CYPRESS FLOWS PROJECT

ENVIRONMENTAL FLOW REGIME AND ANALYSIS RECOMMENDATION REPORT

AUGUST, 2010

ENVIRONMENTAL FLOWS REGIME AND ANALYSIS RECOMMENDATION REPORT

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1 INTRODUCTION

This report is the culmination of an effort begun in 2004 to develop recommendations for environmental flows in the Cypress River Basin and Caddo Lake based on the best available science.

The Cypress Flows Project (CFP) was originally initiated as part of the Sustainable Rivers Project (SRP) partnership developed by the Nature Conservancy (TNC) and the U.S. Army Corps of Engineers (USACE). The purpose of this initiative is to restore and preserve rivers across the country (Richter and others 2006). The CFP was expanded in the initial CFP orientation meeting in December 2004 to reflect the actions and proposals of the Texas Legislature to evaluate environmental flow needs in all river basins in Texas. It was further expanded in 2006 with its integration with a new Watershed Protection Planning process that focused on water quality, aquatic invasive species and related issues in the Cypress basin. The CFP has benefited from the participation of dozens of scientists and stakeholders.

With the continued assistance from the USACE, U.S. Geological Survey (USGS), the Northeast Texas Municipal Water District and many others, the scientists and stakeholders who are participating as the "working group" for the Project are proceeding with implementation using an adaptive management approach.

The documents prepared for and summarizing the results of the major meetings and other work on this project are available on the website of the Caddo Lake Institute (www.caddolakeinstitute.us). This report includes a number of appendices some of which contain information that might be considered beyond the scope of what might normally be expected as part of the development of a purely science based flow regime as defined by Senate Bill 3 (SB 3).

1.1 CYPRESS FLOW PROJECT AND SB 3

In 2007, the 80th Regular Session of the Texas Legislature passed SB 3, a basin-by-basin process to develop environmental flow recommendations throughout the state. At this time, and even earlier in anticipation of the passage of SB 3, the CFP began adopting the direction and guidance developed for SB 3 and incorporating the legislation's central elements. Throughout these various initiatives, the CFP has striven for consistency with SB 3 and respectfully submits this report as the culmination of a voluntary consensus-building process that satisfies the SB 3 legislative mandate.

The Texas Legislature enacted SB 3 to create a process for reserving water for environmental flows. The law provides a state policy for protecting environmental flows, including a process for developing flow recommendations for each river basin and a framework for final decisions by the Texas Commission on Environmental Quality (TCEQ) for a set aside of unappropriated water. The CFP began prior to the passage of SB 3, and therefore, was not executed in exactly the same way as the process was defined in SB 3; however, the CFP is consistent with the goals and outcomes of SB 3.

While the Cypress basin was not included in the schedule of basins to be addressed by SB 3, the law anticipates that some basins may develop their own processes. It provides:

> "...in a river basin and bay system for which the [state environmental flows] advisory group has not yet established a schedule for the development of environmental flow regime recommendations and the adoption of environmental flow standards, an effort to develop information on environmental flow needs and ways in which those needs can be met by a voluntary consensus-building process." [§Sec. 11.02362 (e)]

Participants in the CFP asked that this type of language be added to SB 3 to open the door for the CFP work to move forward to obtain a set aside if the CFP process was accepted as the functional equivalent of the SB 3 process. When the language was added, scientists and stakeholders proceeded with the CFP under the assumption that SB 3 provided for this type of alternative approach and that the CFP is using a process and seeking results consistent with SB 3.

Representatives from TCEQ, the Texas Water Development Board (TWDB) and Texas Parks and Wildlife (TPWD) attended all of the flows meetings. Throughout the process, these agencies were consulted and a very conscientious effort was made to ensure that the work of the CFP would be consistent with expectations of the SB 3 process and goals.

The work of the CFP was also presented to the Texas Environmental Flows Scientific Advisory Committee (SAC) on October 1, 2008, prior to the last stakeholder-scientist workshop of December 2008. Some work of the CFP was also presented to the SAC on March 4, 2009. These presentations were mainly intended to advise SAC members and others of the work of the CFP, but they were also efforts to seek input from the SAC members and others. Since then, every effort has been made to provide the type of scientific analysis that the SAC recommended for other basins.

Thus, the work of the CFP by the stakeholders and scientists of the working group was always focused on the same basic goals and process as SB 3. The similarities and differences between the two approaches will be discussed briefly. The SAC has outlined the technical activities to be performed by the Bay Basin Expert Science Teams (BBESTs) (SAC 2010). These steps are closely mirrored by the process created for the SRP and used to guide the work of the CFP.

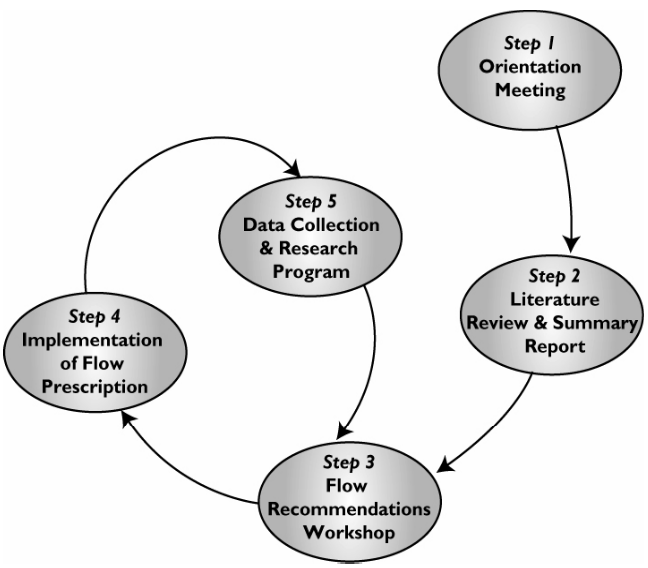

Figure 1 Sustainable Rivers Project process diagram.

The process that was developed for the CFP began before anyone knew what process an environmental flows bill would provide. There was, for example, no formal process available for appointing stakeholders to the CFP. There was no process for determining which scientists or stakeholder would participate. Instead, the process was opened to all who wanted to participate. Recruiting the scientists needed for the work was a three-step process. The first step was to identify institutions or individuals with a history of working in the watershed, including those who have studied the ecology of the system and those who have conducted studies related to proposed water development projects. Next, other institutions that were likely to have an interest in this process were identified. This included local, state and federal agencies, university researchers and private consultants. Finally, the experts identified were then asked to identify others who might be needed or otherwise should be invited to participate.

The Cypress Basin has attracted scientific studies for many years. Given that Caddo Lake is Texas' only naturally formed large lake, there have been strong interests in the Cypress Basin. For example, an expert at the National Wetland Resource Center in Lafayette, Louisiana had worked on regeneration of cypress trees in the basin for a number of years. There were also a number of studies associated with the water projects in the basin. These include studies for existing projects such as Lake O' the Pines and Bob Sandlin Lake and projects that were not completed, such as the proposal for a reservoir on Little Cypress Creek and one for a barge canal across Caddo Lake. A few of these studies included instream flow studies. The studies, and importantly, many of the scientists who participated in them were available to assist with the Project.

Stakeholders were identified in a similar way. The process began with those known to be interested, and with the obvious governmental and non-governmental organizations working in the watershed. That was followed up by requests that stakeholders help identify other potential stakeholder-participants. A number of stakeholders not only played their role of helping set goals for the process to add practical limits to the flow regimes, they also brought their practical experience and observations to help with the technical evaluations and development of the flow regimes.

Anyone was allowed to participate in the meetings, as they were open and all materials prepared for or summarizing the work at the meetings were posted on the website for review and comments. In all, approximately 200 individuals participated in one way or another. The agencies that participated are listed in Appendix A.

