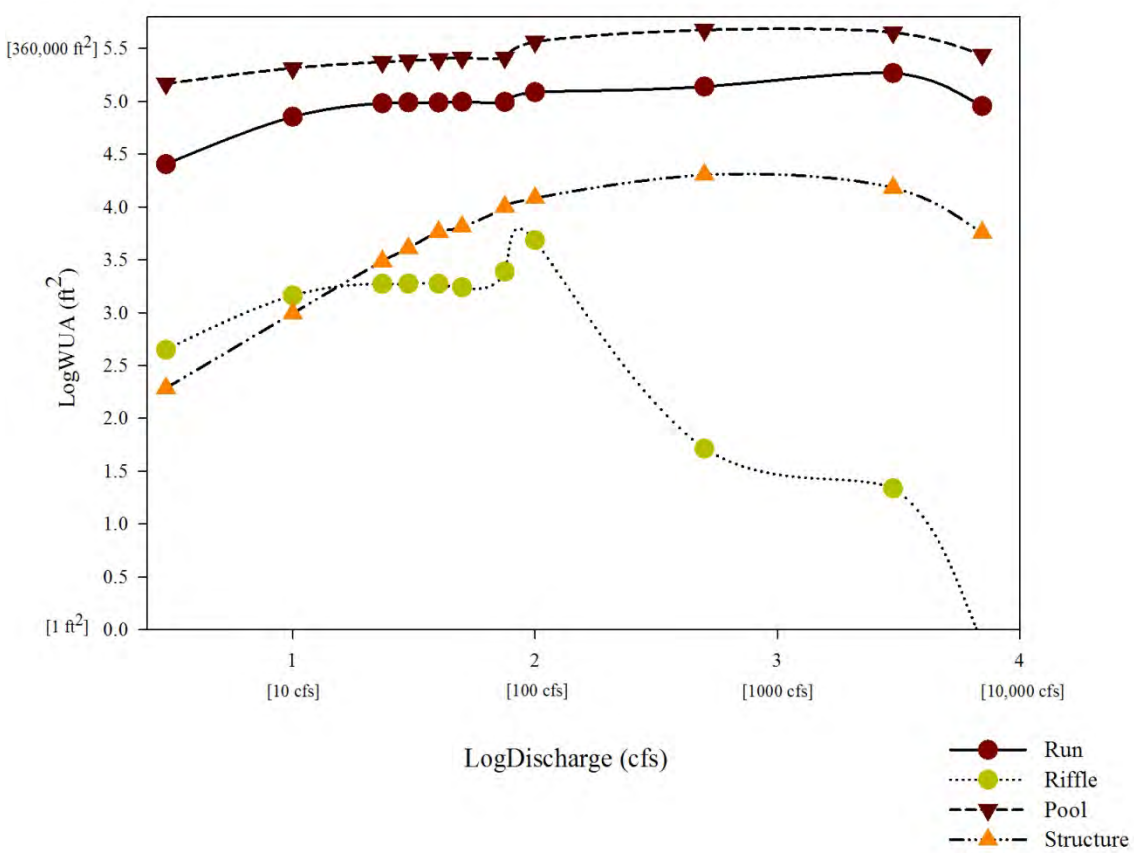
Figure 4.32 graphically illustrates the relationship of discharge to usable habitat, using the WUA calculations. Run and pool habitat curves are high and relatively stable across all discharges. Structure increases until flows reach approximately 100 cfs. At flows between 100 cfs and 7,000 cfs, the amount of usable structure habitat is relatively stable. Above 7,000 cfs the amount of structure habitat begins to decrease. Riffle habitats increase as flows increase up to 10 cfs. Between 10 cfs and 100 cfs riffle habitats remain relatively constant, and then decline rapidly at flows above 100 cfs. Due to the stream morphology there is not sufficient large size bed material to support regular riffle function and habitat at higher flows. At flows greater than 100 cfs, riffle habitat becomes inundated deeply and Bois d'Arc Creek habitats become a complex of fast pools and river runs. The anomalous increase in riffle habitat at approximately 100 cfs shown on Figure 4.32 is caused by a side channel, which becomes inundated at approximately 100 cfs (based on model output and visual observation).

Figure 4.32 Weighted Usable Area (WUA) versus Simulated Discharges at FM 409



It should be noted that physical habitat attributes were measured only at flows less than 30 cfs. Physical habitat variables measurements could not be conducted during higher flows due to unsafe wading conditions and inaccessibility by boat.

4.4 Water Quality

Water quality was evaluated based on data from historical and ongoing water quality monitoring as well as data that were collected as part of the current study. Baseline water quality conditions are summarized in this chapter with an emphasis on dissolved oxygen and temperature. More detailed information on water quality in Bois d'Arc Creek is presented in Appendix D.

WATER QUALITY

- **Dissolved oxygen levels meet high aquatic life criteria except during extremely low flows.**
- **No wastewater discharges are located below proposed dam site.**

4.4.1 Existing Water Quality

Several data sources were available to evaluate existing water quality conditions of Bois d'Arc Creek. Water quality data were collected by the United States Geological Survey (USGS) in cooperation with the North Texas Municipal Water District, the Red River Authority of Texas (RRA) in cooperation with the Texas Commission on Environmental Quality (TCEQ), North Texas Municipal Water District (NTMWD), and Freese and Nichols, Inc (FNI). The sampling site locations are depicted in Figure 4.33 and are described as follows:

- USGS gage at FM 1396 (USGS 07332620), located within the proposed reservoir.
- USGS gage at FM 409 (USGS 07332622), located downstream of the proposed reservoir.
- RRA sampling station (station ID 15749) located upstream of the proposed reservoir.
- NTMWD sampling sites at several locations in and around the proposed reservoir.
- FNI instream flow study data at five locations in and around the proposed reservoir.

The USGS real-time stream gage data on Bois d'Arc Creek at FM 1396 provides the longest continuous water quality record. The gage was installed in August 2006 and records dissolved oxygen, temperature, pH, and specific conductance measurements at 15-minute intervals. The USGS gage at FM 409 was installed in June 2009 and measures the same parameters at the same frequency as the FM 1396 gage. The FM 409 gage would provide post-dam construction flow and water quality monitoring data for Bois d'Arc Creek downstream of the proposed reservoir. Both gages are currently operating and data from these gages can be accessed online from the USGS National Water Information System.

The mean monthly water temperature from the USGS FM 1396 gage is plotted in Figure 4.34. Water temperatures ranged from a low of 6.9 °C in January to a high of 29.0 °C in July and August.

Dissolved oxygen concentrations from October 2006 through January 2010 ranged between 3.6 mg/L and 17.0 mg/L at the USGS FM 1396 gage (Figure 4.35). As expected, dissolved oxygen concentrations in Bois d'Arc Creek exhibited a fairly strong inverse relationship to water temperature, with approximately 60% of the variation in dissolved oxygen being explained by temperature (i.e., $R^2 = 0.59$). While no significant correlation was indicated between dissolved oxygen concentration and flow (Figure 4.36), it was noted that the only recording of dissolved oxygen below the 5.0 and 5.5 mg/L criteria for high aquatic life use set by the Texas Surface Water Quality Standards (Table 4.9) occurred during flows approaching zero. At all other flows, and even in the low flow range, dissolved oxygen concentrations typically exceeded 5.5 mg/L.

The RRA conducted water quality monitoring on Bois d'Arc Creek at a sampling site near FM 78 (Figure 4.33) in conjunction with the TCEQ's Clean Rivers Program (RRA 2005). The purpose of the RRA sampling was to characterize water quality and flow for specific streams in the Red River Basin. Ten samples were collected between March 2004 and July 2005 upstream of the proposed reservoir site within one half mile of the City of Bonham Wastewater Treatment Plant. The sampling data are summarized in Table 4.10.

Table 4.9 Dissolved Oxygen Criteria by Aquatic Life Use Designation

Dissolved Oxygen Criteria, mg/L			
Aquatic Life Use Subcategory	Freshwater mean/minimum	Freshwater in Spring Spawning Period mean/minimum	Saltwater mean/minimum
Exceptional	6.0/4.0	6.0/5.0	5.0/4.0
High	5.0/3.0	5.5/4.5	4.0/3.0
Intermediate	4.0/3.0	5.0/4.0	3.0/2.0
Limited	3.0/2.0	4.0/3.0	

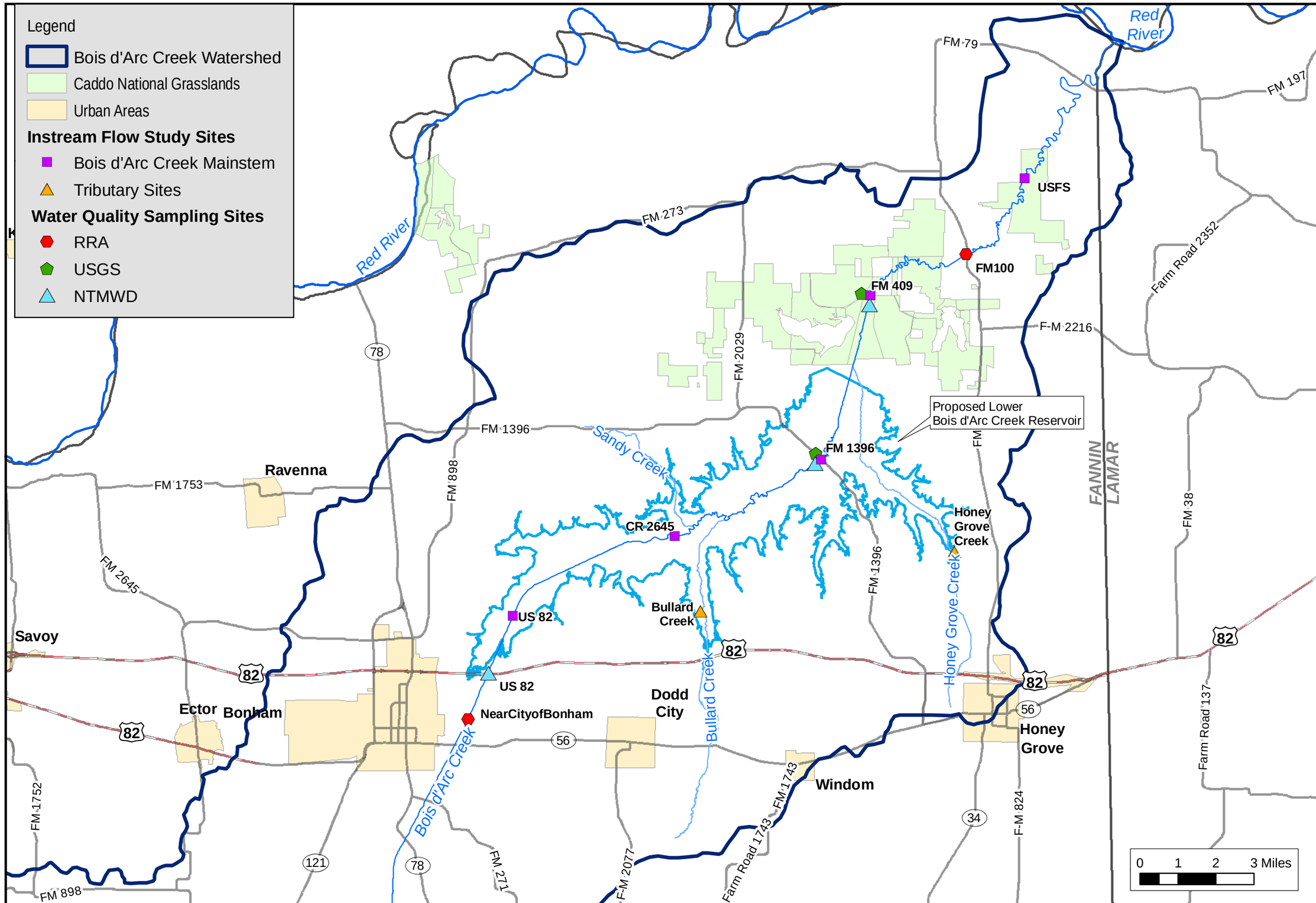


Figure 4.33

FN JOB NO	NTD06128
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SCALE	1:149,333
DESIGNED	BME
DRAFTED	BME

North Texas Municipal Water District
Proposed Lower Bois d'Arc Creek Reservoir

Water Quality Sampling Sites

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Figure 4.34 Mean Monthly Water Temperature at the USGS FM 1396 Gage (September 2006 through September 2009)

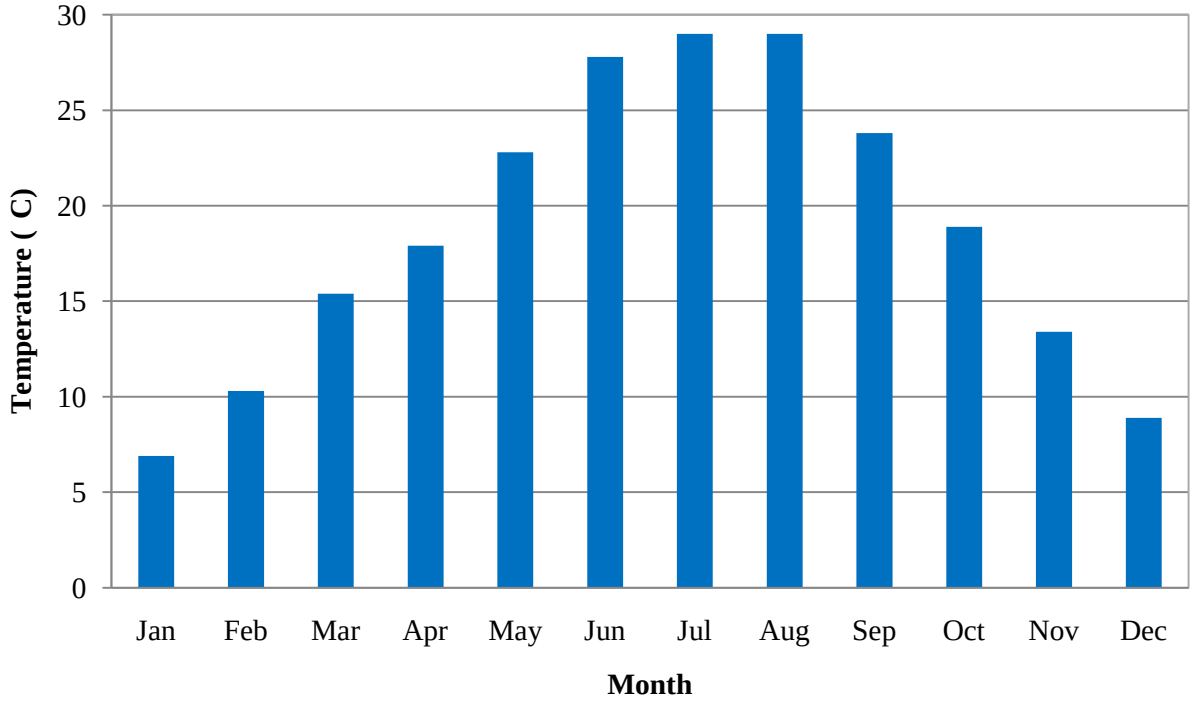


Figure 4.35 Daily Mean Dissolved Oxygen vs. Temperature at the USGS FM 1396 Gage (October 2006 through January 2010)

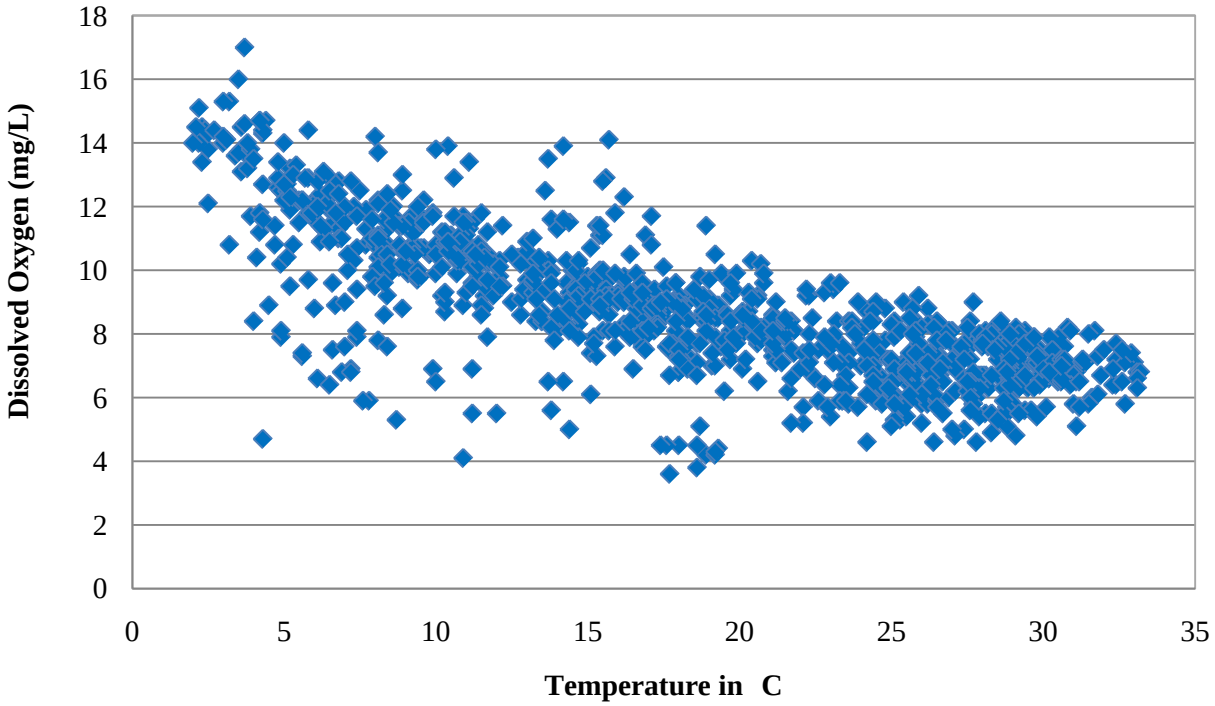


Figure 4.36 Daily Mean Dissolved Oxygen vs Flow at the USGS FM 1396 Gage (October 2006 through January 2010)