In Step 1 of the SRP process (Figure 1), experts in riverine, wetland and lake science were invited to participate in a 3-day orientation meeting to discuss using the SRP process to develop environmental flow recommendations for the streams in the Cypress Basin and Caddo Lake and associated wetlands. In December 2004, 60-70 scientists and stakeholders, including representatives from state and federal agencies, university scientists, regional water suppliers, conservation groups and local stakeholders, attended the initial orientation meeting for the CFP. While SRP encourages stakeholder participation and sharing local expertise and concerns throughout the process, it was repeatedly stressed that the process is firmly rooted in the development of the science to meet technical challenges of developing building blocks for flows based on ecological needs without consideration of the practical limitations or other needs for the water. Therefore, while limitations on implementation, such as flooding urban areas were certainly raised, these were set aside in the process until the science-based recommendations for environmental flow regimes were developed. The building blocks were not constrained nor did they consider such physical or legal limitations or broader goals of stakeholders. Similar to the legislation in SB3, which drew a sharp distinction between the development of the science to determine the flow needs and a recognition that this be done "without regard to the need for the water for other uses" and the consideration of "other factors, including the present and future needs for water for other uses related to water supply planning," participants agreed to table, for consideration after the development of scientifically determined flow from an ecosystem perspective, issues related to implementation. The existence of dams creating Caddo Lake and Lake O' the Pines were taken as basic limitations, but the limitations on current operations or releases were not. The other goals and limitations were later added to the discussion for the development of the recommended environmental flow standards after the science-based regimes had been developed.

The preliminary orientation meeting included an overview of the SRP process, including a case study from the Savannah River (Richter and others, 2006). Using that study as a basic framework, it was emphasized early in the orientation meeting that the purpose of the process is to develop flow recommendations for maintaining or restoring the health of the whole river–floodplain–lake system. Specifically, this implied the development of a flow regime "expressed as a range of magnitudes for each flow component at specific locations, at specific times during the year, and with a specified frequency of occurrence among years." The objectives to achieve these goals were:

1. To engage interdisciplinary scientists in a collaborative process for developing environmental flow recommendations.
2. To facilitate interaction among a variety of agencies, academic institutions, and organizations to gain a shared understanding of the water needs of the basin.
3. To identify critical linkages between various components of the flow regime (low flows, high pulse flows, and over-bank flows), lake level fluctuations, and plant and animal species.
4. To develop initial environmental flow recommendations to protect the health of Caddo Lake and its tributaries
5. To identify research and monitoring activities necessary to fill information gaps and address critical uncertainties in flow-ecology relationships.
6. To provide scientifically credible information about environmental flow needs to water managers and thereby promote the adoption of "ecologically sustainable water management."
7. To demonstrate a process for developing environmental flow recommendations that can be applied in other aquatic ecosystems.

Participants worked in breakout groups and discussions focused on ensuring common understanding of the process that was being proposed, including the level of commitment required to effectively participate, a process for reaching consensus, and recognition of some of the implementation issues that would need to be addressed after the preliminary flow recommendations were developed. Participants reached consensus on adopting the SRP process to develop environmental flows for Caddo Lake and Big Cypress Creek. Action items included identification of personnel and resources (data and analyses) needed to complete the objectives of the study and identification of components to be included in the literature review and summary report.

Steps 2 and 3 are analogous to key aspects of the SB 3 process of developing preliminary flow matrices and the initial application of overlays from the various environmental flow disciplines to produce an environmental flow analysis and ultimately feed back into a refinement of the preliminary matrices based on reasonably available science. Steps 4 and 5 are an adaptive management process that is primarily analogous to the workplan and adaptive management provisions of SB 3. However, because this learning process has already been initiated below LOP, the CFP has also been able to utilize this process to do further overlay analysis and further refine the flow matrices. The technical components of these steps are described in detail in the remainder of this report.

It is worth noting and clarifying some differences in the terminology used by the SRP and SB 3 processes. For example, SB 3 defines "environmental flow regimes" in terms similar to what the SRP refers to as "building blocks." The terms are not however identical. The scientists working on the CFP developed building blocks as the initial determination of the numerical flow regimes, but they also recommended narrative conditions to convert some of the building blocks to the final flow regimes.

For SB 3, SAC guidance has adopted the term "overlay" for the application of expertise and analysis from the multiple disciplines related to riverine science. SB 3 overlays are most synonymous with the work that goes into producing the Literature Survey and Summary Report (Step 2) and applying this information in the development of preliminary flow matrices. Time and resources have allowed the working group to go beyond what is described as reasonably available data for SB 3 overlays, to collect data and perform analysis that would not typically be possible under the time and funding constraints on BBESTs for SB 3. This work (Steps 4 and 5) primarily includes components of what might be included as elements of a SB 3 work plan but also includes part of the overlay analysis. This work is therefore summarized in the section of this report that addresses overlay tasks that are undertaken by the BBEST (Section 2.2). Differences in terminology are unfortunate, in some cases unavoidable. The working group has moved to adopting the conventions of SB 3 and will use that terminology whenever possible.

While the SRP and SB 3 processes produce the same outcomes or “functional equivalents" there are several other differences that are also worth noting. One difference is that the CFP included scientists and stakeholders in combined meetings, while SB 3 provides for separate meetings. One reason for separating these groups in SB 3 may have been to help protect the integrity of the science. Protecting the ability of the participating scientists to develop flow regimes based on science is also central to the SRP process. It was strictly adhered to throughout the development of the environmental flow regime and analysis. It should also be noted that, the CFP did benefit from the input of many of the stakeholders who brought with them real world experience, observations and information on conditions and functioning of the rivers, streams and lakes that may not have otherwise been available to the scientists. The stakeholders also received the benefit of getting a better understanding of the inputs, debates and results of the science process. This interaction is consistent with the BBEST-BBASC interactions suggested by the SAC Lessons Learned document (SAC 2010).

This strong science-based approach with stakeholder participation was explained by Brian Richter of the TNC when he led the CFP orientation meeting in 2004. He said, in essence, what he had written the year before:

> "Initial estimates of ecosystem flow requirements should be defined without regard to the perceived feasibility of attaining them through near-term changes in water management. We reiterate our assertion that ecological sustainability should be presumed to be attainable over the long run, until conclusive evidence suggests otherwise. We have been involved in numerous water management conflicts in which initial perceptions of unfeasibility were overcome through creativity and deeper analysis, or a change in the socioeconomic or political landscapes that made possible what had seemed impossible a decade or two earlier.
>
> Inviting water managers and other interested parties to observe the process of defining ecosystem flow requirements can have important benefits. Water managers can help scientists understand how to prescribe flow targets in a manner that can be implemented. Water managers can learn a lot about the possible effects of water management on river ecosystems, thereby increasing their ecological literacy. Perhaps more important, water managers will gain insight into the nature of the uncertainties in this knowledge, thereby helping them understand the need for experiments and flexibility in water management. It is important for water managers, conservationists, and water users to understand that scientists will not be able to provide comprehensive and exact estimates of the flows required by particular species, aquatic and riparian communities, or the whole river ecosystem. Rather, scientists should be able to provide initial estimates of ecosystem flow requirements that need to be subsequently tested and refined, as described later." (Richter and other 2003)

When SB 3 was passed and the Cypress Basin was not scheduled, the CFP decided to proceed without revising its historic process to fit all of the specifics of the SB 3, in large part because the work had provided a solid basis to develop the flow regimes and recommendations for standards and strategies called for by SB 3. Both processes focus on the same goals, i.e., a sound scientific basis for the flow recommendations and consensus on the process.

1.2 Sound Ecological Environment

The SAC defines a sound ecological environment as one that:

- Sustains the full complement of native species in perpetuity,
- Sustains key habitat features required by these species,
- Retains key features of the natural flow regime required by these species to complete their life cycles, and
- Sustains key ecosystem processes and services, such as elemental cycling and the productivity of important plant and animal populations.

Consistent with the above definition is the definition from the Texas Instream Flow Program (TIFP) Technical Overview document that defines a sound ecological environment as

> "A resilient, functioning ecosystem characterized by intact, natural processes, and a balanced, integrated, and adaptive community of organisms comparable to that of the natural habitat of a region."

Instream flow regimes should include flows to provide for instream aquatic habitats, transport of sediments and maintenance of water quality needed to support diverse plant and wildlife assemblages (SAC 2004). The SAC has adopted a description of a flow regime that is consistent with the majority of the literature on instream flow science (NAS 1992; NRC 2005; Locke et al. 2008; Annear et al. 2004; TCEQ, TPWD and TWDB 2008) that includes a range of flows from subsistence, base, high flow pulse and overbank. These flow components are typically defined in terms of magnitudes, durations, frequencies and timing. The CFP has adopted a similar set of flows with only slight modifications. The CFP did not specifically define a subsistence flow because the functions associated with subsistence flows are captured by what is defined as the dry low flow in the CFP. The CFP also chose to employ the term "low flow" rather than "base flow." While the ecological function to be maintained by these terms is identical, the term "base flow" sometimes carries with it a connotation of being groundwater derived whereas the meaning of "low flow" in the CFP environmental flow analysis is intended to be based solely on the ecological function expected from these flows and does not connote a source of those flows.

1.3 Geographic Scope

SB 3 defines geographic scope based on basin areas and states that flow regimes be developed that "typically would vary geographically, by specific locations in the watershed." SB 3 does not specify the level of resolution (number of gages or stream segments) for which flow recommendations must be developed. Clearly, resources and time prohibit the development of site-specific recommendations for every river segment.

The entire Cypress basin is within the Austroriparian biotic province and the South Central Plains ecoregion. Most of the land area within the basin drains primarily from the northwest to the southeast and eventually feeds into Caddo Lake. It extends upstream from Caddo Lake at the Texas-Louisiana state border, to the westernmost extreme of the Cypress Creek Basin, near Winnsboro, Texas. This watershed, which includes several reservoirs, is formed in the southern part of Hopkins and Franklin and northern part of Wood Counties and flows eastwardly into Camp, Titus, Morris, Upshur Marion, and Harrison Counties. Black Cypress is to the north of Big Cypress and begins in Morris County. It flows through Cass and joins Big Cypress in Marion County. Little Cypress is to the south of Big Cypress and begins in Wood County. It flows through Upshur and Gregg and converges with Big Cypress along the Marion and Harrison County boundary. Big Cypress Creek, above Lake O' the Pines, is intermittent in its headwaters. It forms the boundary line between Camp and Titus, Camp and Morris, and Morris and Upshur counties. The stream runs through flat, rolling terrain surfaced by sandy and clay loams that support water-tolerant hardwoods, conifers and grasses. Big Cypress Creek flows into Caddo Lake through a jungle-like bottomland where cypress trees are common.

The navigable waters of Big Cypress Creek contributed to the rise of the City of Jefferson as a commercial center prior to the railroads. Between 1842 and 1872, the town was a principal port in Texas, serving as a distribution point for much of North and East Texas. Once the railroads arrived in the early 1870s, river traffic declined. Since World War II, Big Cypress Creek has been dammed to form a series of reservoirs including Lake Cypress Springs, Lake Bob Sandlin, Monticello Reservoir and Lake O' the Pines. Caddo Lake has undergone several very large changes in the last 200 years. It originally was a natural lake formed by the presence of a tremendous and apparently ancient logjam. In the 1800s, the original natural dam was removed. This caused the original lake to shrink with typically very shallow water. This condition persisted for more than 100 years, when, in 1917, the USACE completed the first dam and spillway to raise the water level. That dam was replaced in 1971 with the current weir. Outflow cannot be manipulated from the Caddo Lake dam. Water leaves the lake when it overtops the spillway.

Caddo Lake drains roughly 2,800 square miles, the vast majority of it in Texas. Major tributaries into the Lake are Big Cypress, Little Cypress and Black Cypress Creeks[1] (Figure 2). Together these account for about 70% of the total drainage area of Caddo Lake. Input from the other 30% of the drainage area is not monitored on a routine basis.

It is up to both the scientists and stakeholders to make some basic decisions on the geographic scope. The scientists should define a sufficient number of points in keeping with the spirit and intent of the legislation. This is also an area where stakeholder values play a legitimate and valuable role, as stakeholders may wish to focus on particular segments or issues. The options for the scope should be sufficient to find an approach that satisfies the scientific and stakeholders' needs. Thus, for example, one of the CFP Stakeholders' initial goals was protection of Caddo Lake.

CFP defined a geographic scope focused initially on flows into and in Caddo Lake. This focus is partially the result of the initial impetus of the project, namely the application of the SRP on Big Cypress Creek and Caddo Lake. The SRP program, as it was developed by the USACE and TNC focuses on changes to reservoir operations to restore ecosystems that have been impacted by dams. Given the high resource value associated with the lake and surrounding wetlands, this area was identified as a priority. Caddo has been designated as a Wetland of International Importance under the 1971 International Ramsar Convention, which has now been ratified by 160 countries including the U.S. Specifics on the designation, its role and impact on the Caddo wetlands can be found at http://www.caddolakeinstitute.us/ramsar.html. As Texas' only naturally formed large lake, Caddo Lake also has important environmental, historic and social values, all of which add to the economic base of the area.

After the orientation meeting in 2004, it became clear that maintaining a healthy ecosystem could not be limited to a consideration of only Big Cypress Creek, which only represents one third of the watershed for Caddo Lake. (Big Cypress Creek drains approximately 940 square miles out of the 2,800 total drainage area for Caddo Lake).

[1] The terms "Creek" and "Bayou" are used somewhat interchangeably in the Cypress Basin. For ease of writing the term "Creek" will be used in this document although it should be noted that the USGS gage on Black Cypress uses the term "Bayou".

With gages on Black and Little Cypress Creeks, those streams became obvious systems to include. There was, in fact, an assumption that the Cypress Basin was small enough and its watershed similar enough that other stream contributions to Caddo Lake, such as James Bayou, and streams that flow into Louisiana outside the Caddo Lake Watershed could be evaluated initially based on work done in Big, Little and Black Cypress Creeks. This approach is necessary because none of these other streams are gaged. By the third flows workshop in December 2008, this approach led to flow regime recommendations for the ungaged streams in the Cypress Basin. Although the working group did not make specific recommendations at every gage in the basin (notably at a gage near Pittsburg on Big Cypress Creek between Lake Bob Sandlin and Lake O' the Pines see Figure 2), they did recommend that the approach used in the CFP could be used at other locations.