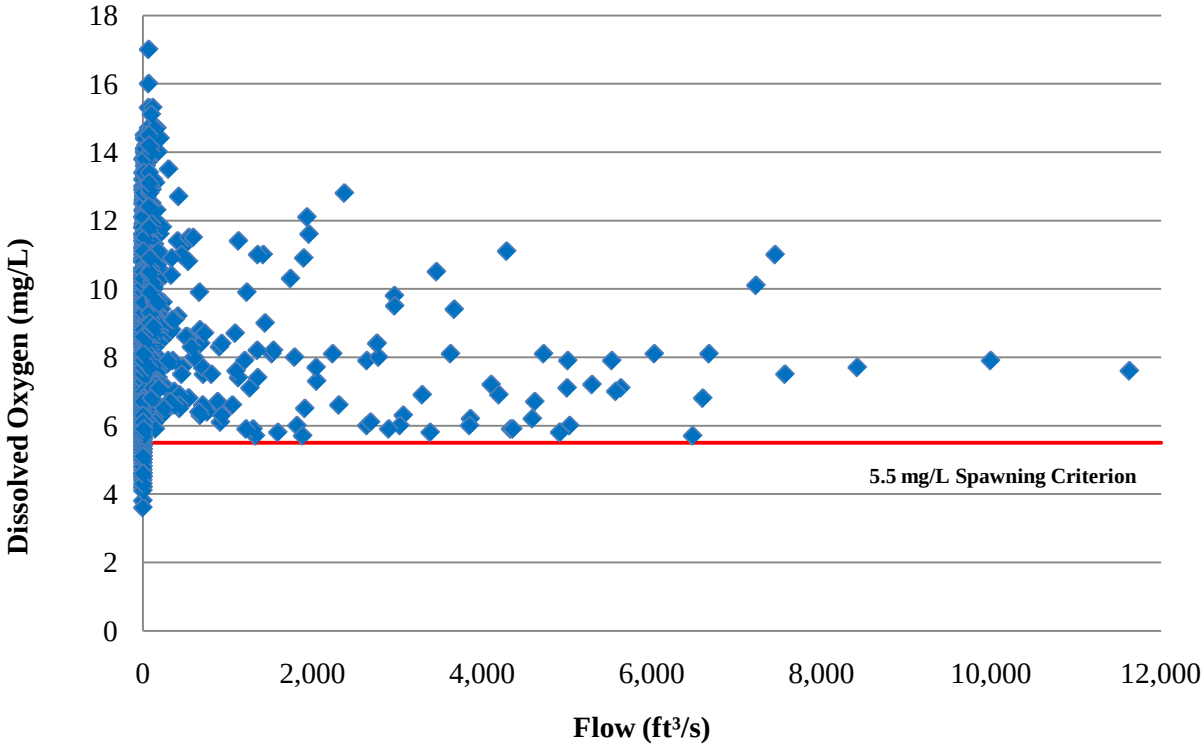


Table 4.10 Summary of Red River Authority Water Quality Data from Bois d'Arc Creek Near Bonham

Sampling Years	Range of Flow (cfs)	Mean Temperature (°C)	Mean Specific Conductance (µS/cm)	Mean pH (SU)	Mean Dissolved Oxygen (mg/L)	Mean Lab Turbidity (NTU)	Number of Samples (n)
2004 to 2005	0.0375 to 52	19.2	542	8.1	8.1	9.4	10

North Texas Municipal Water District (NTMWD) collected water samples at three locations along Bois d'Arc Creek (Figure 4.33) on nearly a monthly basis from June 2007 through December 2008. A statistical summary of the NTMWD water quality sampling data is included in Table 4.11. The dissolved oxygen measurements at all sites ranged between 2.5 mg/L and 13.0 mg/L. The dissolved oxygen concentrations observed by NTMWD at its three Bois d'Arc Creek sampling locations are compared in Figure 4.37, and the associated flows at the USGS FM 1396 gage on the respective sampling dates are depicted in Figure 4.38. Most of the observed dissolved oxygen concentrations were

above the applicable criteria set by the Texas Surface Water Quality Standards for high aquatic life uses. The lower concentrations were primarily associated with extreme low flow conditions. A detailed description of NTMWD sampling data for Bois D'Arc Creek is presented in Appendix E.

Table 4.11 Summary of NTMWD Bois d'Arc Creek Water Quality Data (June 2007 through December 2008)

Sample Site	Mean Temperature (°C)	(n)	Mean Specific Conductance (µS/cm)	(n)	Mean pH (SU)	(n)	Mean Dissolved Oxygen (mg/L)	(n)	Mean Lab Turbidity (NTU)	(n)
US 82	18.1	22	497	19	7.53	8	6.45	22	137	22
FM 1396	17.9	17	428	15	8.06	3	7.69	17	151	17
FM 409	18.1	18	488	16	7.95	4	7.69	18	119	18

Figure 4.37 Dissolved Oxygen Concentrations at NTMWD Sampling Sites in Bois d'Arc Creek

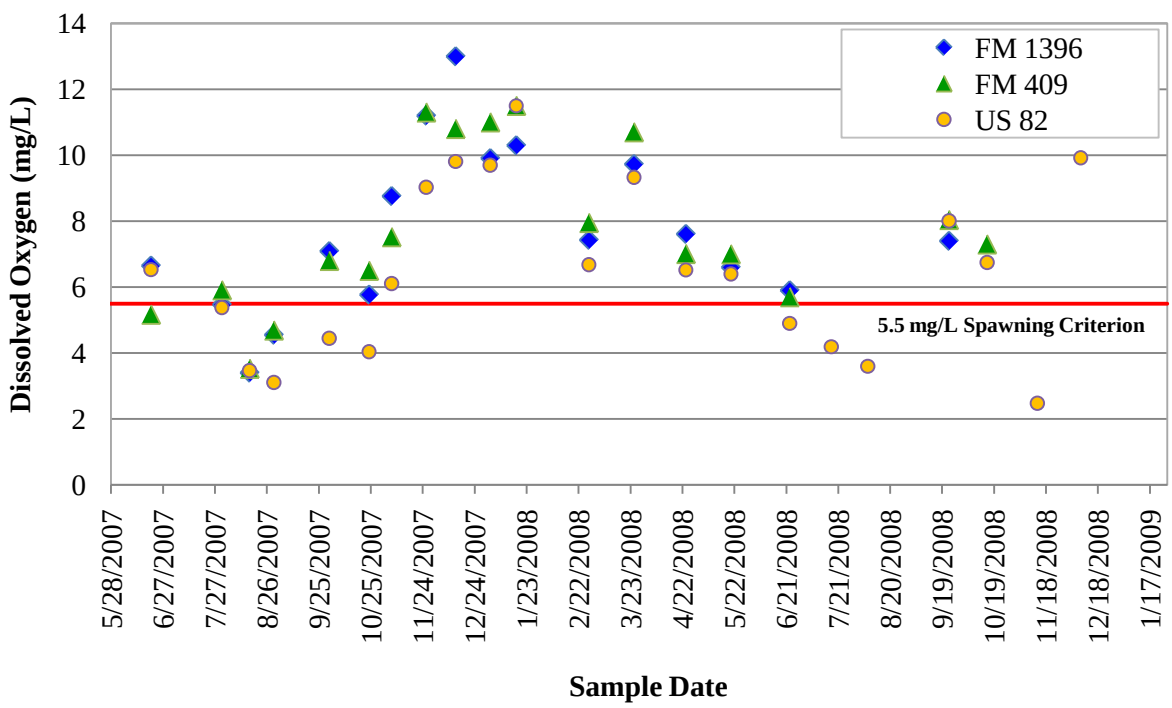
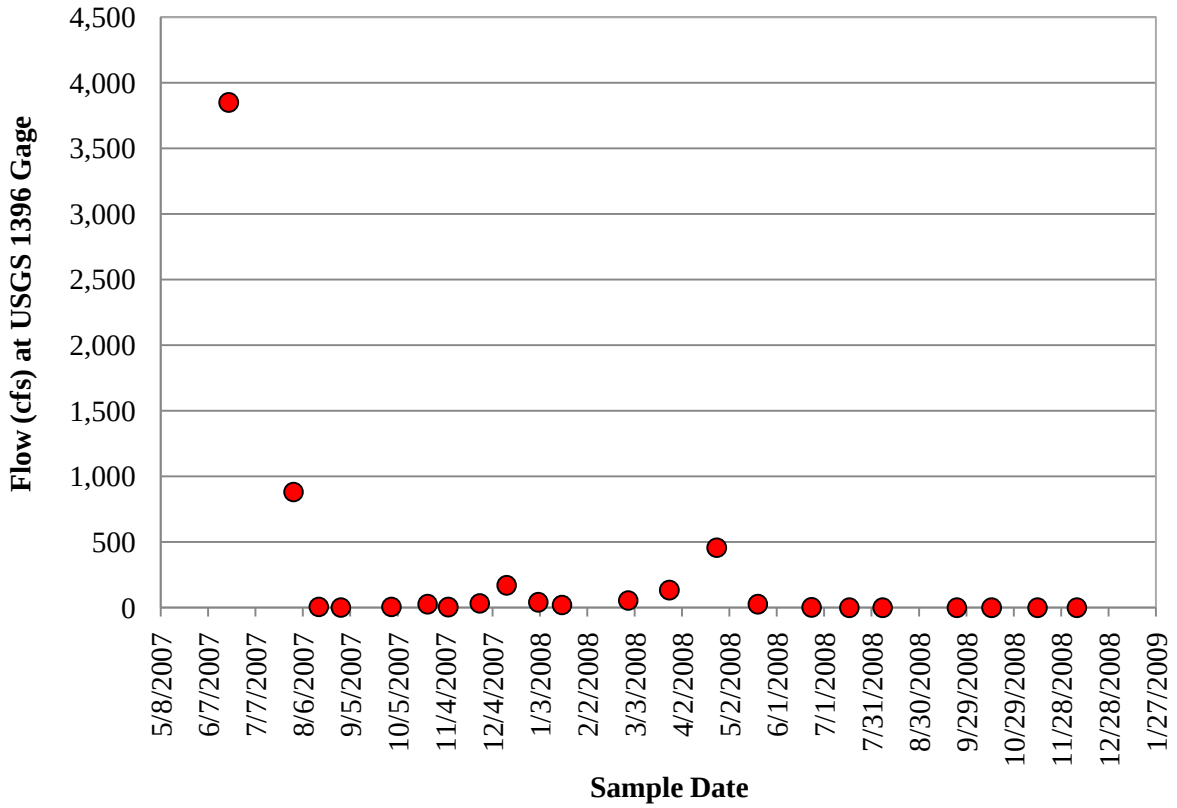


Figure 4.38 Mean Daily Flow in Bois d'Arc Creek at the USGS FM 1396 Gage on the NTMWD Water Sampling Dates



FNI measured dissolved oxygen, temperature, pH, specific conductance, and streamflow during biological sampling events at five locations along Bois d'Arc Creek (Figure 4.33). The observed dissolved oxygen concentrations and other water quality measurements from the sampling events are summarized in Table 4.12 The mean dissolved oxygen concentrations ranged between 5.4 and 10.7 mg/L at all but the US 82 site. At this site, dissolved oxygen levels ranged between 2.8 and 2.9 mg/L. These low readings were attributed to warm water temperature and low current velocity due to a logjam that blocked the creek's flow. By comparison, dissolved oxygen measurements made on the same day at the next downstream sampling location (CR 2645) ranged between 5.9 and 6.2 mg/L.

Table 4.12 Summary of FNI Water Quality Sampling Data (June and July 2009)

Site	Date	Mean Dissolved Oxygen (mg/L)	Mean Temperature (°C)	Mean Conductivity (us/cm)	pH (su)	Mean Instantaneous Flow (cfs)	Measure -ments (n)
FM1396	6/8/09	9.0	28.5	424	7.90	0.94	8
FM409	6/9/09	8.2	29.1	435	7.97	1.21	7
CR2645	6/10/09	5.4	28.6	503	7.67	0.94	5
FM1396	7/7/09	9.4	28.4	443	7.89	0.30	9
FM409	7/7/09	10.7	30.1	552	7.99	0.54	7
CR2645	7/8/09	6.1	30.5	508	7.68	0.73	2
US82	7/8/09	2.9	25.9	481	7.21	0.03	2
USFS	7/9/09	6.6	25.7	654	7.39	0.10	4

4.4.2 Water Quality Modeling

The TCEQ developed a waste load evaluation for Bois d'Arc Creek using the Qual-TX water quality model. The model was used by TCEQ to evaluate the effects on dissolved oxygen of treated effluent discharges from five publicly owned treatment works (POTWs) in the Bois d'Arc Creek watershed in order to issue Texas Pollutant Discharge Elimination System (TPDES) permits. The POTWs are identified in Table 4.13 along with their permitted flow, effluent limitations, and effluent outfall location upstream from the proposed dam site. No POTWs were identified downstream of the proposed dam site.

Table 4.13 Publicly Owned Treatment Works Authorized by TPDES Permit to Discharge in the Bois d'Arc Creek Watershed

Publicly Owned Treatment Work	Permitted Flow (Million Gallons per Day)	Effluent Limitations (CBOD/TSS/NH_3-N/DO, mg/L)	Distance of Outfall Upstream from Proposed Reservoir, (Stream Miles)
Whitewright, TX	6.272	20/20/5/5	41.4
Randolf, TX	0.022	30/30/8/4	28.5
Bonham, TX	2.500	10/15/2/6	17.3
Dodd City, TX	0.048	30/30/8/4	15.8
Windom, TX	0.032	30/30/8/4	16.5
Honey Grove, TX	0.500	30/30/8/4	9.1

CBOD- carbonaceous biochemical oxygen demand
TSS - total suspended solids
DO – minimum dissolved oxygen
NH_3-N ammonia-nitrogen

The TCEQ uses the Qual-TX model to establish effluent limitations for TPDES permits that will maintain the dissolved oxygen criteria prescribed by the Texas Surface Water Quality Standards for the effluent receiving streams affected by each POTW. Thus, the effluent limitations listed in Table 4.13 are presumed to be protective of dissolved oxygen criteria in Bois d'Arc Creek and the tributaries receiving effluent from these POTWs.

4.5 Future Conditions in Bois d'Arc Creek without the Proposed Reservoir

Without any changes in the watershed, Bois d'Arc Creek is expected to continue to downcut and erode. As the channel becomes even more incised, lateral connectivity with the surrounding flood plain will decrease. Due to the unstable nature of much of the stream banks along Bois d'Arc Creek and easily erodible bed materials, the stream channel will continue to enlarge. This will further reduce longitudinal connectivity at low flows and continue to constrain aquatic species to specific habitats that contain water (e.g., pools).

The Bois d'Arc Creek watershed has been significantly impacted by channelization, which began in the 1920s and continued well into the 1970s. The channelization was probably in response to frequent overbanking events in the watershed. As a result of the channelization, the watershed is no longer in equilibrium. Downcutting and streambank erosion have increased, and lateral migration of the stream (i.e., meander creation) has

slowed. Channelization has also most likely increased the "flashy" nature of flows in the watershed, with rapid rise and fall in flow in response to rainfall events. This probably has reduced base flows in the watershed as well. Habitats in the watershed change rapidly, as high flows wash away gravel bars and large woody debris or low flows reduce connectivity along the stream. The frequency of extreme flow events, both high and low, has resulted in an environment that favors generalist species. Although water quality in the watershed is generally good, Bois d'Arc Creek is not able to support a large variety of aquatic life because the relatively few habitat features in the watershed are frequently washed away by high flow events, and the apparent lack of reliable subsistence or baseflow hydrology from year to year may be a limiting factor for fish and other aquatic species.

Water quality does not appear to have been a primary limiting factor to aquatic life in Bois d'Arc Creek, and this would be expected to hold true into the future in the absence of large scale watershed or stream system modifications that would result in a combination of decreased streamflow and increased water temperatures. Observed data indicated that dissolved oxygen concentrations were adequate to support aquatic life as long as there was adequate flow in the creek. Dissolved oxygen levels were depressed primarily during periods when streamflow approached zero and especially during warm months of the year when higher water temperatures limited the amount of oxygen that could be dissolved in the stream. It is assumed that TCEQ would continue to protect water quality in Bois d'Arc Creek and its tributaries in accordance with the Texas Surface Water Quality Standards if the proposed reservoir is not built. This would include waste load allocation permitting and evaluation of effluent limits through the use of appropriate water quality modeling tools such as Qual-TX to ensure that applicable water quality criteria would be met in the receiving waters.

5 FUTURE CONDITIONS WITH RESERVOIR

This chapter is an overview of expected conditions once the reservoir has been built. This evaluation includes an assessment of future habitat conditions within the reservoir pool and downstream of the dam. Environmental release criteria are included to mitigate the impacts of the reservoir and help support a sound ecological environment below the dam.

5.1 Potential Impacts of Reservoirs on Streams

Reservoirs that impound streams can have varying impacts to the aquatic communities, especially fish, within the drainage or watershed. This section includes a summary of literature regarding the potential impacts of dams and ways that those impacts can be mitigated. Such impacts can vary pending existing stream conditions and watershed factors. It is not always true that reservoirs have diversity in aquatic species, especially fish, than the stream that was impounded. Several studies have documented cases where reservoirs have not impacted or have increased species diversity, while in other cases reservoirs have decreased diversity.