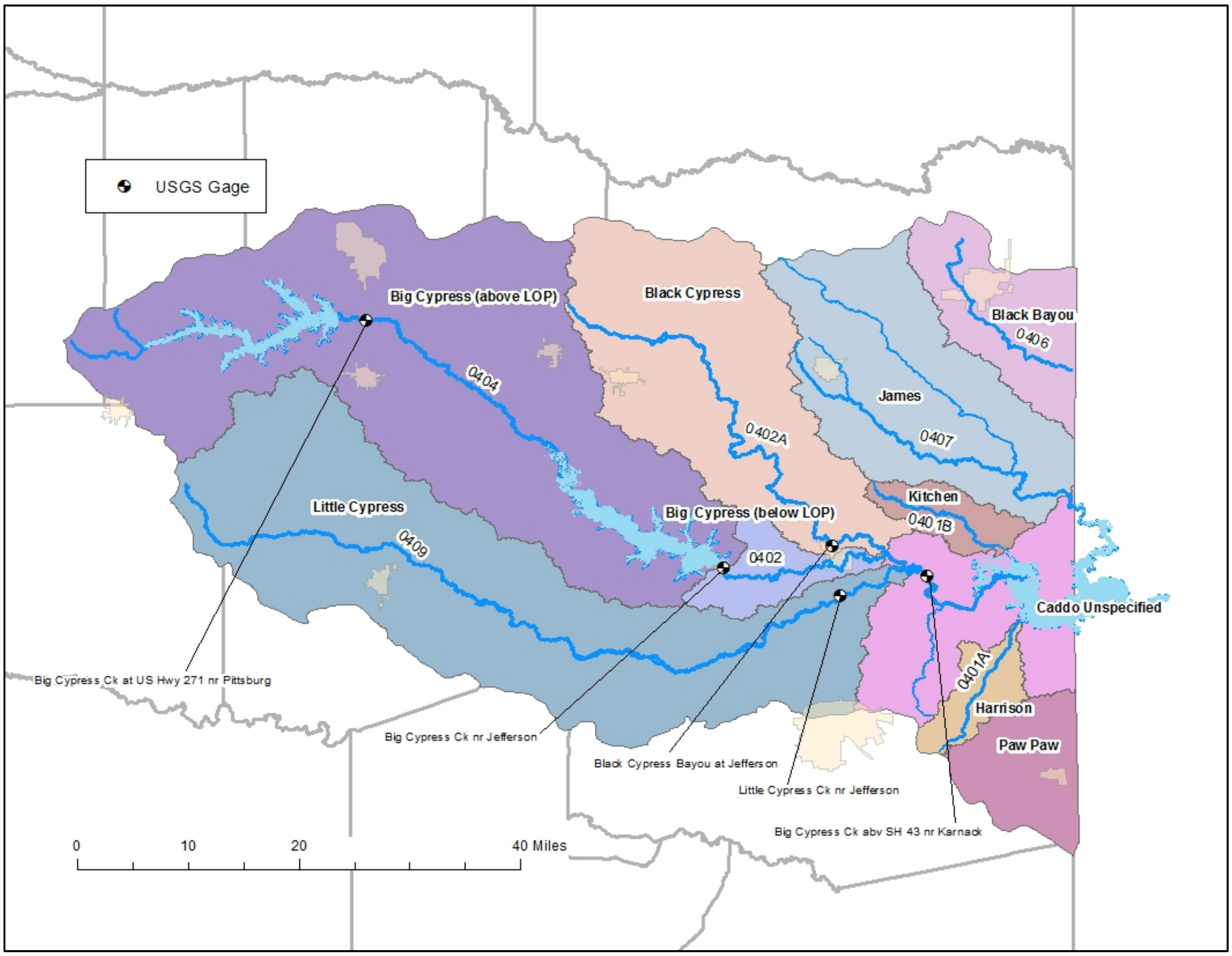

Figure 2 TCEQ segments in the Cypress Basin in Texas.

TCEQ has divided the Cypress Creek Basin into 9 classified segments[2]. There are currently five active USGS flow gages in the Cypress Basin and, of these, three are part of the core gage network (Big Cypress Creek near Jefferson, Black Cypress Creek at Jefferson, and Little Cypress Creek near Jefferson). The three USGS core gages were selected as primarily sites for the development of instream flow recommendations. The USGS gage at Karnak is a relatively recent gage with very short period of record. The working group also recommended that flow targets be

[2] A TCEQ segment is a section of a river, creek, or stream that has relatively similar chemical, physical, and hydrological characteristics.

developed for major ungaged tributaries to Caddo Lake (James, Kitchen and Harrison) based on the size of their drainage areas. In addition, although there was only limited discussion, the group also recognized that the approach used at the three primary gages could be applied at other segments in the basin, such as Black Bayou.

Table 1 Cypress Basin watershed areas.

Watershed	Square Miles	Percent	TCEQ Segment
Big Cypress	937	32%	
above LOP	875	30%	0404
below LOP	63	2%	0402
Little Cypress	719	25%	0409
Black Cypress	399	14%	0402A
James Bayou	322	11%	0407
Kitchen Creek	47	2%	0401B
Harrison Bayou	47	2%	0401A
Caddo (Unspecified)	206	7%	
Black Bayou	137	5%	0406
Paw Paw	99	3%	
Cypress, Texas	2,911		

2 DEVELOPMENT OF SCIENTIFICALLY BASED ENVIRONMENTAL FLOW REGIME AND ANALYSIS

2.1 DEVELOPMENT OF BUILDING BLOCKS (ENVIRONMENTAL FLOW REGIMES)

"Environmental flow regime" means a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies. [§Sec. 11.002 (16)]

What were called Building Blocks at the beginning of the CFP is generally synonymous with what SB 3 refers to as preliminary flow regime matrices. In the CFP, the Building Blocks were developed after compiling all reasonably available data (SRP Step 2 - Literature Review and Summary Report) and then assembling scientists with expertise in hydrology and hydraulics, water quality, fluvial geomorphology and aquatic ecology at a series of flows workshops (SRP Step 3 - Flow Recommendation Workshops). The scientists analyzed available data and developed preliminary flow matrices based on an application of expert judgment.

2.1.1 LITERATURE REVIEW AND SUMMARY REPORT (REASONABLY AVAILABLE SCIENCE)

A team of scientists from Texas A&M University was contracted to conduct literature review and write a summary report. (Winemiller and others, 2005) Consistent with state (TIFP 2008) and national (Annear and others 2008) guidelines, this report included sections on the important river and lake components including Hydrology, Geomorphology, Water Quality and Macrophytes, Floodplain Vegetation, Aquatic Fauna, Terrestrial and Semi-Aquatic Wildlife as well as a summary of Environmental Flow Relationships.

The purpose of the literature report was to synthesize available data and literature associated with Caddo Lake, Lake O' the Pines and the streams flowing into Caddo Lake. It was prepared after the orientation meeting in order to arm initial workshop participants with sufficient information to develop ecologically based flow recommendations for the Big Cypress Creek below Lake O' the Pines Dam and Caddo Lake. Supplements to this initial report were added as the CFP expanded the geographic scope to include the stream s in the Cypress Basin.

It should be pointed out that hydrologic modifications have not been the only negative impact to this system. Other perturbations, such as nutrient and contaminant loading, altered sediment transport, logging, drainage and conversion to agriculture or residential development, have altered the system to varying degrees. However, the consensus is that some restoration of the timing, magnitude, and duration of flows in Big Cypress Creek together with the protection of some flows in the other rivers and streams that flow to Caddo are critical to the sustainability of the lotic, lentic, and floodplain habitats as well as beneficial ecosystem functions.

The following sections were largely extracted from the Literature Survey and Summary Report (Winemiller and others 2005)

2.1.1.1 HYDROLOGY

With the notable exception of Big Cypress Creek, most of the Cypress Basin is largely unaltered by major instream impoundments. The major disruption of natural flows into Caddo Lake was caused by the closure of Ferrells Bridge Dam and creation of Lake O' the Pines on Big Cypress Creek, upstream from Caddo Lake. The Lake O' the Pines reservoir was completed in late 1959 and has dramatically altered the flow regime of Big Cypress Creek directly below Lake O' the Pines. The annual hydrograph for post-dam conditions is very damped in comparison to pre-dam conditions with increased summer low flows, reduced high flow pulses and elimination of larger flood flows (Figure 3).

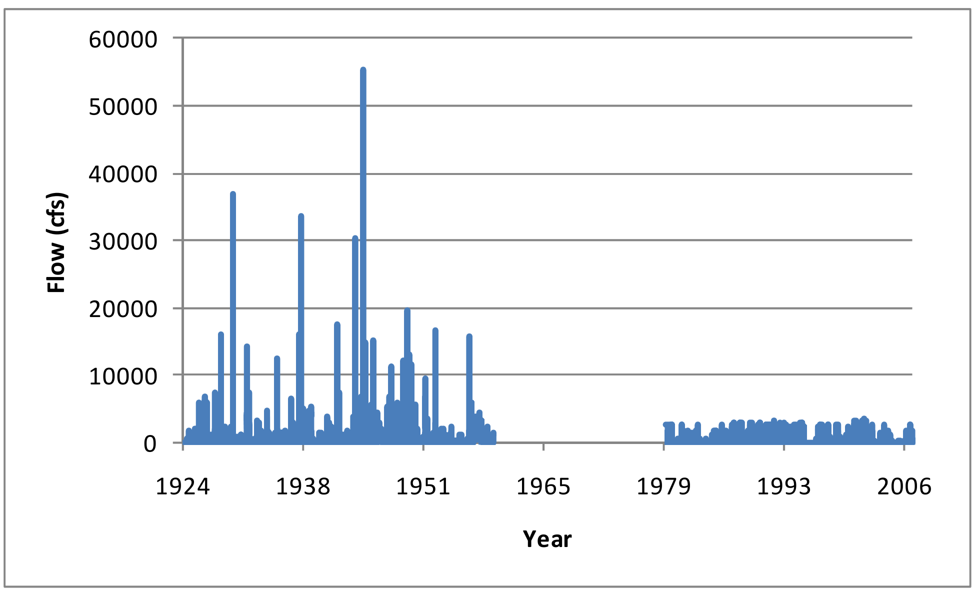

Figure 3 Flow data for USGS gage 07346000 Big Cypress Creek near Jefferson (gage was not active from 1960-1979).

The natural variability of the flow regime of Little and Black Cypress has been largely unaltered. (Figure 4 and Figure 5)

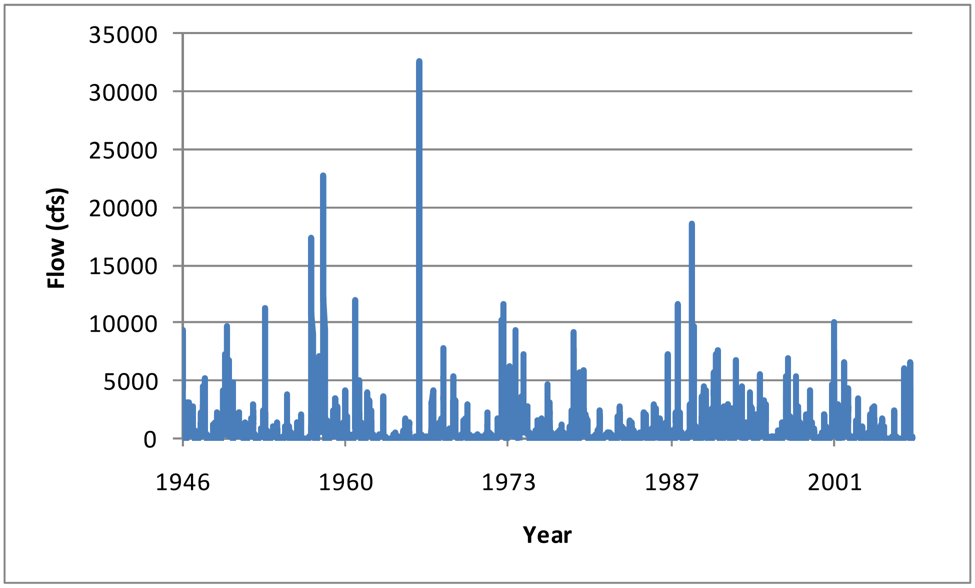

Figure 4 Flow data for USGS gage 07346070 Little Cypress Creek near Jefferson.

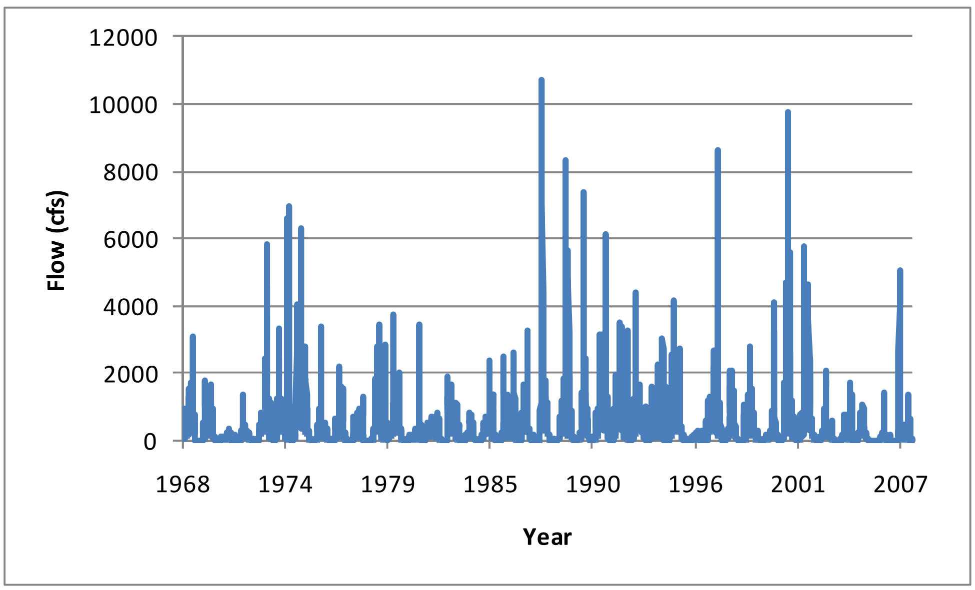

Figure 5 Flow data for USGS gage 07346045 Black Cypress Creek at Jefferson.

The largest change to flows on Big Cypress has been the change in peak or flood flows as highlighted in Figure 6. Prior to dam construction, the annual peak flow was as high as 57,000 cfs as occurred in 1945. Following dam construction peak flows remained around 3,000 cfs with very little variation. The median annual peak flow for Big Cypress prior to the dam was around 15,000 cfs.

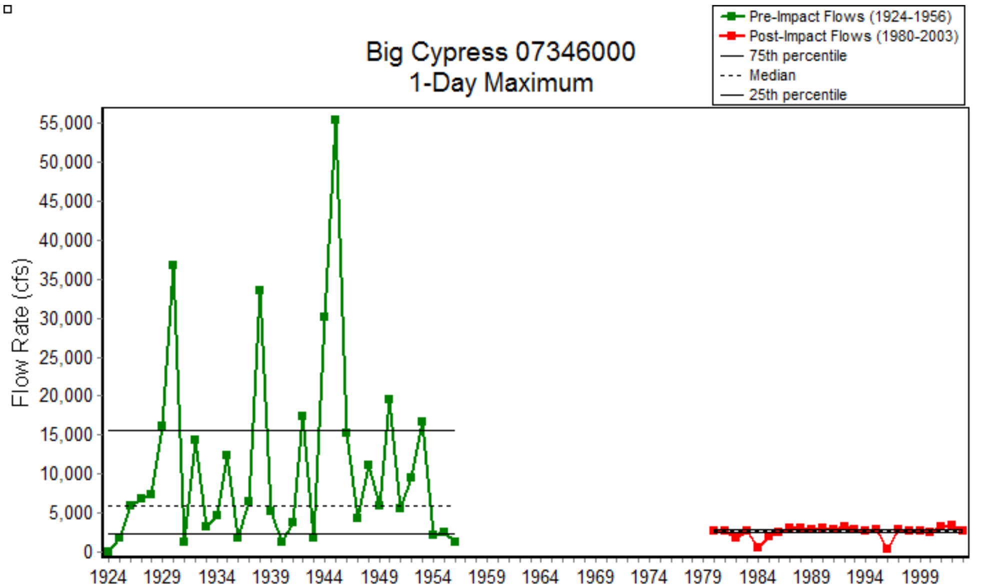

Figure 6 1-day maximum flows for USGS gage 07346000 Big Cypress Creek near Jefferson.

Peak flows at Little Cypress are as high as 30,000 cfs and for Black Cypress are as high as 10,000 cfs.