5.1.1 Potential Impacts within the Reservoir Pool

5.1.1.1 Impacts on Fish

RESERVOIR POOL

- **Expect similar aquatic species found in this study to thrive in lake environment**
- **Expect similar water quality conditions to existing North Texas lakes.**
  - **Some stratification during hot summer months**
- **May decrease sediment loading due to reduced hydraulic gradient and current velocities**

Impoundments interrupt the continuity of river ecosystems. One of the expected effects of this interruption is a change in the fish assemblage in the reservoir (Vannote et al. 1980; Poff et al. 1997). The change from lotic (river) to lentic (lake) habitat will shift the present species composition toward more pool-associated species, largely composed of sunfish (Centrarchids), temperate bass (Moronidae), catfish (Ictalurids), and suckers (Catostomids) (Aaland 1993). However, the magnitude of the change is dependent upon impoundment size, position of the impoundment along the stream (i.e., near headwaters or near the mouth of the stream), stream size, and current species composition (Marmulla 2001). Fish assemblages that are found only in rivers will be lost, but the newly created lentic habitat can compensate for some of these losses. In some cases reservoirs can increase productivity in terms of fish yield or recreational capacity, particularly in inland streams that do not support popular game fish. The compensatory potential for the newly created lentic habitat is higher in lower order upland streams with more shallow average depths (Marmulla 2001). The average North American reservoir produces a biomass of 24 kg/ha/yr (Jenkins 1982; Marmulla 2001). Additionally, shallow shoreline reservoir habitats can maintain healthy populations of native riverine fishes (Fernando and Holcik 1991).

Taylor et al. (2001) conducted a study to document the effects of an impoundment on a small creek in southern Illinois. Historical collections documented 48 fish species and one hybrid in the creek's drainage. After impoundment a total of 74 species and two hybrids were collected. The 50 percent increase in species richness Taylor et al. (2001) found was attributed to introductions (intentional and unintentional) of non-native species; range expansions from other regions; and creation of habitat favorable to certain species. Six species (*Carpiodes carpio, Notropis atherinoides, Pimephales promelas, Percopsis omiscomaycus, Microptus punctulatus, and Percina maculata*), previously documented in the drainage were not collected post-impoundment. They cited studies that showed that reservoirs resulted in:

- Little change in overall fish species richness (Rogner and Brinton, 1982);
- Substantial reductions in richness (Ely et al. 1981; Kapasa and Cowx, 1991); and
- Large shifts in dominant species within assemblages (Erman, 1973; Martinez et al., 1994).

Reservoir Fish Communities in Texas

Hubbs (2002) reported that 86 species of fish have been documented from Caddo Lake located in northeast Texas on the Louisiana border. He noted that the lake is "unique for Texas as a relatively undisturbed and biologically diverse ecosystem." It should be pointed out that Caddo Lake is actually a reservoir created and maintained by a dam on Cypress Creek.

Hubbs et al. (1991) reported that 247 species of fish are known to inhabit freshwaters of Texas. However, 78 of these species are marine or estuarine that may also be found in freshwater. The remaining 169 species would be considered restricted to freshwater habitats.

Dolman (1990) classified 132 large reservoirs in Texas based on fish species associations. He reported that 104 fish species were collected from 132 reservoirs, nearly 62 percent of freshwater fish species in the state. The following 20 species were found to be generally abundant in Texas reservoirs:

Aplodinotus grunniens
Dorosoma cepedianum
Dorosoma petenense
Gambusia affinis
Ictalurus melas
Ictalurus punctatus
Lepomis auritus
Lepomis microlophus
Lepomis cyanellus
Lepomis gulosus
Lepomis humilis
Lepomis macrochirus
Lepomis megalotis
Menidia beryllina
Micropterus salmoides
Notemigonus crysoleucas
Percina caprodes
Pimephales vigilax
Pomoxis annularis
Tilapia aurea

Expected Fish Communities in Lower Bois d'Arc Creek Reservoir

Lower Bois d'Arc Creek Reservoir would probably fall into the Dolman (1990) "Group 3: Longear sunfish" category. This group of 27 reservoirs located in central to northeast Texas was characterized by combinations of longear sunfish, bullhead minnow, freshwater drum, logperch, and orange spotted sunfish as the domanant species.

Other common fish expected in the proposed Lower Bois d'Arc Creek Reservoir would include gizzard shad, threadfish shad, bluegill, redear sunfish, channel catfish, white bass, largemouth bass and others.

Mussel Species

Detrimental impacts to mussel species resulting from construction of the proposed Lower Bois d'Arc Creek Reservoir project are not expected to occur. According to available literature, it appears that all species identified during site visits can and do adapt to life in a lake environment.

5.1.1.2 Expected Water Quality in the Reservoir

Reservoirs alter the water quality of a stream system by increasing the surface area, depth and volume of water at the site, thereby changing the physical, chemical and biological processes of the aquatic ecosystem. For example, in a reservoir, current velocities decrease, sediment particles fall from suspension, and water that may have exhibited low transparency as a flowing stream might become relatively clear. The retention of water in a reservoir, as compared to the transient nature of stream water at any given site, influences the types of physical and chemical processes that will occur in a reservoir.

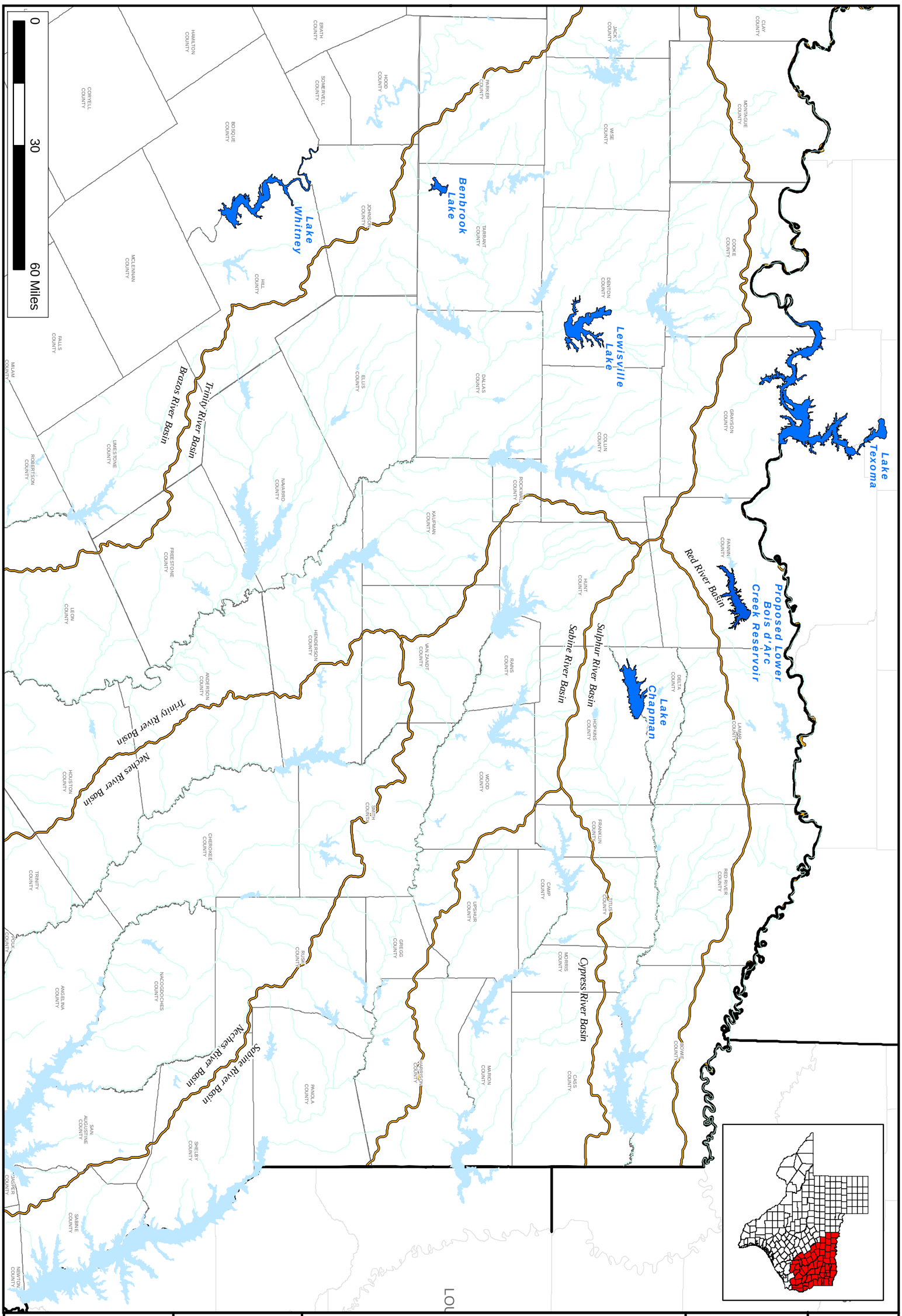
By virtue of their depth and lack of movement compared to a flowing stream, reservoirs in North Texas and elsewhere often stratify during the late spring through fall as surface water warms at a faster rate than the deeper water. As the summer progresses and the surface water becomes markedly warmer and relatively lighter than the deeper water, a strong temperature gradient known as a thermocline may develop and become a barrier separating the surface water from the deeper water. The layers above and below the thermocline are known as the epilimnion and the hypolimnion, respectively. The epilimnion tends to be well aerated due to processes such as wind mixing and oxygen generated by phytoplankton, but the hypolimnion can become anoxic due to the lack of mixing with epilimnetic waters and consumption of dissolved oxygen by organisms residing below the thermocline. The anoxic condition in the hypolimnion results in the release of sulfides and other reduced compounds and is generally undesirable for gamefish and other aquatic species that require adequate dissolved oxygen concentrations to survive. This stratified condition typically begins to break down in the fall as epilimnetic waters cool in response to reduced solar heating and atmospheric cooling. As the epilimnetic and hypolimnetic water temperatures begin to equalize, wind movement

across the surface can effectively mix the entire water body, restoring dissolved oxygen throughout the water column.

In order to estimate the magnitude and timing of stratification in the proposed reservoir, records of temperature and dissolved oxygen with depth in several North Texas reservoirs were examined. These lakes were selected based on proximity to the proposed Lower Bois d'Arc Creek Reservoir site, geographic latitude with respect to the proposed site, and availability of depth related dissolved oxygen and temperature data. No single reservoir site had complete monthly coverage, so the selected sites were identified to provide an estimate of dissolved oxygen and temperature with depth over an entire year. The selected sites included Jim Chapman Lake (also known as Cooper Lake; USGS 331938095374701), Lake Texoma (USGS 334910096342700), Lake Whitney (USGS 315203097222601), Lewisville Lake (USGS 330419096575401), and Benbrook Lake (USGS 323858097265601). The locations of these reservoirs relative to the proposed Lower Bois d'Arc Creek Reservoir site are depicted in Figure 5.1.

Jim Chapman Lake, located northwest of Sulphur Springs, TX, is in close proximity to the proposed Lower Bois d'Arc Creek Reservoir and has similar size, depth, and geology. Accordingly, Jim Chapman Lake data, where available, were used to estimate dissolved oxygen concentrations and temperature in the proposed Lower Bois d'Arc Creek Reservoir Table 5.1. For the months of April, October, November, and December, Jim Chapman Lake USGS data were not available. Consequently, USGS data from the other lakes were used to characterize these months, as noted in Table 5.1.

Based on data from these reservoirs, there is little to no thermocline evidenced in the wetter cooler months (October to April). As temperatures begin to increase in the month of May, existing North Texas lakes begin to exhibit temperature differences with depth along with decreased dissolved oxygen concentration with depth. Similar conditions would be expected in the Lower Bois d'Arc Creek Reservoir. Low dissolved oxygen levels may occur in the proposed reservoir in deeper water during the very hot summer months. By September, dissolved oxygen levels would begin to increase such that by October the levels would exceed the High Aquatic Life criertion of 5.5 mg/L throughout the reservoir pool.



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North Texas Municipal Water District
Proposed Lower Bois d'Arc Creek Reservoir

Proposed Lower Bois d'Arc Creek Reservoir and Other North Texas Reservoirs

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Figure

Table 5.1 USGS Water Quality Data (Temperature and Dissolved Oxygen Concentrations) for Selected North Texas Lakes

		Depth (ft)	Mean Temperature	Mean Dissolved Oxygen
Lake Chapman	January	1	7.3	10.1
		10	7.3	10.0
		20	7.3	10.0
		30	7.3	9.9
		37 - 43	7.3	9.6
Lake Chapman	February	1	11.3	10.5
		10	11.0	10.4
		20	11.0	10.3
		30	11.0	10.4
		37 - 43	11.0	10.5
Lake Chapman	March	1	12.3	9.8
		10	11.8	9.1
		20	11.8	9.0
		30	11.8	8.8
		37 - 43	11.6	8.7
Lake Texoma	April	1	15.3	8.1
		10	15.3	8.2
		20	15.2	8.2
		30	15.2	8.3
		37 - 43	15.3	8.3
Lake Chapman	May	1	24.1	8.2
		10	22.7	7.3
		20	22.0	5.7
		30	21.3	4.6
		37 - 43	20.9	2.6
Lake Chapman	June	1	27.8	7.8
		10	27.7	7.7
		20	27.2	7.0
		30	25.8	3.7
		37 - 43	23.2	0.3
Lake Chapman	July	1	30.0	5.0
		10	29.5	2.6
		20	28.5	0.3
		30	26.0	0.4
		37 – 43	24.0	0.8

Table 5-1 USGS Water Quality Data (Temperature and Dissolved Oxygen Concentrations) for Selected North Texas Lakes (Continued)

		Depth (ft)	Mean Temperature	Mean Dissolved Oxygen
Lake Chapman	August	1	30.2	7.0
		10	29.6	6.0
		20	29.0	4.6
		30	28.4	1.4
		37 - 43	27.5	0.1
Lake Chapman	September	1	27.3	6.5
		10	26.8	4.9
		20	26.5	3.5
		30	26.0	3.2
		37 - 43	25.3	2.4
Lake Whitney	October	1	19	7.1
		10	19	7
		20	19	7
		30	19	7
		37 - 43	19	7
Lake Lewisville	November	1	15.8	7.8
		10	15.8	7.7
		20	15.8	7.8
		30	15.8	7.8
		37 - 43	15.8	7.8
Benbrook Lake	December	1	11	8.4
		10	11	8.3
		20	11	8.3
		30	11	8.2
		37 - 43	11	8.2

5.1.1.3 Geomorphology and Sediment Transport

All reservoirs created by dams on stream channels are subject to sediment inflow and deposition. When a stream is stilled behind a dam, most of the sediment contained in the water will sink to the bottom of the reservoir, making it a very efficient sediment trap. Every reservoir loses water storage to sedimentation, although the rate at which this happens varies greatly. The rate of reservoir sedimentation depends mainly on the size of a reservoir relative to the amount of sediment flowing into it. Large reservoirs in the US lose storage capacity at an average rate of around 0.2 percent per year (McCully 1996).

Sediment accumulation in a reservoir is usually distributed below the top of the conservation pool or normal water surface. Once sediment inflow enters the reservoir it is distributed by depth and by longitudinal profile distance. Studies show that sediment deposition is not necessarily confined to the lower storage increments of the reservoir (US Department of Interior, Bureau of Reclamation 2006; Strand and Pemberton 1982; US Department of Agriculture 1978). Delta deposits are another issue regarding reservoir sediment deposition. This causes the distribution of sediment longitudinally in the extreme upstream portion of the deposition profile. Predicting delta development within a reservoir is very complex because of variables, including operation of the reservoir, sources of sediment, and hydraulics.

The potential sources of sediment to the proposed Lower Bois d'Arc Creek Reservoir include incised channel erosion (bed and banks) and watershed erosion (sheet, rill, ephemeral gully). With the reservoir in place, channel bed and bank sediment yields should decrease as the hydraulic gradients along the tributaries and upper Bois d'Arc Creek decreases. A considerable portion of the incised and highly degraded sections of Bois d'Arc Creek and tributaries is expected to be inundated by the conservation pool, thereby reducing the amount of sediment inflow and deposition that is currently being contributed from these segments. Sediment yields from the watershed will be dependent on the land use and land cover within the remaining watershed, in the areas surrounding and upstream of the proposed reservoir.

5.1.2 Potential Downstream Effects

The flow regime downstream of a reservoir can be substantially different than before the reservoir was built. These changes can be mitigated by establishing release criteria from the reservoir.

5.1.2.1 Impacts on Fish

The change in flow regime downstream from the proposed reservoir could negatively impact fish species with narrower habitat requirements (Freeman 2005). Species sensitive to reservoir operations are those that use temperature or flow for reproductive cues, substrate-specific spawners, and those that depend on higher flows for egg dispersal (i.e., pelagic spawners) (Freeman 2005). Additional impacts may include nutrient limitation (as impoundments can retain nutrients), water temperature regulation, and loss of stream connectivity. Biological interactions may be secondarily affected as decreased instream habitat diversity and changes to water quality may increase competition, predation, and alter community structure (Mosier and Ray 1992). In warmwater systems, cold-water releases from the bottom of a reservoir can impact fisheries below dams (Pasch et al. 1980), as reproduction and growth of some warmwater species are dependent on temperature.

In a study of impacts of reservoirs and water withdrawals, Freeman (2005) analyzed data from 27 sites and found that out of 45 fluvial specialist fish species, about one to five species were "lost" at sites downstream from reservoirs compared to sites with direct stream withdrawals.

Kinsolving and Bain (1993) found that there was "spatial recovery gradient" for fish assemblages downstream of a hydroelectric dam in Alabama. They observed a longitudinal gradient of increasing abundance and richness of fluvial specialists downstream of the dam, but no spatial gradient was observed for macrohabitat generalists. If their longitudinal gradient hypothesis is correct, then at some point downstream there would be a recovery of fluvial specialists.

Given that most fish species collected from Bois d'Arc Creek during the instream flow study are mesohabitat generalists, with the possible exception of a few cyprinids and percids, then it is likely that there would be little impact to the downstream fish community and biodiversity as long as there is water flowing in the creek. It could be speculated that providing a perennial flow, especially during common spawning months, could increase fluvial specialist populations or the number of species. It could also provide better habitat for generalist species.

The proposed flow regime for Bois d'Arc Creek downstream of the proposed dam would provide a sound ecological environment that would support the existing and future aquatic ecosystem environment, barring unforeseen actions by others. The flow regime proposed would maintain flowing water in the creek channel, provide for stream sediment transport processes, maintain existing aquatic habitat and communities, and protect water quality.