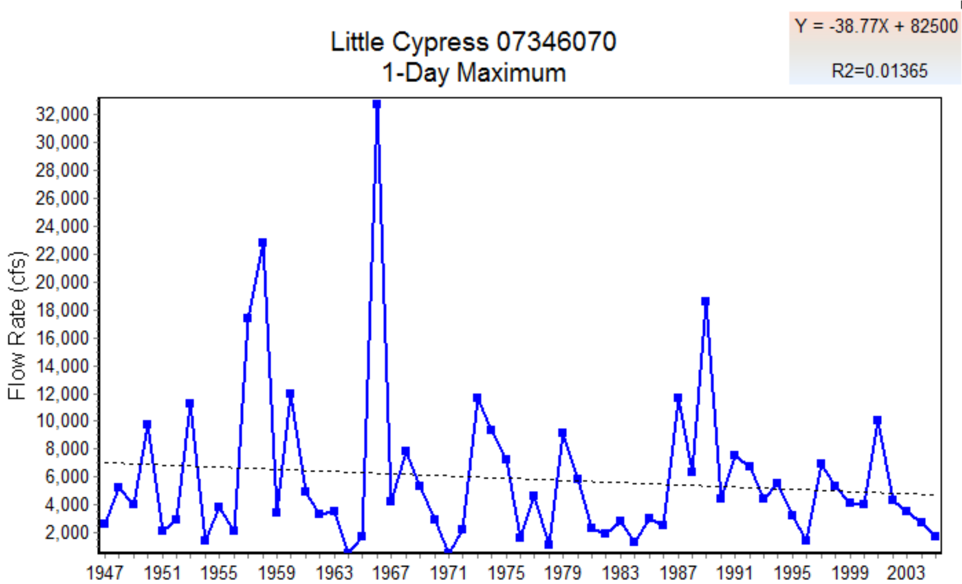

Figure 7 1-day maximum flows for USGS gage 07346070 Little Cypress Creek near Jefferson.

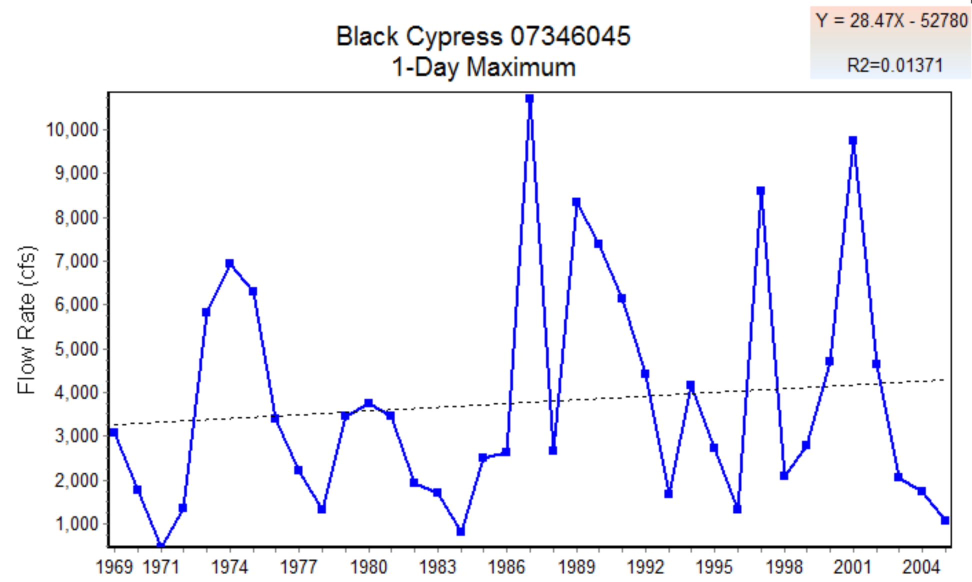

Figure 8 1-day maximum flows for USGS gage 07346045 Black Cypress Creek at Jefferson.

Recurrence interval calculations demonstrate the dramatic changes in peak flows that have occurred on Big Cypress (Figure 9). Prior to dam construction, peak flow of at least 6,000 cfs occurred on an interval of every 2 years. A 20,000 cfs flow occurred on average about every 10 years. The two-year recurrence interval flows for Little and Black Cypress are 3,000 and 4,000 cfs respectively.

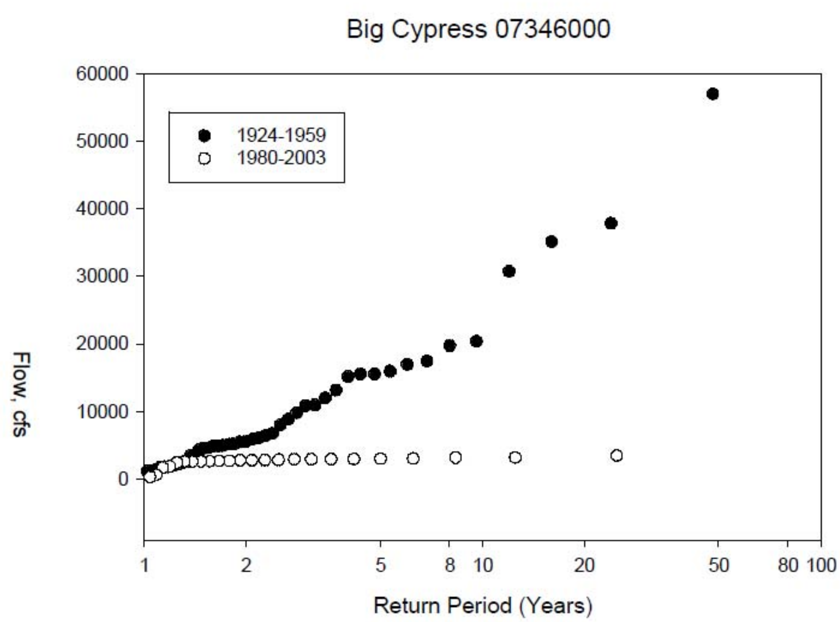

Figure 9 Flow recurrence graph for Big Cypress Creek near Jefferson for pre and post-dam years.

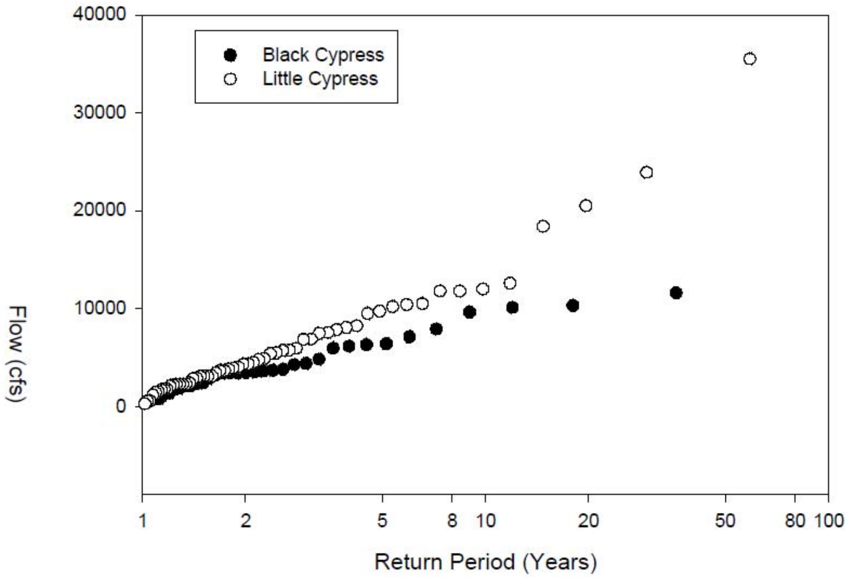

Figure 10 Flow recurrence for Black Cypress Creek and Little Cypress Creek at Jefferson.

Prior to dam construction at the Lake O' the Pines, most peak flows in Big Cypress were concentrated between April and May. After the dam construction, the timing of peak flows was shifted more towards the beginning of the year (Figure 11)

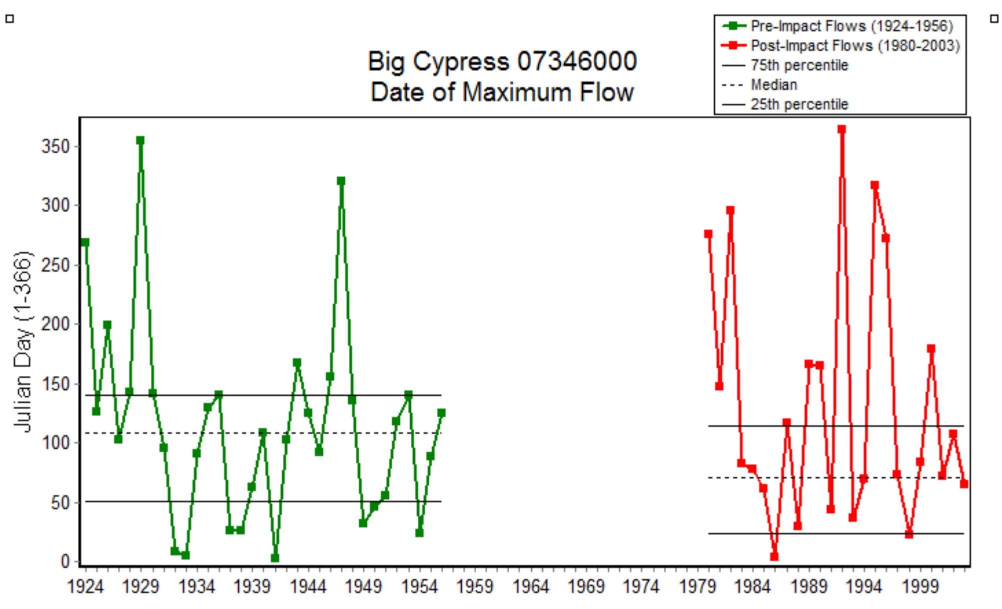

Figure 11 Date of maximum flow for USGS gage 07346000 Big Cypress Creek near Jefferson.

Low flow conditions in Big Cypress Creek have also changed since the Lake O’ the Pines reservoir was constructed. Figure 12 highlights how the 7-day low flows have increased in the post-dam years. The median 7-day low flow prior to the dam was around 5 cfs. After the dam, it is around 20 cfs. Of equal if not more importance is that the timing of low flow conditions has changed dramatically as highlighted in Figure 13. Prior to the dam, low flows were consistently around the first part of September (Julian day 250). Following construction of the dam, the date of low flow conditions became much more variable.

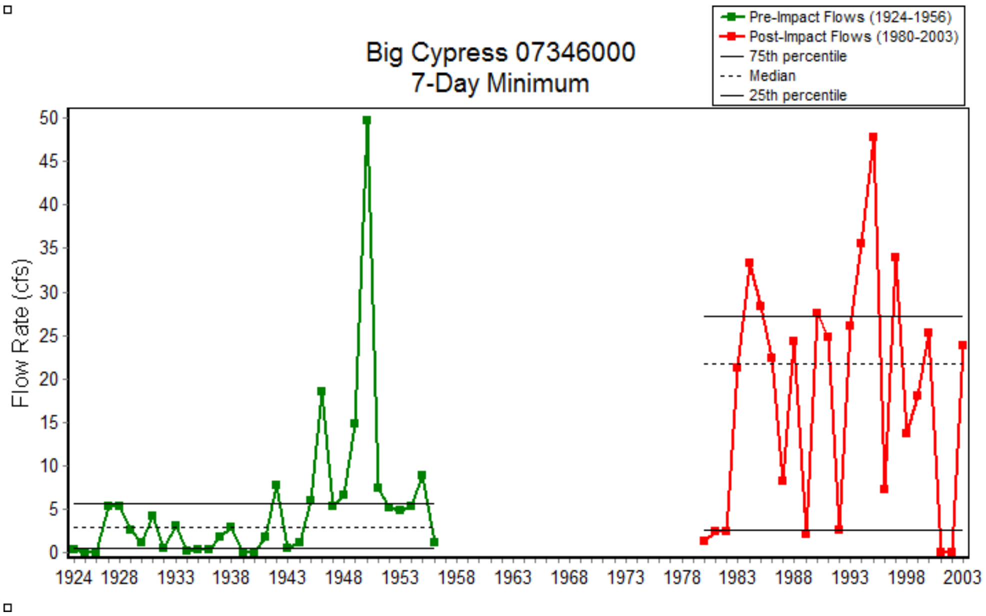

Figure 12 7-day minimum flows for USGS gage 07346000 Big Cypress Creek near Jefferson

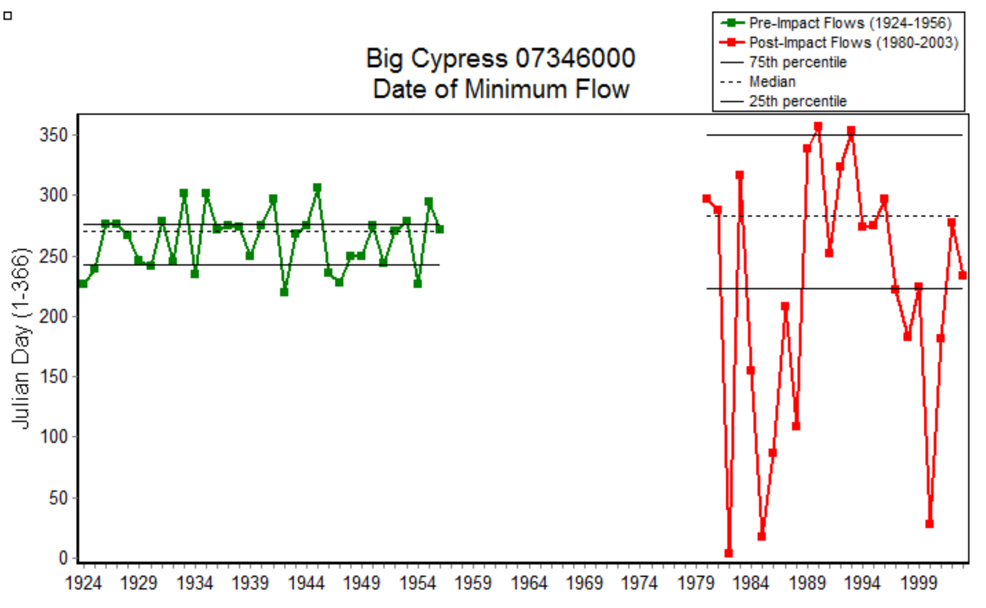

Figure 13 Date of minimum flow for USGS gage 07346000 Big Cypress Creek near Jefferson.

From an annual average inflow perspective, flow in Big Cypress has been reduced by about 5% following dam construction, probably because of increases in evaporation from the lake surface. The complete results of the IHA analysis for Big, Little and Black Cypress are available at caddolakeinstitute.us/flows.html.

2.1.1.2 GEOMORPHOLOGY

Changes in Geomorphological Processes

The Cypress drainage basin reflects geomorphological processes active during the past 2 million years. The geomorphology of Big Cypress Creek (reach between Lake of the Pines and Caddo Lake) was mapped by the U.S. Army Corps of Engineers, Vicksburg District as part of the Red River Waterway Project (USACOE 1994). Three geomorphic surfaces were identified according to their physical characteristics, apparent age, and types of processes active on the surfaces: floodplain, terrace, and valley slopes (Table 2).

Table 2 Geomorphic surfaces in the Big Cypress drainage basin (USACOE, 1994).