5.1.2.2 Riparian Vegetation

Vegetation cover in and along channels downstream of dams has been shown to remain the same or increase following the placement of a dam. In the case of the Canadian River downstream from Sanford Dam (Lake Meredith) in Texas, virtually no releases of any magnitude have been made since the dam closure in 1964, and there has been a major increase in vegetation cover (Williams and Wolman 1984). Due to the scarcity of major tributaries introducing flow that would uproot vegetation, the effect is still very pronounced 120 kilometers downstream from the dam. It should be noted that the annual precipitation at Lake Meredith is less than one-half of the Bois d'Arc Creek site. The reduction in overbanking events can allow stream bank vegetation to become more permanently established. Chin et al. (2002) found that channel vegetation cover along Yegua Creek downstream of the Somerville Dam increased as a result of increased duration of low flow throughout the summer months due to reservoir releases when the channel historically experienced no flow conditions prior to dam construction.

For the Lower Bois d'Arc Creek Reservoir, stream bank vegetation is expected to follow the same trend and increase after the dam is built. The reduction in large erosive flow events would allow vegetation to become readily established along the banks. Increases in vegetation cover would provide multiple functions following the proposed impoundment of ther Bois d'Arc Creek. In incised channels, riparian forest buffers can help increase stream bank stability because of the deeper and denser rooting habits of trees than those of crops or grasses (Lee et al. 2000; Zaimes et al. 2006). Plants that become established on the bank slopes would serve the same function, with their roots reinforcing the bank material, making it more resistant to erosive forces. Additionally, plant matter on bank faces deflects flowing water away from the banks, effectively reducing shear stress exerted on the banks by flowing water.

5.1.2.3 Fluvial Geomorphology

Impoundments can alter downstream flows by possibly reducing base flows as well as disrupting magnitude and frequency of high flow events. This can affect stream geomorphology in reference to aquatic habitat, including filling interstitial spacing in gravel substrates, stabilizing and narrowing channels, and reducing the formation of point bars, oxbows, and secondary channels (Poff et al. 1997).

Channel incision commonly occurs in the area directly downstream of a dam (Wolman 1967; Williams and Wolman 1984; Annandal et al. 1995; Collier et al. 2000). River channels immediately downstream of reservoirs typically experience a decrease in sediment inflows, contributing to the channel incision. The distance downstream that a channel is affected by a dam is typically dependent on the magnitude and duration of uncontrolled spills and releases and the contribution of flow by downstream tributaries (Park 1977; Petts 1979).

The placement of a dam on Bois d Arc Creek would effectively cut off the sediment supply from the upstream channel to the lower reaches. The lack of sediment load will increase the tendency of the channel downstream of the reservoir to erode and incise during high flow events. With the dam in place, there would be fewer highly erosive flow events. Release criteria should be prescribed that will maintain the existing geomorphic features and remove accumulated fine sediments from those features while reducing the potential for additional erosion or downcutting below the reservoir.

5.1.2.4 Water Quality Below the Proposed Reservoir Without an Instream Flow Regime

The quality in Bois d'Arc Creek downstream of the proposed dam without a proposed instream flow regime would be dictated by seepage from the dam, runoff from the watershed downstream from the dam, and baseflow in the channel. As noted from the review of existing water quality data, dissolved oxygen concentrations in the stream are

dependent upon temperature and flow. The lower the flow, especially during warm weather, the more depressed dissolved oxygen will be in the creek. Thus, the stream reach closest to the dam would be more likely to suffer from suppressed concentrations, but the effect would be expected to diminish downstream from the dam as baseflow sources and drainage area increase.

5.2 Development of Environmental Flow Criteria

Site-specific environmental flow criteria for the proposed Lower Bois d'Arc Creek Reservoir have been identified to support a Sound Ecological Environment, as defined in Chapter 1 of this report. This section briefly describes how the four components of the study (hydrology and hydraulics, fluvial geomorphology, biology and water quality) were integrated in developing these flow criteria. More detailed information may be found in the Appendices that discuss each of these components.

RECOMMENDED ENVIRONMENTAL FLOW RELEASES

Subsistence flow of 1 cfs.
- **To maintain minimal water quality levels during extreme drought.**

Base flows of 3 cfs and 10 cfs
- **To maintain connectivity of habitats, soil moisture, and provide suitable water quality.**

Pulse releases of 50 cfs, supplement naturally occurring pulse events.
- **To move sediments for habitat maintenance**

5.2.1 Flow Components

The Texas Instream Flow Program (TIFP) divides flows into four components or classifications (TCEQ, 2008):

- *Subsistence flow* – minimum streamflow during extreme drought conditions. During times of subsistence flow one would expect elevated temperatures, increased concentrations of dissolved material in water, and sediment deposition. For Bois d'Arc Creek, a subsistence flow criteria should be designed to maintain minimal water quality levels to limit impacts on aquatic organisms.
- *Base flow* – "normal" flow conditions found between storm events. For Bois d'Arc Creek, base flow criteria should be designed to maintain connectivity between a variety of habitats to support the natural community, maintain soil moisture, and provide suitable water quality.
- *High flow pulses* – short-duration, high flows within the stream channel resulting from a storm event. For Bois d'Arc Creek, high flow pulse criteria should be designed to maintain channel characteristics, move sediments to maintain habitats and restore water quality after periods of low-flow.
- *Overbank flows* – high-flow events that cause flow beyond the riverbanks. Currently overbanking flows are relatively frequent on the Bois d'Arc Creek watershed and follow and precede channel-degrading bank-full flows. Overbank

flow criteria were not developed for Bois d'Arc Creek in order to minimize potential bed and bank erosion and to limit property damage.

Based on the instream flow needs analysis, the following environmental flow releases are proposed for the Lower Bois d'Arc Creek Reservoir:

- During normal and wet conditions, release of a base flow of 10 cfs during the months of April, May and June and 3 cfs during the rest of the year as measured at the FM 409 USGS gage.
- During normal and wet conditions, ensuring that a pulse flow event of at least 50 cfs occurs at FM 409 during the spring season (April through June) and at the end of the summer (September to October).
- Release of a subsistence flow of 1 cfs during extreme, prolonged drought. Pulse releases are not required or proposed during subsistence periods. Extreme drought can be identified using reservoir storage. At this time it is proposed that subsistence flows be released when the reservoir content is less than 40 percent of the conservation storage. If it is found that subsistence conditions occur more than 10 percent of the time, then the storage trigger may be adjusted.

Consistent with the Inter-Agency Team discussions, the proposed criteria do not include deliberate overbanking flows. The hydrologic regime of Bois d'Arc Creek has been so dramatically altered by channelization and straightening with the resulting channel down-cutting and increased erosion, that artificial high pulse flow releases would be counterproductive to maintaining a Sound Ecological Environment. There are also liability issues connected with making deliberate flood releases. For these reasons, the TCEQ has stated that the State of Texas will not issue water rights permits with deliberate overbank release requirements.

The proposed flow regime is substantially different from the current flow regime. Specifically, pulse flow events will be substantially different in magnitude. The reach below the reservoir will become a perennial stream during all but extended droughts, whereas now it is an intermittent stream with extended periods of little to no flow. A flow regime that mimics current conditions would only exacerbate the on-going erosion and frequent habitat destruction currently observed in the watershed and, thus, would not be supportive of a Sound Ecological Environment. The proposed flow regime is expected to stabilize the stream downstream of the reservoir so it can reach equilibrium, thereby providing support for a Sound Ecological Environment.

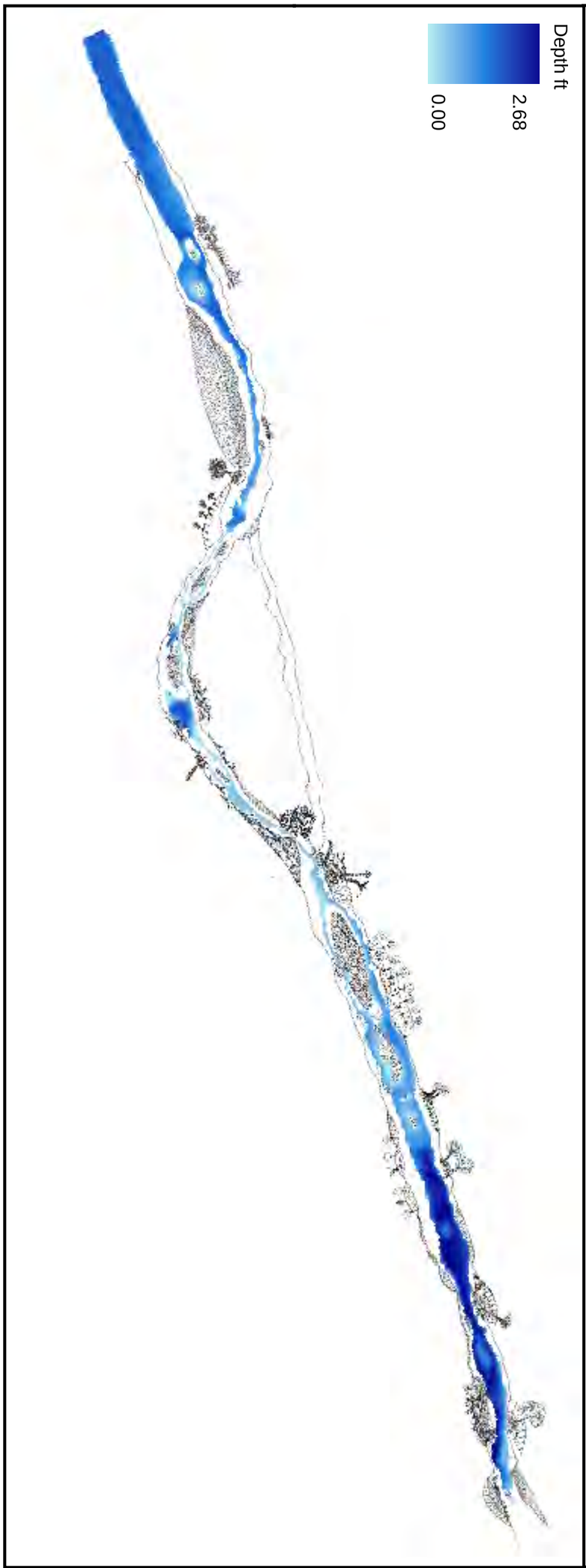
5.2.2 Base and Subsistence Flows

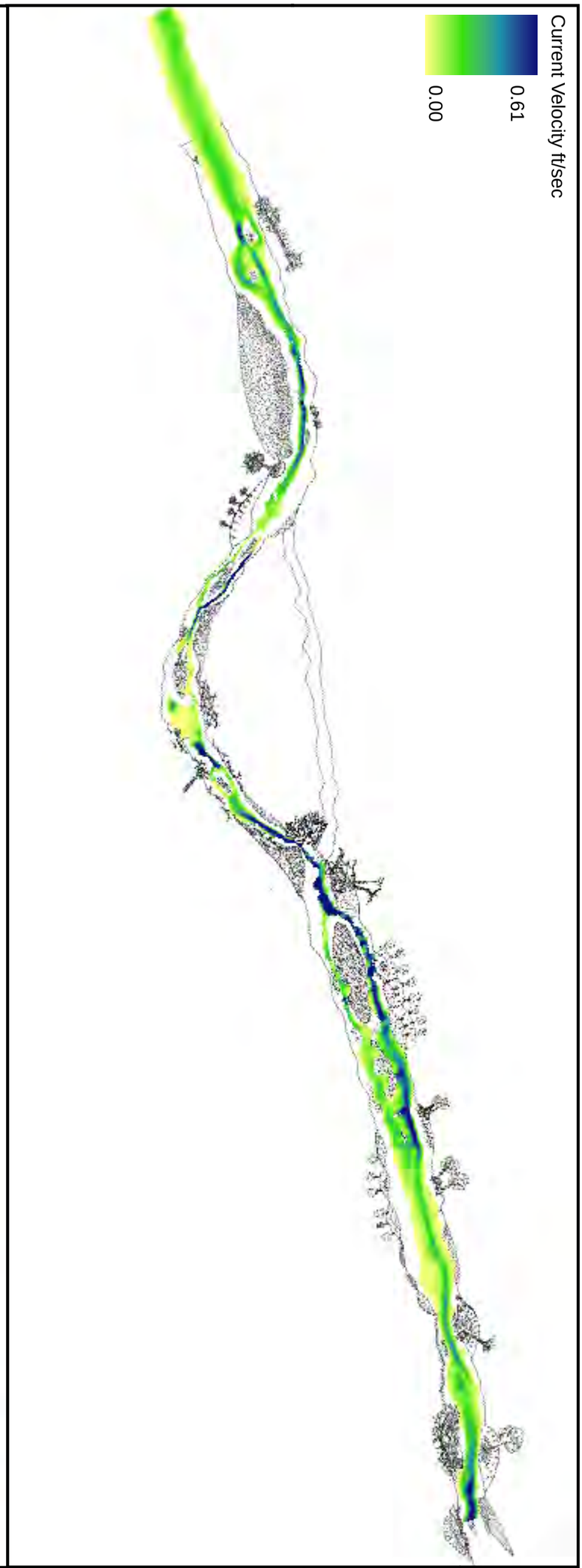
The recommended base flow of 3 cfs is based on River2D modeling at the FM 409 study reach. This modeling determined that flows between 2 and 3 cfs would achieve longitudinal stream connectivity, with modeled pool habitats connected by run-riffle

habitats (Figure 5.2). This connectivity is important for maintaining fish passage, aquatic habitat, and suitable water quality (i.e., dissolved oxygen and temperature). At a 3 cfs discharge, physical attributes include a maximum water depth of 2.68 ft and current velocity of 0.61 ft/sec. The base flow of 3 cfs has the potential to transport approximately 0.9 tons/day of very fine sand, silt, and clay. A base flow of 10 cfs is recommended for April, May and June. Figure 5.3 shows the modeled flow depth and current velocity at this flow.

The additional base flow at this time of year would provide expanded habitat during the spawning period of the dominant species in Bois d'Arc Creek (Figure 5.4). It would also provide additional depth for fish passage during spawning season and maintenance of dissolved oxygen levels. The 10 cfs base flow release has the potential to transport 5.3 tons/day of sand, silt, and clay.

Subsistence flow recommendations are proposed based on maintaining water quality requirements – mainly temperature and dissolved oxygen, and maintaining soil moisture in the creek channel. A flow of 1 cfs does not maintain full lateral connectivity. However, this flow should be sufficient to maintain some key habitats and pool refugia. (i.e., prevent dewatering) The subsistence flow of 1 cfs has the potential to transport approximately 0.26 tons/day of silt and clay.





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North Texas Municipal Water District

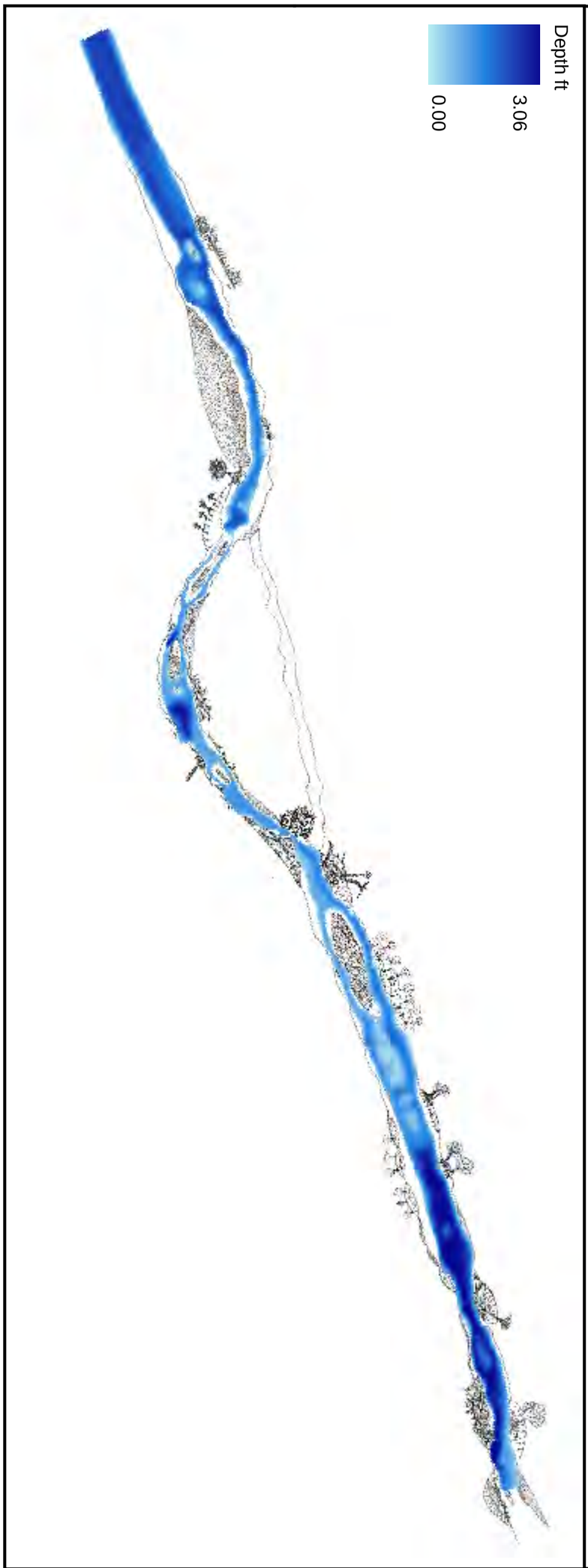
Proposed Lower Bois d'Arc Creek Reservoir

F.M. 409 Current Velocity and Depth
3 CFS

FN JOB NO	NTD06128
FILE	5.2_Depth_CV_3.mxd
DATE	April 2010
SCALE	1:1,200
DESIGNED	MJA
DRAFTED	MJA

5.2

Figure



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North Texas Municipal Water District

Proposed Lower Bois d'Arc Creek Reservoir

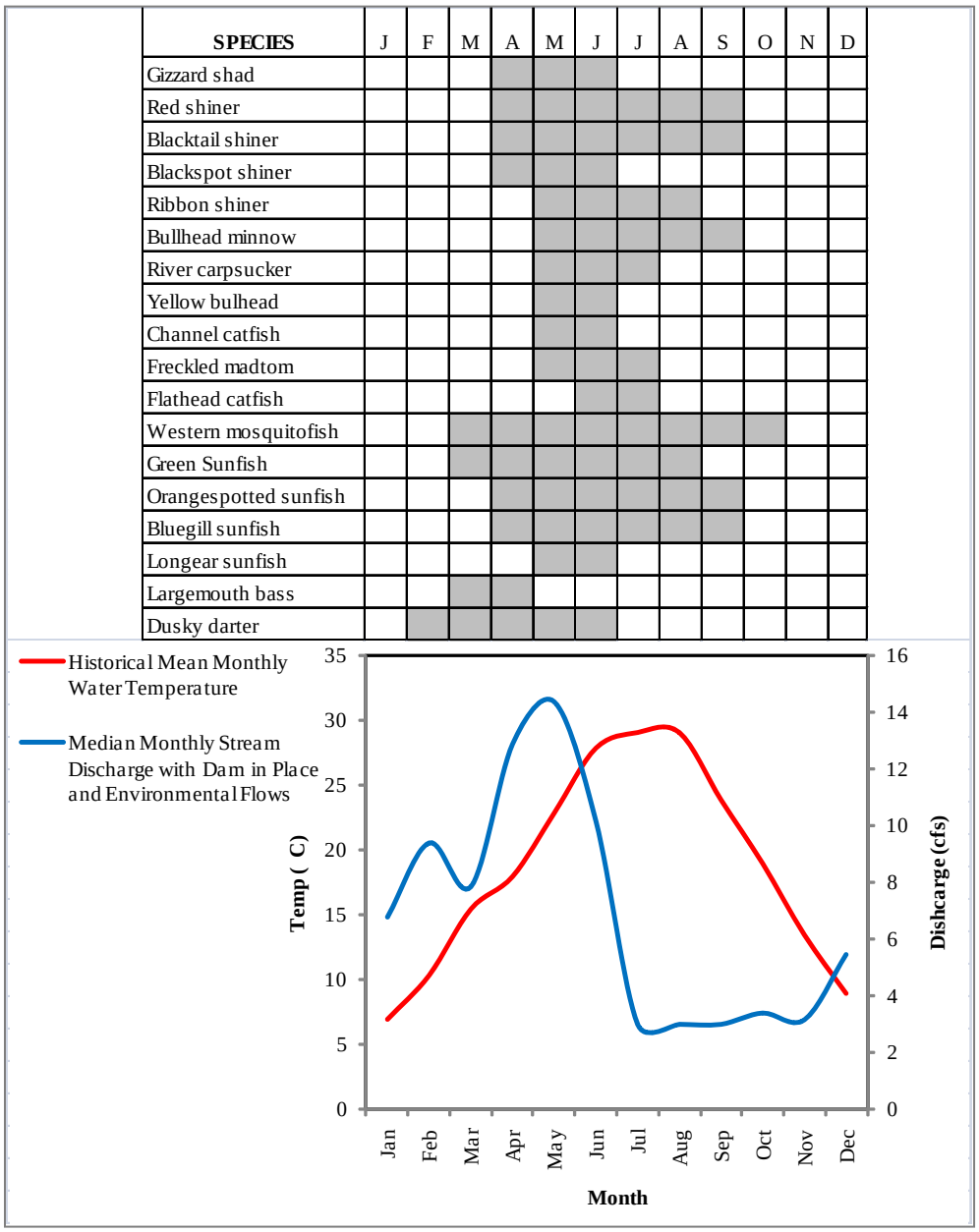
F.M. 409 Current Velocity and Depth
10 CFS

FN JOB NO	NTD06128
FILE	5.3_Depth_CV_10.mxd
DATE	April 2010
SCALE	1:1,200
DESIGNED	MJA
DRAFTED	MJA

5.3

Figure

Figure 5.4 Reproductive Timing of Dominant Species at Bois d'Arc Creek with Mean Monthly Temperature vs. Median Monthly Stream Discharge



5.2.3 Pulse Flows

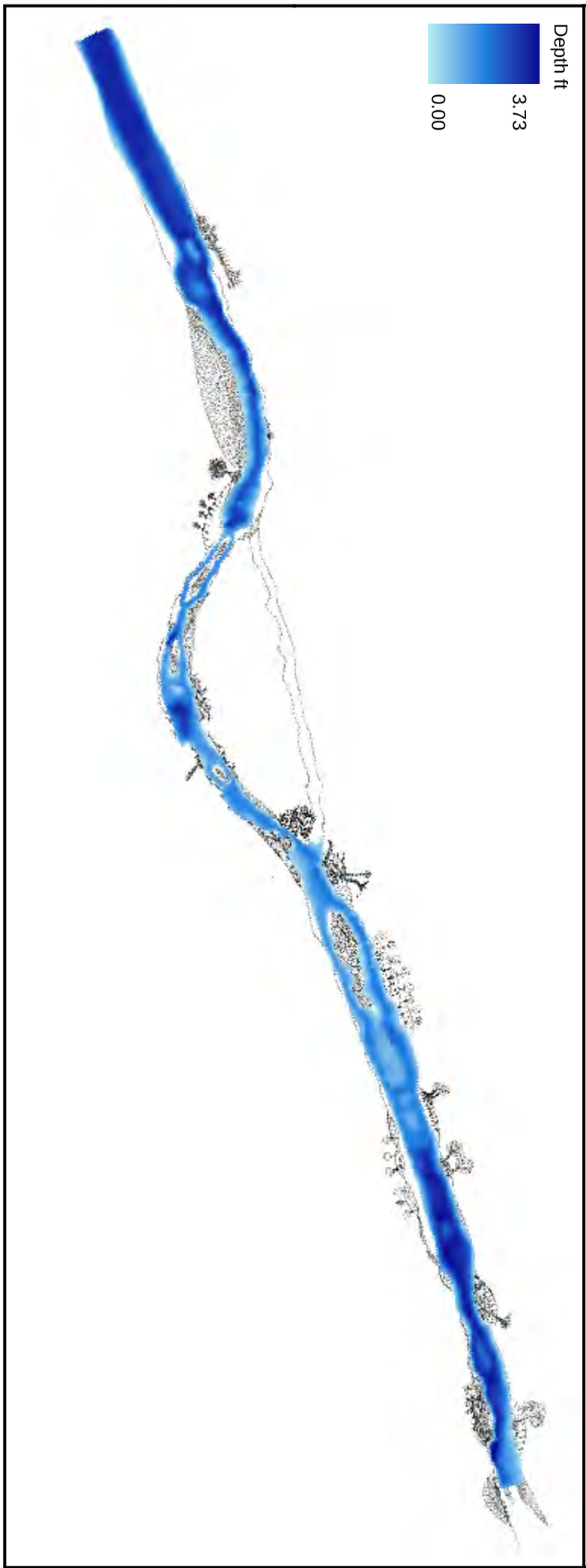
Pulse flows improve water quality, maintain and improve riffle habitat, remove surficial fine sediment deposits, restore and enhance pool habitat, and maintain active channel width and topographic diversity (Kondolf and Wilcock 1996). Figure 5.5 shows the modeled flow depth and current velocity at 50 cfs. Sediment transport analyses and field

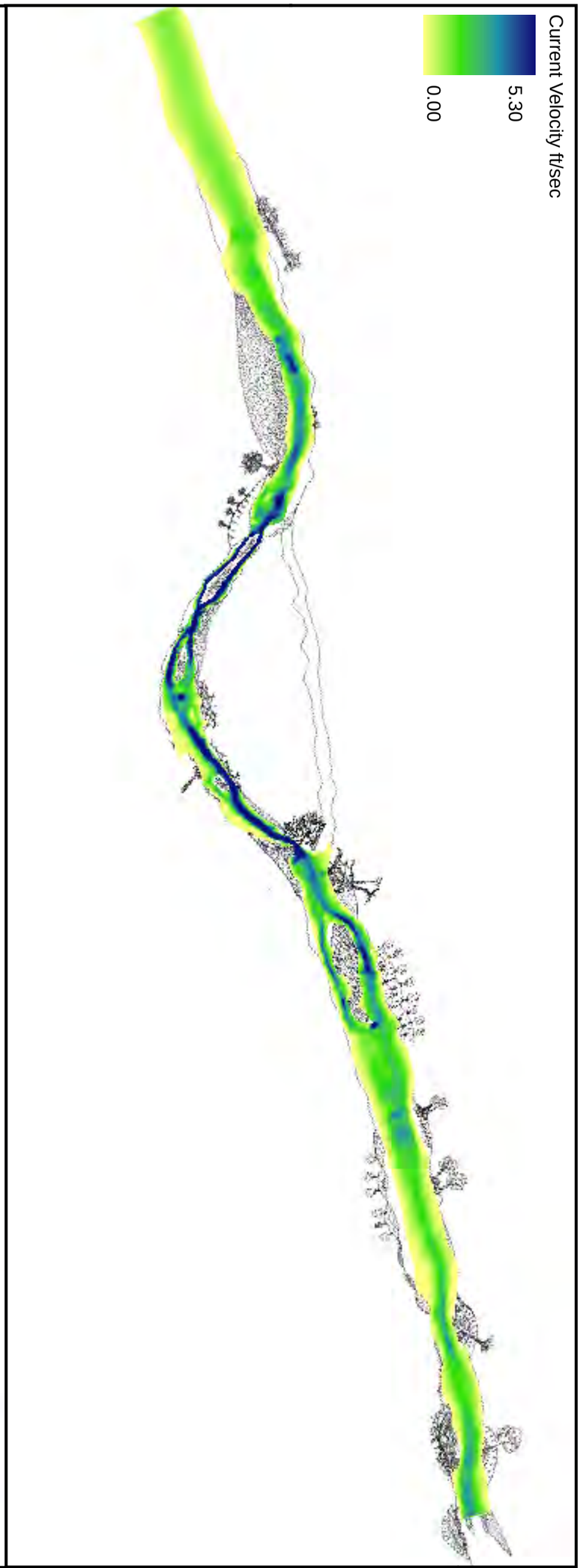
observations indicate that pulse a flow of 50 cfs is sufficient to move the bed material and flush accumulated fine sediment while maintaining the integrity of gravel beds.

Pulse flow releases are proposed during two seasons each year, if needed due to the absence of natural pulse flow events.

The April to June pulse event is designed to coincide with the spawning season of dominant fish species in Bois d'Arc Creek. The September to October pulse event is designed primarily to flush out the stream, improving water quality and removing sediment. It may also serve as a spawning cue for late-season spawners, such as red shiner, blacktail shiner, bullhead minnow, western mosquito fish, orange spotted sunfish and bluegill.

Currently in the Bois d'Arc Creek watershed the frequent occurrence of very high pulse flows impacts the development of aquatic habitat. Currently these habitats are replaced to a limited extent by sediment and large woody debris from upstream. With the reservoir in place the supply of sediment and large woody debris in the reach below the dam will be limited, exacerbating the potential negative impacts of high flows on habitat. Although the magnitude of pulse events will be reduced, events higher than 50 cfs can and will occur with the reservoir in place. Runoff from the watershed below the reservoir will produce pulse events, and spills from the reservoir will provide flows with sufficient energy to re-work habitats and remove large woody debris. The proposed flow regime is expected to allow the establishment of and preservation of relatively long-lived habitats, while less frequently occurring larger events will perform the "house cleaning" that is needed from time-to-time in every habitat. In other words, the new flow regime should help support a Sound Ecological Environment.





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F.M. 409 Current Velocity and Depth
50 CFS

FN JOB NO	NTD06128
FILE	5.5_Depth_CV_50.mxd
DATE	April 2010
SCALE	1:1,200
DESIGNED	MJA
DRAFTED	MJA

5.5

Figure

5.3 Expected Downstream Conditions with Proposed Flow Regime

5.3.1 Hydrologic Modeling

The proposed release criteria were programmed into a modified version of the RiverWare model that includes Lower Bois d'Arc Creek Reservoir. Figure 5.6 shows the model layout. (The FM 1396 gage would be inundated by the reservoir and was not included in the model.) Appendix B contains more detailed output from the modeling.

The release of base flows and subsistence flows are not dependent on inflow into the reservoir – stored water will be used for releases when inflows are less than the proposed criteria. Releases for base flows and subsistence flows would be measured at the reservoir outlet structure. The measurement point for pulse flow criteria would be at USGS gage at FM 409, which is approximately 2.35 river miles downstream of the proposed reservoir.

HYDROLOGIC MODELING

Hydrologic modeling shows higher median flows during low flow periods.

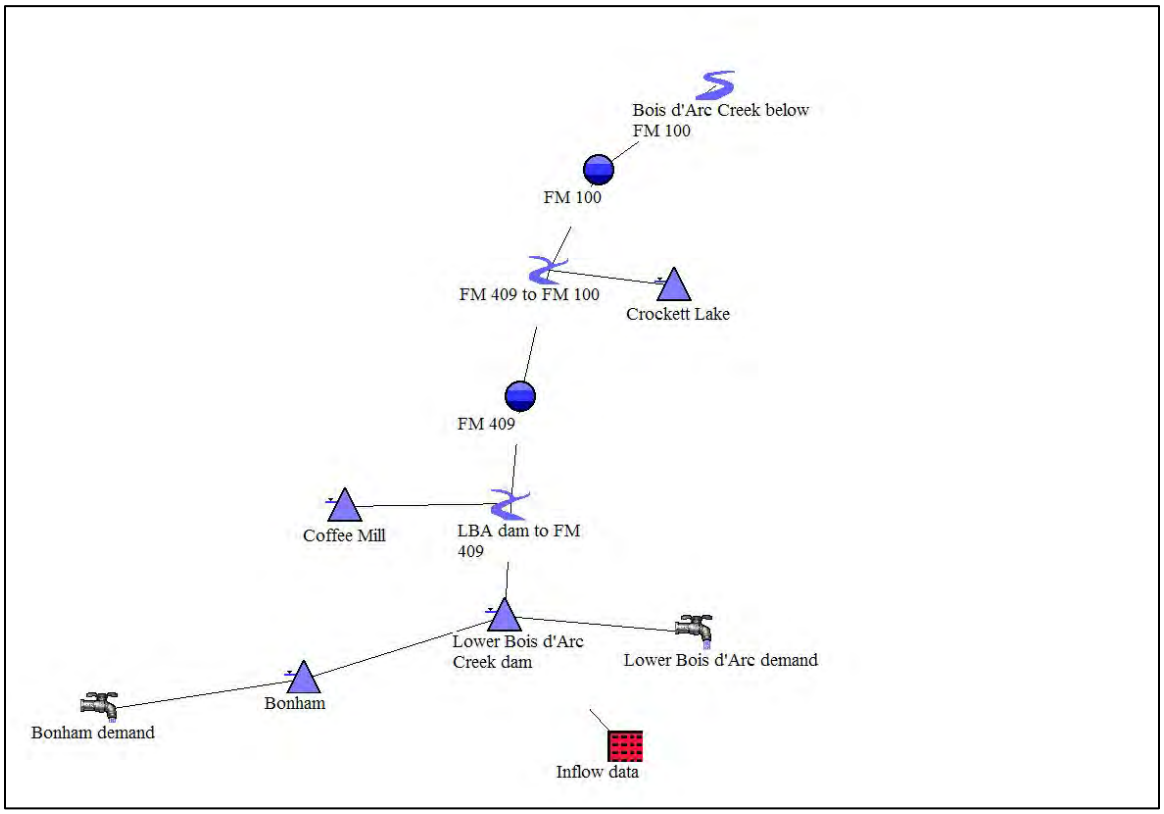
Frequency of pulse events will be reduced. However, modeling shows that watershed below reservoir will continue to produce pulse events.

Reduction in frequency of highly erosive high-flow events will reduce current erosion and downcutting.

New flow regime will help stabilize currently unstable channel.

Release policies will maintain water quality below reservoir.

Figure 5.6 RiverWare Model with Lower Bois d'Arc Creek Reservoir



For modeling purposes, if a flow event of at least 50 cfs has not occurred at the FM 409 gage in the months of April or May, a release is made from the reservoir on June 1. On the first day of the event the flow is set to 50 cfs. On subsequent days the flow is gradually reduced by 75 percent over the next five days until the base flow criteria of 10 cfs is reached, making the pulse a 6-day event. (The 75 percent reduction criterion is based on inspection of historical pulses of similar sizes measured at FM 1396.)

Similarly, if an event with a flow of at least 50 cfs has not occurred at FM 409 during the month of September, a pulse is released on October 1. The first day of the pulse is 50 cfs and declines by 75 percent over the next nine days until the base flow criteria of 3 cfs has been reached, resulting in a 10-day event. Table 5.2 shows the flow for each day of the event. In the model subsistence flows occur when the storage in the reservoir is less than 40 percent of conservation storage (147,043 acre-feet).

Table 5.2 Pulse Release Schedule

	Day	Release (cfs)	
October Pulse	1	50.0	June Pulse
	2	37.5	
	3	28.1	
	4	21.1	
	5	15.8	
	6	11.9	
	7	8.9	
	8	6.7	
	9	5.0	
	10	3.8	

Table 5.3 compares statistics for the modeled flows at the FM 409 gage before the dam is built to flows after the dam is built with the proposed release criteria.

Table 5.4 compares the statistics on environmental flow components at FM 409 before and after construction of the dam. Before construction of the dam, periods of little or no flow occur frequently. After construction of the dam and using the proposed release policy, subsistence flows only occur during extreme drought, and never fall below 1 cfs. With the proposed release policy, the median of base flows is slightly higher in the spring and summer months (April through October) when compared to conditions before the dam is built. During the rest of the year the median is lower with the proposed release policy when compared to the period before the dam was constructed. Peak flows for proposed pulses are substantially less than pre-dam conditions. However, this should be beneficial because the lower flows will be less erosive than current flows.

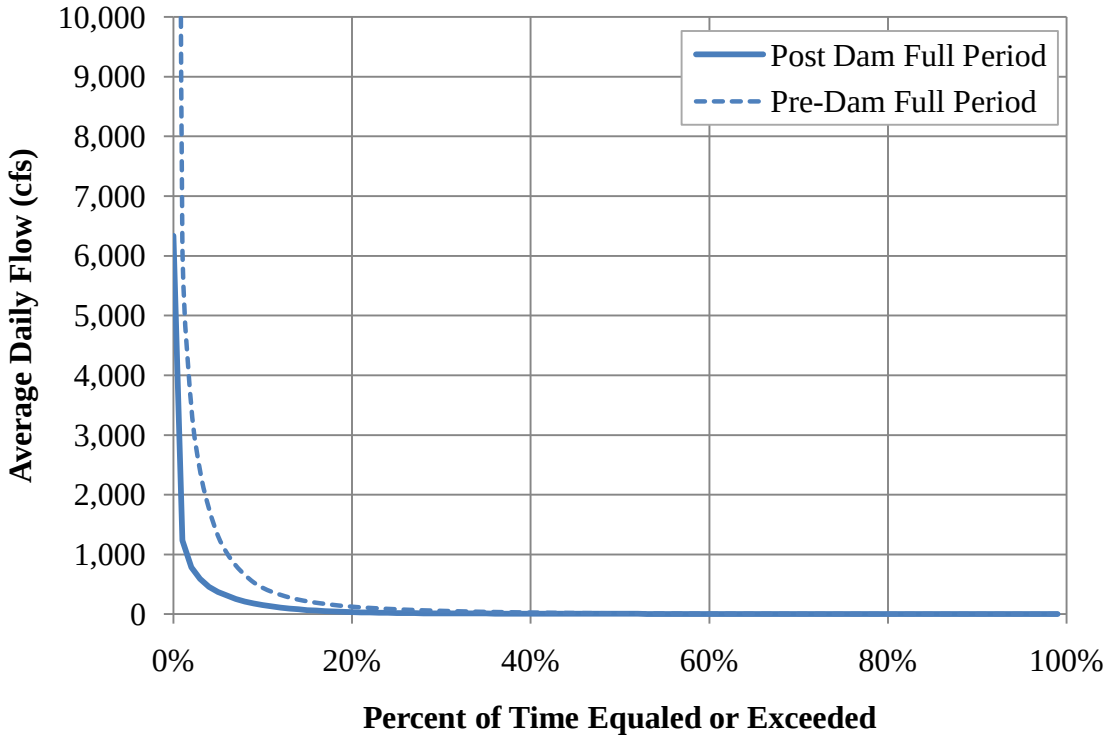
Figure 5.7Figure 5.7 compares the flow-duration curves before and after the dam is built for the full period of data. Note that with the dam, low flows (flows less than the 35th percentile) are higher than the period before the dam. Before the dam, there is no flow about 20 percent of the time, while with the dam the subsistence flow of 1 cfs occurs about 5 percent of the time. There are no periods with zero flow with the proposed release criteria. Flows higher than 3 cfs occur less frequently with the dam in place. Extreme flood events are much lower with the dam, being reduced from 40,000 cfs or more to a maximum of around 6,400 cfs. This implies that flows will be within the current banks most of the time after the dam is built. Currently flows overtop the banks about 1 percent of the time.

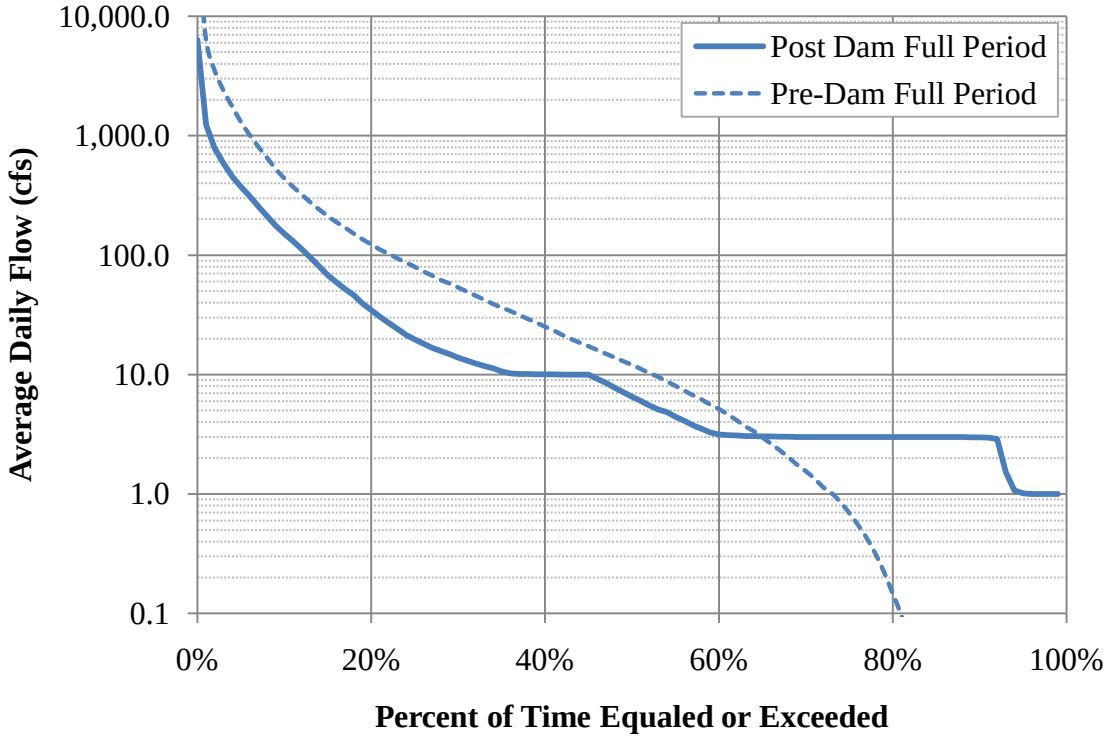
Table 5.3 Comparison of Modeled Flow Statistics at FM 409 - Pre-Dam and Post-Dam with Proposed Releases

Statistic	Pre-Dam				Post Dam with Proposed Operation			
	Full Period	April-June	July-October	November-March	Full Period	April-June	July-October	November-March
Average	313	462	140	364	73	125	22	82
Minimum	0.0	0.0	0.0	0.0	0.5	0.5	0.7	0.7
15%	0.0	2.5	0.0	1.4	3.0	10	3.0	3.0
30%	1.6	9.1	0.0	8.0	3.0	10	3.0	3.1
Median	12	26	0.4	31	6.5	12	3.0	6.2
70%	54	91	4.4	95	14	30	3.1	20
85%	213	357	29	336	67.9	156	9.0	113
Maximum	48,345	48,345	40,047	37,379	6,421	6,421	3,601	4,422

Table 5.4 compares the statistics on environmental flow components at FM 409 before and after construction of the dam. Before construction of the dam, periods of little or no flow occur frequently. After construction of the dam and using the proposed release policy, subsistence flows only occur during extreme drought, and never fall below 1 cfs. With the proposed release policy, the median of base flows is slightly higher in the spring and summer months (April through October) when compared to conditions before the dam is built. During the rest of the year the median is lower with the proposed release policy when compared to the period before the dam was constructed. Peak flows for proposed pulses are substantially less than pre-dam conditions. However, this should be beneficial because the lower flows will be less erosive than current flows.

Figure 5.7 Comparison of Flow Duration at FM 409 Before and After Dam





Even though the release criteria only require two pulses (one in the spring and one at the end of the summer), the average number of pulses per year downstream of the reservoir is not substantially less than before the dam is constructed. After the dam is constructed, pulse flows at FM 409 will originate from four sources:

- Spills from Lower Bois d'Arc Creek Reservoir
- Deliberate releases from Lower Bois d'Arc Creek Reservoir
- Direct runoff into the reach between the dam and FM 409
- Spills from Coffee Mill Lake

Figure 5.8 is the simulated storage trace for Lower Bois d'Arc Creek Reservoir. Lower Bois d'Arc Creek Reservoir is expected to go for long periods of time without spilling, so a significant number of pulse events must come from the other two sources. Coffee Mill Lake is one of two small recreation lakes located on the major tributaries below the proposed dam (Figure 5.6). The other is Lake Crockett. Spills from Coffee Mill Lake enter Bois d'Arc Creek above FM 409, and spills from Lake Crockett enter Bois d'Arc Creek between FM 409 and FM 100. Neither lake is used for water supply. Figure 5.9 is the storage trace for Coffee Mill Lake, and Figure 5.10 is the storage trace for Lake Crockett. Table 5.5 shows the average, minimum and maximum number of days per year that Lower Bois d'Arc Creek Reservoir, Coffee Mill Lake and Lake Crockett spill in the simulation. It also includes the number of days per year that the spills exceed 50 cfs pulse flow. Lakes Coffee Mill and Crockett spill at least once in every year of the simulation. It is these spills, plus the intervening flow below the reservoir, that create the pulse events shown in the simulation.

The frequency of overbanking flows with the dam would substantially less than before the dam based on the flow simulation. Prior to construction of the dam, there are 130 events that exceed the overbank threshold of 6,000 cfs in the 51-year period in the model, or about 3 events per year. With the dam in place, only 2 events with flows greater than 6,000 cfs occur during the same 51-year simulation period, an average of 0.04 per year or about once every 25 years.

Table 5.4 Comparison of Modeled Environmental Flow Components at FM 409 – Pre-Dam and Post-Dam with Proposed Releases

	Pre-Dam				Post Dam with Proposed Release			
Median Flow	**Full Period**	**Nov-Mar**	**Apr-Jun**	**Jul-Oct**	**Full Period**	**Nov-Mar**	**Apr-Jun**	**Jul-Oct**
Subsistence (cfs)	0.00	0.01	0.11	0.00	1.00	1.00	1.00	1.00
Base (cfs)	8.2	15	8.2	2.2	3.1	3.1	10	3.0
Pulse Flows	**Full Period**	**Nov-Mar**	**Apr-Jun**	**Jul-Oct**	**Full Period**	**Nov-Mar**	**Apr-Jun**	**Jul-Oct**
Avg No Per Year	19.6	8.9	5.7	4.9	15.8	7.5	5.1	3.2
Median Peak Flow (cfs)	223	329	299	88	96	122	111	50
Avg Duration (days)	7	7	7	6	7	7	7	7
Flood Flows	**Full Period**	**Nov-Mar**	**Apr-Jun**	**Jul-Oct**	**Full Period**	**Nov-Mar**	**Apr-Jun**	**Jul-Oct**
Avg No Per Year	2.55	1.16	0.98	0.41	0.04	0.00	0.04	0.00
Median Peak Flow (cfs)	11,496	10,927	12,184	11,404	6,379	-	6,379	-
Avg Duration (days)	14	13	13	15	23	-	23	-

Figure 5.8 Simulated Lower Bois d'Arc Creek Reservoir Storage

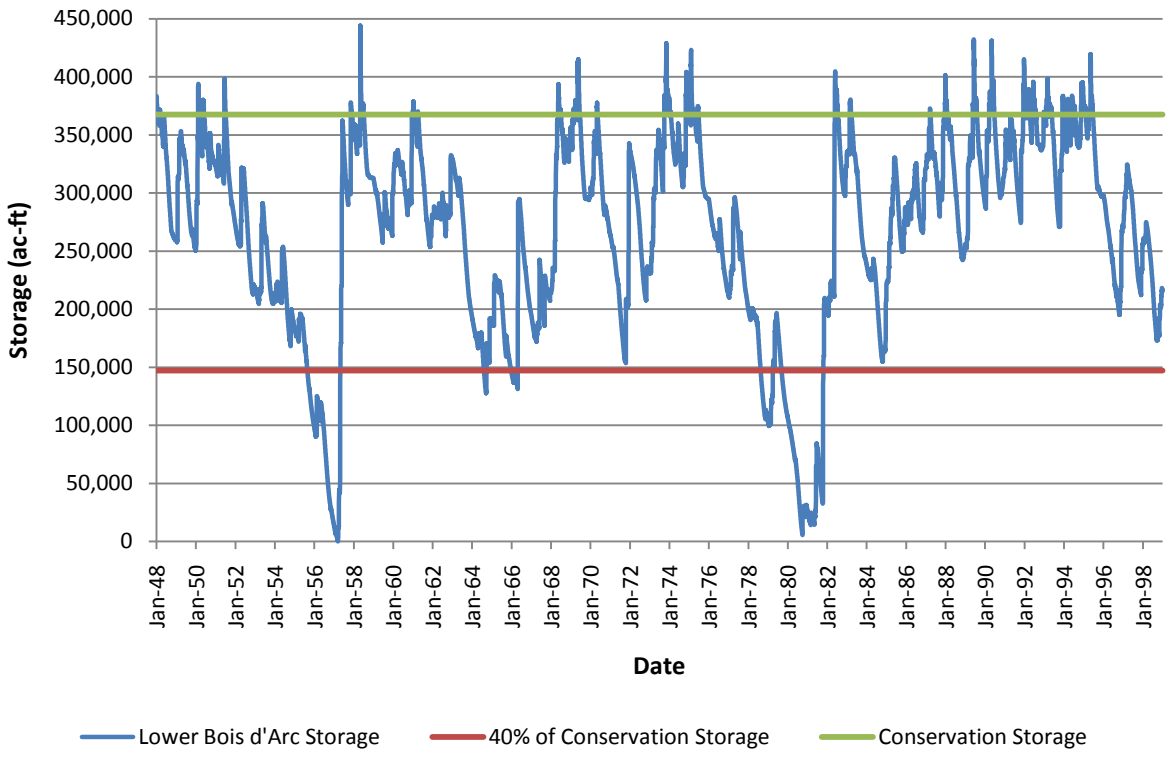


Figure 5.9 Simulated Coffee Mill Lake Storage

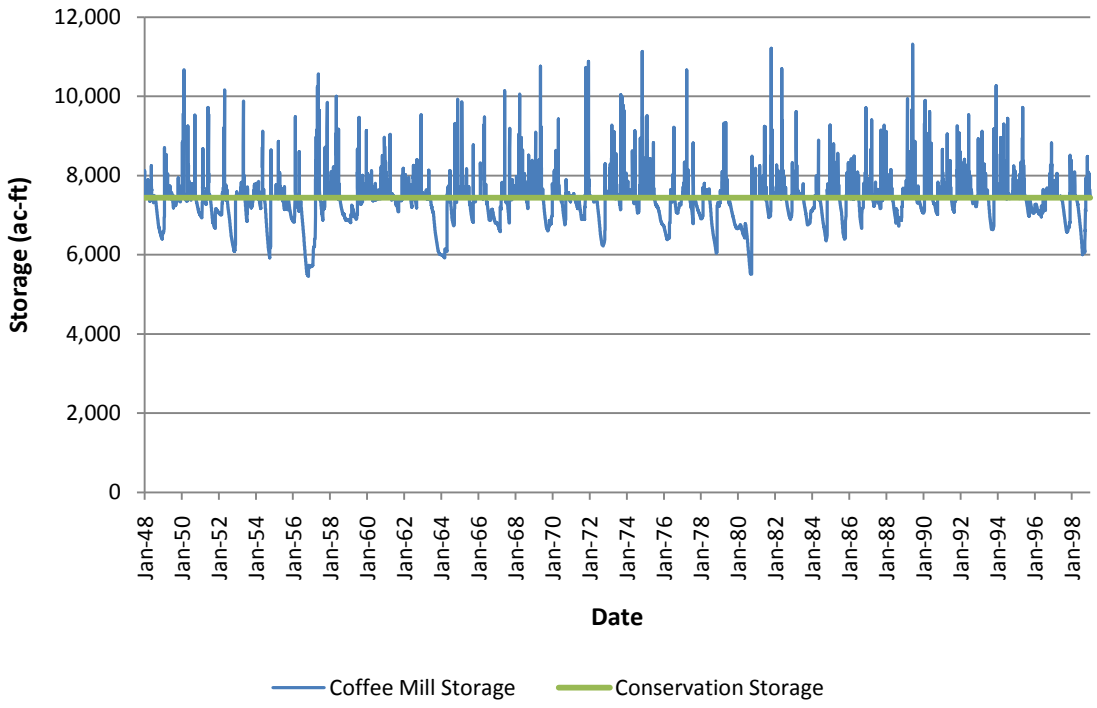


Figure 5.10 Simulated Lake Crockett Storage

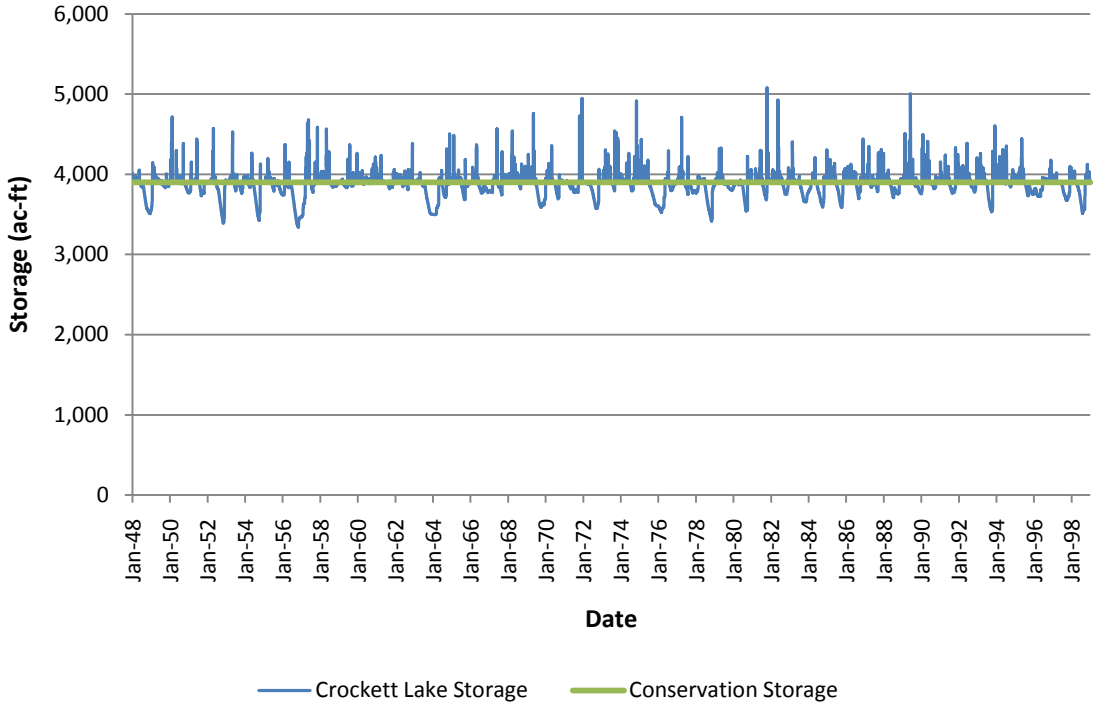


Table 5.5 Number of Reservoir Spill Days per Year in Simulation

Statistic	Lower Bois d'Arc Creek Reservoir		Coffee Mill Lake		Lake Crockett	
	Number of Spill Days	Number of Spills Days > 50 cfs	Number of Spill Days	Number of Spills Days > 50 cfs	Number of Spill Days	Number of Spills Days > 50 cfs
Average	29	26	173	42	181	16
Min	0	0	27	8	30	1
Max	152	137	332	94	300	39

Table 5.6 shows how the number of pulse and overbank events increase with distance downstream from FM 409 to the lower reaches of Bois d'Arc Creek with the proposed release policy. There are 130 more pulses in the lower reach than at FM 409 during the 51-year simulation period, and six more overbank events.

The modeling does not include backwater effects from high flows in the Red River. If high flows are present in the Red River at the same time as high flow events in Bois d'Arc Creek, the frequency of overbank events in the lower portion of Bois d'Arc Creek would be expected to increase.

Table 5.6 Comparison of Pulse and Overbank Events with Proposed Bypass During 1948 to 1998 Simulation Period

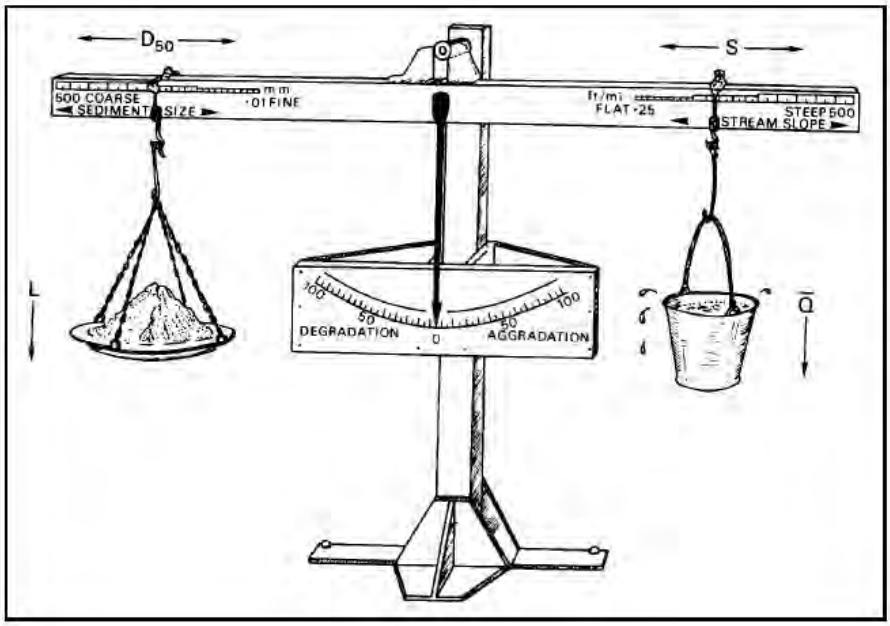
Location	Type of Event	Full Period	Nov-Mar	Apr-Jun	Jul-Oct
FM 409	Pulse	806	381	261	164
FM 100	Pulse	879	416	264	199
Lower Reach	Pulse	936	439	289	208
FM 409	Overbank	2	0	2	0
FM 100	Overbank	3	0	2	1
Lower Reach	Overbank	8	3	3	2

5.3.2 Fluvial Geomorphology

5.3.2.1 Stream Equilibrium and Channel Evolution

There is an important balance between the supply of bedload at the upstream end of a channel reach and the stream power available to transport it. This is known as the Lane's sediment balance. This balance is illustrated schematically by the scale shown in Figure 5.11.

Figure 5.11 Lane's Balance



Source: Chester C. Watson et al. 1999.

The left hand side of the scales represents the volume and size of sediment supplied to a channel reach over a given period of time. Balanced against this is the stream power available to transport it. This is determined by both the volume of water that enters the reach and by the slope over which it flows. The scale is in balance if the stream power is exactly sufficient to transport the sediment load, and therefore there is no net erosion or deposition along the reach. This does not mean that there is no erosion or deposition whatsoever within the reach, since these processes do occur at a localized scale in response to local variations in hydraulic condition. Instead it means that, on balance, neither erosion nor deposition will dominate. Over time, un-impacted streams tend toward an equilibrium condition between the water discharge and the sediment discharge.

An imbalance will occur if there is an increase in the volume of sediment load in relation to the available stream power. If the stream power is insufficient to transport all of the sediment in the reach, then the balance tips towards aggradation, with net deposition occurring along the reach. Aggradation occurs when sediment supply is increased by upstream channel erosion, mass movement, or human activities. Deposition in the channel may lead to the channel bed becoming elevated above the surface of the floodplain, and reduced channel capacity increases flooding and promotes channel migration (Charlton 2008).

A different situation occurs when the stream power exceeds what is needed to transport the sediment load through the reach. This is the predominant factor that affects artificially straightened channels such as Bois d'Arc Creek. By straightening the channel,

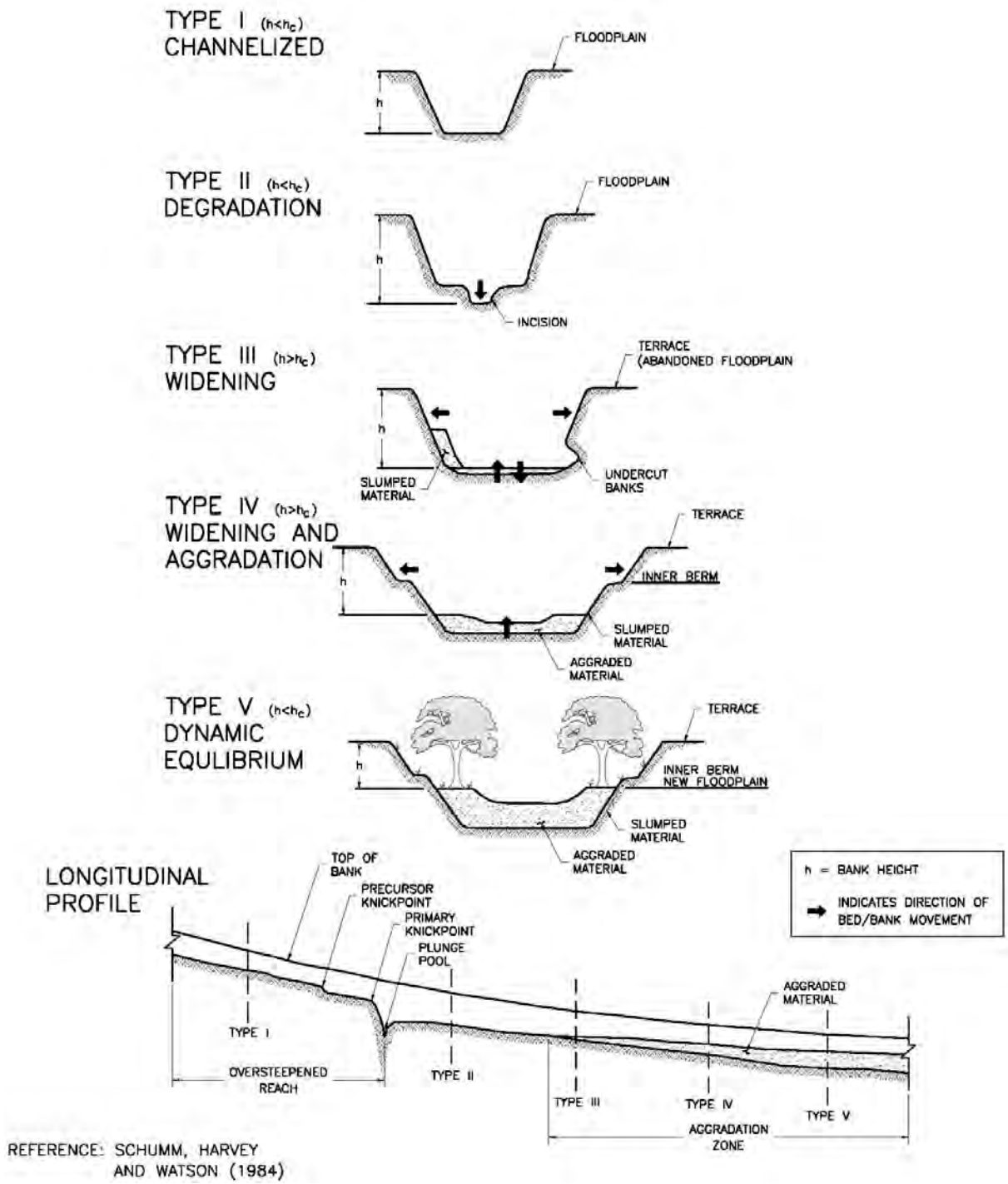
the reach is artificially shortened and the gradient is steepened as flow follows a shorter path. This in turn increases flow velocity and transport capacity. The excess energy has to be expended somehow, so it is used to entrain sediment from the bed and erode the banks. In this case degradation predominates. This degradation may promote bank collapse as the channel incises and thereby results in widening of the channel.

Linder (1976) stated, "Once disturbed, a stream channel begins an automatic and relentless process that culminates in its reaching a new state of equilibrium with nature. Reaching a new state of equilibrium may take decades, or even hundreds or thousands of years depending on local conditions and the level of disturbance. The new equilibrium may or may not have the characteristics similar to the stream's original state."

A change in the flow regime below the proposed dam would affect the relationship between stream power and sediment as described in Lane's balance. The reduction in high flow magnitude and frequency as a result of the proposed dam would effectively reduce stream power, therefore reducing the sediment transport capacity of the stream system. Chin et al. (2002) showed that a reduction of stream power in Yegua Creek downstream of Somerville Dam has caused a 61 percent decrease in channel depth from estimated pre-dam conditions as a result of reduced stream power. Similar changes in channel dimension have been observed on the Platte River in Nebraska (Williams 1978), Rio Grande River in Texas (International Boundary Condition 1959), Canadian River in Texas (Williams and Wolman 1984), and Sandstone Creek in Oklahoma (Bergman and Sullivan 1963). These changes in channel dimensions result from aggradation of sediment when carrying capacity is reduced, and from the establishment of vegetation on channel banks that is no longer removed by high magnitude flows. This situation represents an improvement over current conditions downstream of the proposed reservoir site, which are characterized by on-going erosion and downcutting in the reach.

Present and future conditions on Bois d'Arc Creek can be described by the channel evolution model shown as Figure 5.12. This model identifies the stages of channel form beginning with the channelized section, which disrupts the dynamic equilibrium, through major stages of disequilibrium and channel evolution back to a state of dynamic equilibrium. As shown, the channel incises then widens as a result of bank failure and mass wasting. As the channel becomes over-widened it will begin to aggrade (accumulate sediment) because the stream power will be insufficient to carry the existing sediment load. Eventually a new channel will form within the over-widened section with sufficient stream power to carry the total sediment supply and a new dynamic equilibrium will become established.

Figure 5.12 Incised Channel Evolution Model.



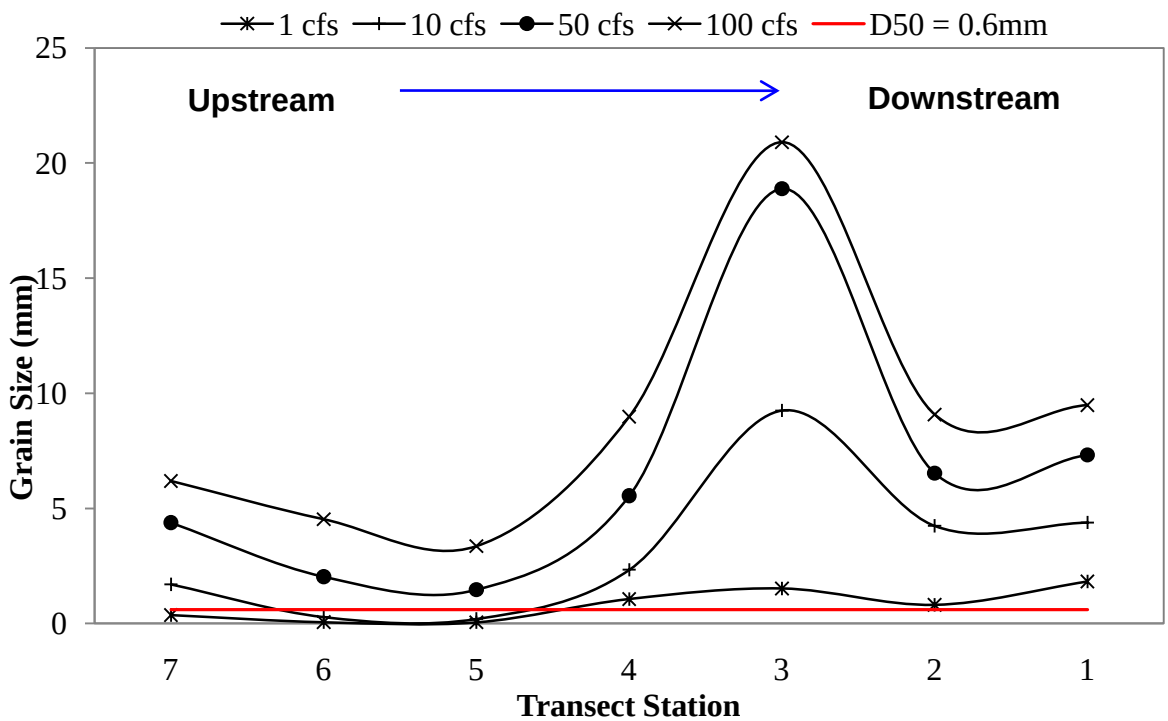
Currently, Bois d'Arc Creek exhibits conditions similar to Types II through IV as shown on Figure 5.12. The stream system has not begun to approach equilibrium, and may not do so for many years. By reducing stream power, the proposed flow regime is expected to speed up the processes by which the channel below the dam achieves equilibrium. With the upstream sediment supply to the lower reaches cut off by the reservoir, it is important that existing bedforms (e.g., gravel bars) be maintained. Replenishment of these bedforms will be dependant entirely on the Bois d'Arc Creek banks as well as tributaries and gullies downstream of the dam. Excessive high flow pulse releases from the proposed reservoir could exceed the capacity of these sources to contribute gravel for maintenance of these bedforms. The magnitude and frequency of proposed pulse flows is expected to balance the need to re-work and cleanse these channel features but not displace them at a rate exceeding the contribution of the bed materials that form them.

5.3.2.2 Predicted Geomorphological Conditions Downstream of Reservoir

Figure 5.13 shows the sediment transport capacity for flows of 1, 10, 50 and 100 cfs in the FM 409 study reach in Bois d' Arc Creek based on the results of the SAMWin hydraulic design model. The red line in the figure signifies the median grain size (D_{50}) of the subsurface sediment at the FM 409 study reach. According to the TIFP guidelines (2008), this grain size is generally thought to be the controlling influence on physical processes. The figure illustrates that a pulse flow of 50 cfs is approximately the minimum flow capable of transporting materials larger than the D_{50} through the entire study reach. Flows greater than 50 cfs would have increasingly greater capacity to transport larger sediment which would result in an increased potential to degrade the stream channel and habitat.

It is anticipated that sediment would be introduced to the channel from bank erosion downstream of the proposed dam to replace sediment lost from the system during the pulse flow releases. Additional sediment would be supplied from tributaries and ephemeral gullies, as well as overland flow, during precipitation driven flow events downstream of the proposed dam. However, it should be noted that the two main tributaries below the proposed dam are also impounded by Coffee Mill Lake dam and Crockett Lake dam, minimizing sediment contributions from these tributaries. The proposed pulse flow regime is expected to provide sufficient flows to benefit and maintain habitat and not cause erosion and channel degradation.

Figure 5.13 Results of the Incipient Motion Analysis Through the FM 409 Study Reach Using Four Different Flows



5.3.3 Water Quality with Proposed Instream Flow Regime

5.3.3.1 Qual-TX Water Quality Model

The proposed flow regime was evaluated using the Qual-TX water quality model to predict the effects of releases of water under varying conditions of flow and temperature. The TCEQ's waste load evaluation model (i.e., the Qual-TX input file developed to evaluate effluent limitations for POTWs in the Bois d'Arc Creek watershed) was modified by truncating the upper model reaches at the proposed dam site. The resulting model has 57 computational elements that begin at the confluence of Honey Grove Creek and Bois d'Arc Creek, 29 kilometers upstream from the mouth of Bois d'Arc Creek. The hydraulic coefficients, oxygen demand rates, and other model coefficients set by TCEQ were not modified.

The model was used to evaluate the impacts of the proposed flow regime on dissolved oxygen downstream of the dam. The applicable criteria for evaluation included 5.0 mg/L dissolved oxygen during all months of the year except the spring spawning season, April through June, which require 5.5 mg/L of dissolved oxygen to meet the high aquatic life use designation assigned by the TCEQ.

The water to be released from the dam was modeled by adjusting the headwater data cards in the model to reflect the proposed flows. The quality of the flows was adjusted for temperature and dissolved oxygen based on the expected stratification characteristics of the proposed reservoir as indicated by existing temperature and dissolved oxygen profile data from Lake Chapman and other North Texas reservoirs. The proposed reservoir would be designed with a multiple level intake structure to allow water to be selectively withdrawn from a depth that would not be likely to result in dissolved oxygen problems downstream.

It was assumed for modeling purposes that no aeration would result from the released water moving through the dam. However, a stilling basin or other energy dissipation system is proposed for the dam. Chanson (1995) demonstrated that, in addition to dissipating the kinetic energy of the water, significant gas exchange occurs in these types of systems. For this reason it can be assumed there would be higher initial dissolved oxygen concentrations in the released water than the Qual-TX model results indicate.

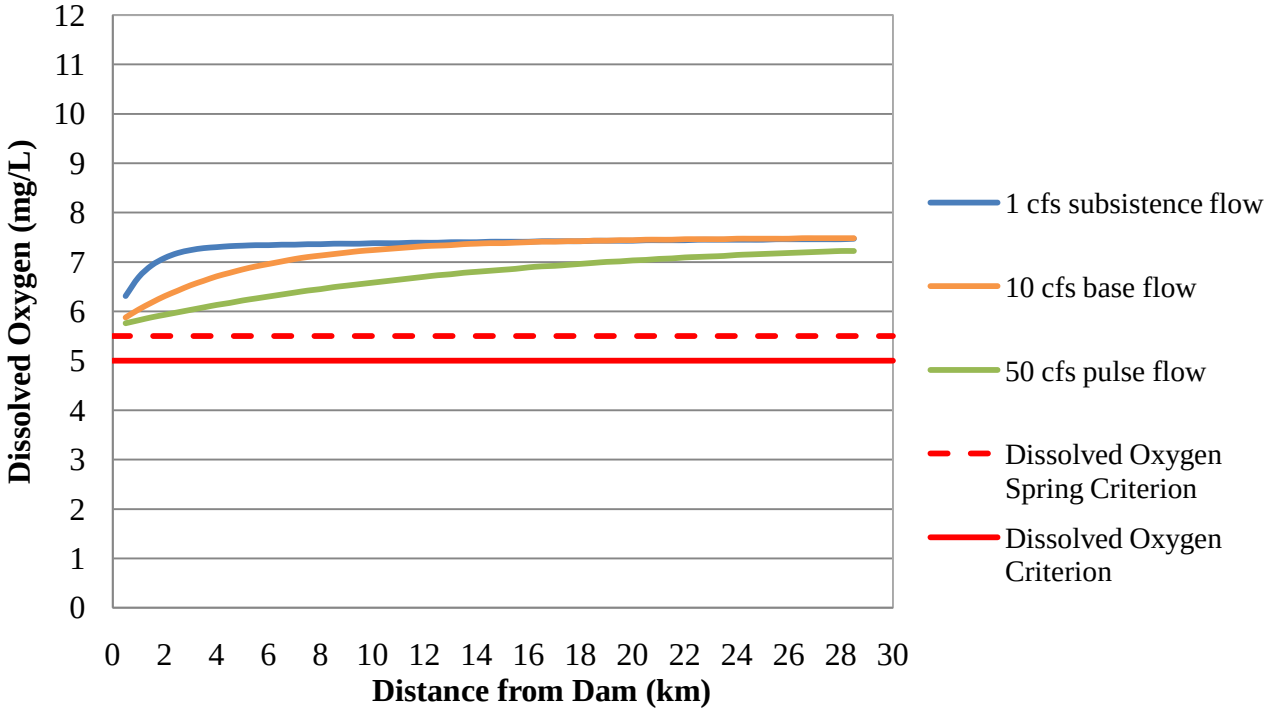
5.3.3.2 Water Quality Modeling Results for the Proposed Flow Regime

The proposed instream flow releases, including subsistence flow (1 cfs), base flows (3 cfs and 10 cfs), and pulse flow (50 cfs), were modeled based on the expected highest mean temperatures and lowest dissolved oxygen concentrations that were observed in the profile data from North Texas reservoirs.

For the April through June season, the proposed subsistence flow of 1 cfs, 10 cfs baseflow, and 50 cfs pulse flow were evaluated with Qual-TX. The initial input values for dissolved oxygen and water temperature for each of these proposed flows were 5.7 mg/L and 27.2°C, respectively. The Qual-TX model results show the minimum downstream dissolved oxygen concentration to be 5.82 mg/L as a result of releasing water from a reservoir depth between 1- and 20-feet (Figure 5.14). This meets the 5.5 mg/L criterion for the spring spawning period. Spring criteria are applied to protect fish spawning periods during that portion of the first half of the year when water temperatures are 17.2 to 22.8 °C.

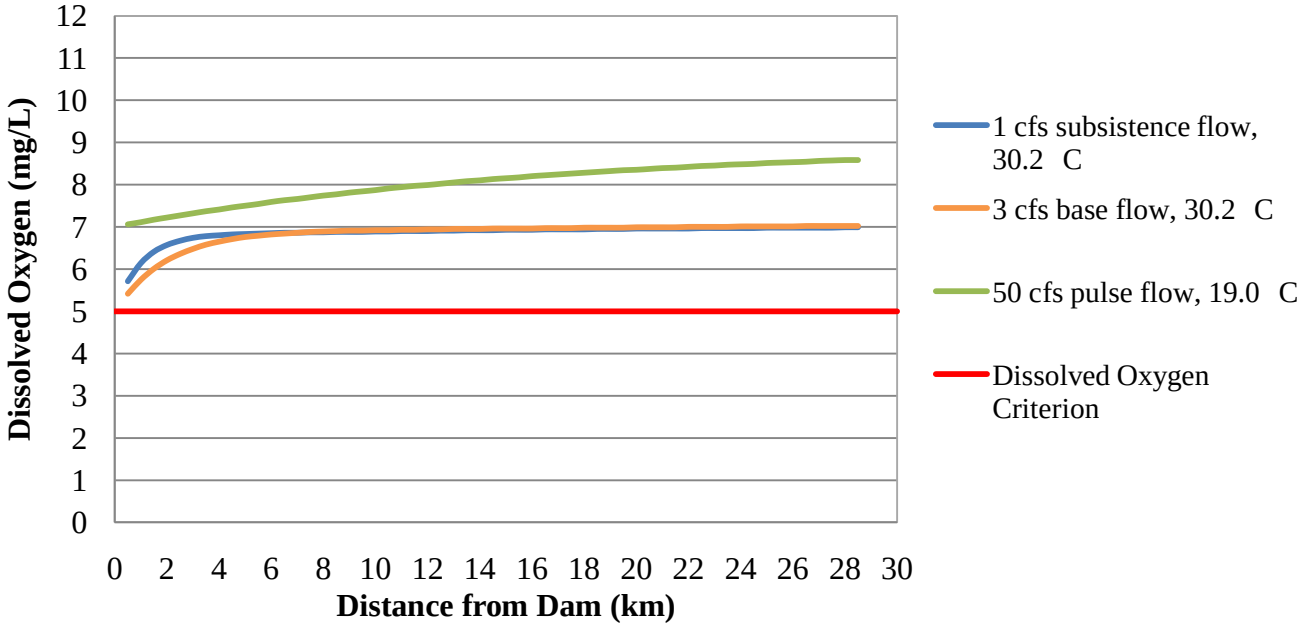
For the July through October season, the proposed 1 cfs subsistence flow and 3 cfs base flow were modeled. The initial input values for dissolved oxygen and water temperature for these flows were 5.0 mg/L and 30.2°C, respectively. In addition, the 50 cfs pulse flow event proposed for the month of October was modeled using a dissolved oxygen value of 7.0 mg/L and the water temperature value of 19°C as the initial input values (based on October lake profile statistics). The Qual-TX model results show the minimum downstream dissolved oxygen concentration to be 5.75 mg/L as a result of releasing water from a reservoir depth of 1-foot (Figure 5.15). This meets the 5 mg/L criterion for non-spawning periods. These results indicate that the proposed flow regime would

Figure 5.14 Predicted Dissolved Oxygen Concentrations in Bois d'Arc Creek Downstream of the Proposed Reservoir for April through June



Proposed Flow Releases at 27.2°C and 5.7mg/L Dissolved Oxygen

Figure 5.15 Predicted Dissolved Oxygen Concentrations in Bois d'Arc Creek Downstream of the Proposed Reservoir for July through October Proposed Flows

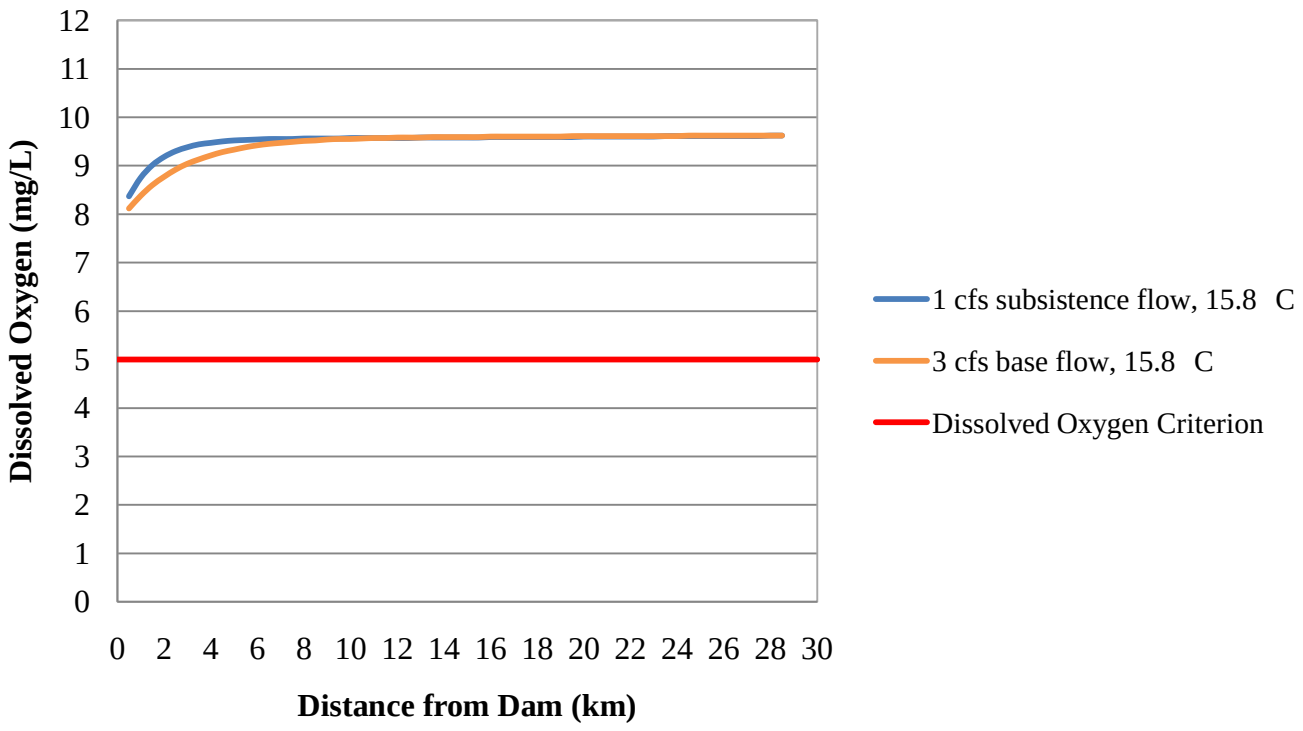


Subsistence and Base Flow Releases at 30.2°C and 5.0 mg/L Dissolved Oxygen, and October Pulse at 19°C and 7.0 mg/L Dissolved Oxygen

provide dissolved oxygen levels necessary to support a sound ecological environment during the critical (i.e., warmest) months of the year, July and August.

For the November through March season, the proposed 1 cfs subsistence flow and 3 cfs baseflow were modeled. The initial input values for dissolved oxygen and water temperature for these proposed flows were 7.8 mg/L and 15.8 °C, respectively. The Qual-TX model results show the minimum downstream dissolved oxygen concentration to be 8.38 mg/L as a result of releasing water from reservoir depths ranging between 1- and 40-feet (Figure 5.16). This meets the 5 mg/L criterion for non-spawning periods.

Figure 5.16 Predicted Dissolved Oxygen Concentrations in Bois d'Arc Creek Downstream of the Proposed Reservoir for November through March Proposed Flows



Releases at 15.8°C and 7.8 mg/L Dissolved Oxygen

5.4 Impact on Reservoir Yield

Table 5.7 compares the firm yield of Lower Bois d'Arc Creek Reservoir with the proposed release criteria to other environmental flow criteria. The Consensus Criteria were used in the original application for the reservoir. Note that the yields using the monthly WAM model are about 1,500 acre-feet per year higher than the yield using the daily RiverWare model. Since the monthly total of the flows are identical in these two models, the primary difference is the use of the daily time step. The yield with the proposed release criteria is about 1,500 acre-feet per year less than the yield with the Consensus Criteria using the RiverWare model.

Table 5.7 Impact of Environmental Flows on Reservoir Yield

Model	Environmental Flow Criteria	Firm Yield (ac-ft/yr)
Red River WAM (FNI hydrology)	Consensus	126,280
RiverWare	None	125,907
RiverWare	Consensus	124,757
RiverWare	Proposed	123,309

6 MONITORING AND ADAPTIVE MANAGEMENT

The proposed conceptual monitoring program (described below) is based on the indicators used to quantify the baseline (current conditions) biological, chemical, physical, and hydrologic characteristics of the monitoring reach. The baseline study reach located upstream of FM 409 will be used for monitoring the effectiveness of the prescribed flow regime.

6.1 Monitoring

Detailed pre- and post-construction monitoring plans will be developed to measure representative stream system attributes that will quantify the success of environmental flow releases in supporting a "sound ecological environment," as defined previously in this report. Attributes that would be measured include: water quality, geomorphology, hydrology, and biology. Changes in the values of monitored parameters after construction of the dam will be assessed in consultation with the USACE (the lead permitting agency) and other resource agencies to determine if adjustments to the permitted instream flow regime are warranted to maintain a sound ecological environment.

6.1.1 Water Quality

Water quality will be recorded from the USGS gaging station located at the FM 409 bridge and quarterly at selected stations as part of the Red River Authority's Clean Rivers Program. Dissolved oxygen levels will continue to be monitored at the USGS gage at FM 409 to verify that the operation of the reservoir has not caused dissolved oxygen levels to drop below criteria (5.5 mg/L spring, 5.0 mg/L in the remainder of the year). In addition, water temperature, pH, and specific conductance will be measured continuously at the USGS gaging station as supplemental indicators of water quality and to allow detection of trends over time.

6.1.2 Geomorphology

Stream bank erosion rates will be quantified by measuring changes in cross-section area annually and changes in bank erosion pin exposure during the required biological monitoring period. This will be accomplished by establishing a permanent cross section in the FM 409 study reach Upstream of the bridge. Pre- and post-dam closure measurements will be made to compare channel cross-section changes before and after construction.

The composition of the stream bed and banks also will be used as an indicator of changes in stream character, channel form, hydraulics, erosion rates and sediment supply. This will be accomplished by making pebble counts and sediment grain size measurements at the stream cross-section established in the study reach at FM 409.

A photographic record will be established at the FM 409 monitoring cross-section by taking an upstream and downstream photograph on the annual sampling date. Photographs would be used to subjectively evaluate channel aggradation or degradation, bank erosion, and other visual stream characteristics in the monitoring reach.

Increased erosion rates, if indicated by channel cross-section or erosion pin measurements after implementation of the required instream flow releases, will be assessed in light of other monitoring data (e.g., biological or water quality) and in consultation with the USACE and other state and federal resource agencies to determine if the permitted instream flow regime should be adjusted.

6.1.3 Hydrology:

Stream flow will be recorded from the USGS gaging station located at the FM 409 bridge. Compliance with the 50 cfs pulse flow criteria will be measured at this point. Base and subsistence flow criteria will be measured at the outlet works at the dam.

Observations will be made during field visits to document actual flow conditions at representative prescribed flows of 1, 3, 10, and 50 cfs. This will include instantaneous flow measurements using portable flow metering equipment and photographic documentation.

6.1.4 Biology

Aquatic integrity metrics were used to establish the baseline condition of Bois d'Arc Creek and the adjacent riparian zone, and they will be used as monitoring tools to assess impacts of the proposed Lower Bois d'Arc Creek Reservoir downstream of the proposed dam. Biological attributes will follow the protocols established during the instream flow study for the following:

- Fish community (IBI)
- Macroinvertebrate community (RBA)

Biological monitoring will be performed bi-annually for five years (i.e., in years 1, 3, and 5) following closure of the dam and then at 5-year intervals for 10 years (i.e., years 10 and 15). Monitoring will be conducted in the FM 409 instream flow study reach established by the current study. If the metrics show no statistically significant deviation from the baseline metrics, then monitoring will end.

6.2 Adaptive Management

If measured attributes and variables indicate that a sound ecological environment is not being maintained, then an interagency team of hydrologists, biologists, water quality experts, and geomorphologists will be convened to identify the cause of the problems and recommend solutions to the problems. This team would consist of the Tulsa District

USACE, other appropriate federal and state resource agency personnel, and representatives of NTMWD. Potential solutions would be suggested and after receiving appropriate approvals, the recommended actions would be implemented.

As part of the adaptive management process, the Reservoir Operation Plan would be subject to revision as demands and sources available to the NTMWD change. The Reservoir Operation Plan would have the goals of maintaining sufficient supply in the Lower Bois d'Arc Creek Reservoir to meet local demands and supply a constant release of 1cfs during a repeat of drought-of-record conditions. These goals would be evaluated using reservoir operation models similar to the RiverWare Model developed for this study.