Surface	Landform-Formation	Age	Geomorphic Processes
Floodplain	Point Bar (PB)	H	LA
	Point Bar (PB2)	H-(P?)	LA-VA-BT-SF
	Lacustrine Delta (LD)	H	LA-VA
	Abandoned Course (ACO)	H	VA-LA
	Abandoned Channel (AC)	H	VA-LA
	Undiff. Tributary Alluvium (QAL)	H	VA-LA
Terrace	Abandoned Flood Plain (QTU and QTP)	H-P	E-SF
Valley Slopes	Claiborne Group	T	E-SF
	Sparta (ECS)	T	E-SF
	Weches (ECW)	T	E-SF
	Queen City (ECQ)	T	E-SF
	Reclaw (ECR)	T	E-SF
	Carrizo (ECC)	T	E-SF
	Wilcox Group (EWU)	T	E-SF
	Midway Group (PMU)	T	E-SF

AGE: H – Holocene, P = Pleistocene, T= Tertiary
PROCESS: VA = Vertical Accretion, LA = Latetral Accretion, ET = Sioturbation, SF = Soil Forming Processes, E = Erosion

Whereas valley slopes are Tertiary in age (65 to 2 million years), the terrace and floodplain were formed primarily in the Quaternary (2 million years to present) and specifically during the Holocene. Terraces are abandoned floodplains elevated above the present river's floodplain; they flood on the order of 100 to 500 years. Floodplains form by deposition of sediments transported by the stream. In the geomorphic analysis conducted by the U.S. Army Corps of Engineers (1994), floodplains were defined as the area subject to inundation by a flood with a recurrence interval of 2 years, following Leopold, Wolman and Miller (1964). The floodplain contains point bars (which range in thickness from 25 to 30 feet and in texture from sand at the base to finer silts and clays toward the surface), levees (formed by vertical accretion when the stream floods and deposits suspended sediments along the banks), and numerous abandoned channels and courses as well as oxbow lakes that form when river channels cut across their point bars (Figure 14). The Big Cypress is therefore characteristic of a lowland meandering river.

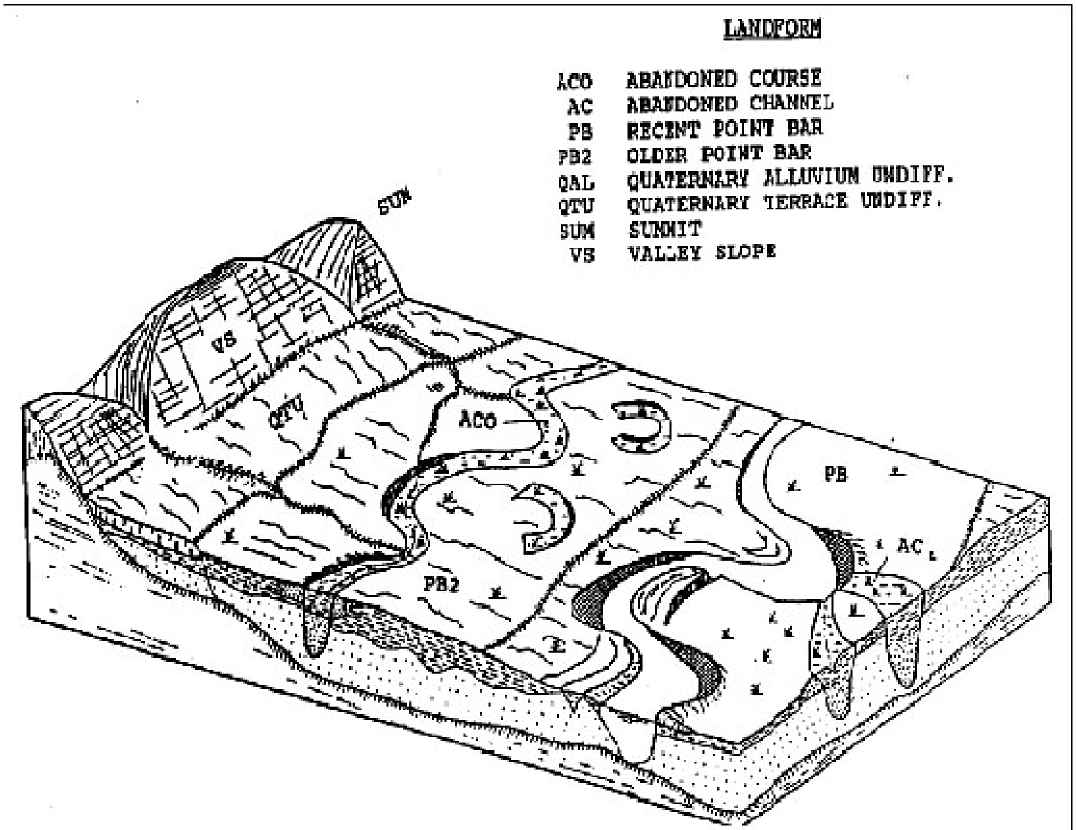

Figure 14 Generalized block diagram of Big Cypress Drainage Basin showing geomorphic features (USACOE, 1994).

Channel-Floodplain De-coupling

The geomorphological features present on the floodplain are evidence of active river migration and a tight channel-floodplain coupling under natural conditions. Before closure of Ferrells Bridge Dam in 1960, the floodplain upstream of Caddo Lake was inundated every 1-2 years at a discharge of 6,000 cfs (Figure 9). This flow occupied the bankfull river channel and is the dominant discharge necessary to form and maintain an equilibrium channel geometry (Knighton 1998). This is also the discharge needed to sustain floodplain development and riparian ecosystem.

The immediate result of flow regulation by Ferrells Bridge Dam has been the decoupling of the floodplain from river channel processes. The closure of Ferrells Bridge Dam has changed frequency-magnitude relations so that at present, little variation in flow magnitude exists, and maximum flows do not exceed ~3,000 cfs (Figure 6 and Figure 9). Floodplains are therefore not inundated under the present flow regime. (Quantification of bankfull flow was identified as a priority research issue early in the CFP. Subsequent field observations indicate that riparian and flood plain inundation begins at significantly lower flows; between 1,800 and 2,500 cfs in the segment of Big Cypress Creek above the City of Jefferson. This flow validation work is discussed in detail in Section 2.2.4) Maximum flows of ~3,000 cfs are also below the dominant discharge necessary to maintain an equilibrium channel geometry.

Sediment Trapping by Lake O' the Pines Reservoir

Construction of Ferrells Bridge Dam has also affected sediment movement and delivery into Caddo Lake. As expected, sediment trapping by Lake O' the Pines Reservoir has reduced sediment input into the downstream channel reach and ultimately into Caddo Lake. The extent of sediment trapping can be estimated by assessing changes in storage capacity in the reservoir (Phillips et al. 2004). In 1958, the original conservation reservoir storage capacity of Lake O' the Pines Reservoir was 254,900 acre-feet. By 1998, the reservoir capacity as reported by the USGS was 238,933 acre-feet (TWDB 2004). This represents a decrease of 6% in reservoir capacity due to sedimentation, equaling 492,378 cubic meters of trapped sediments per year behind the reservoir. In some cases, such as the nearby Trinity River (Phillips et al. 2004) and Sabine Rivers (Phillips 2003), this reduction in sediment supply downstream of reservoirs is partly offset by increased bank and bed erosion. However, insufficient information is available for Cypress Creek to determine whether similar erosion processes are producing additional sediments for delivery into Caddo Lake.

Reduced Transport Capacities

The drastic reduction in flood peaks (Figure 6) is also expected to decrease sediment transport capacities downstream of Ferrells Bridge Dam. Stream power for a cross-section represents the total transport capacity of the river at a given cross-section and can be calculated for the pre-dam and post-dam period. These calculations were performed for the cross-section immediately downstream of the dam, where USGS gauging station 07346000 is located.

Stream power is $\Omega = wQS$

where Ω = stream power (N/s)
w = specific weight of water = 9807 $kgm^{-2}s^{-2}$
Q = discharge (m^3/s)
S = slope

Using a slope of 2.47 feet/mile or 0.000468 (Slack et al. 2001), the stream power for the pre-dam bankfull discharge of 6,000 cfs (that occurred every 2 years, and that inundated the floodplain) is ~779 N/s (Table 3).

Table 3 Stream power of a 2-year recurrence interval flow before and after dam construction.

Time Period	Q with 2-yr R.I. cfs (cms)	N/s
Pre-dam (12924-1959)	6000 (169.8)	779.33
Post-dam (1980-present)	3,000 (84.9)	389.66

Now, under the present flow regime, because the maximum discharge has been reduced to 3,000 cfs (Figure 6), the maximum transport capacity is ~390 N/s. These results show that sediment transport capacity has been reduced by 50%. Thus, although increased erosion has been demonstrated to occur below some dams due to clear-water or "hungry-water" effects (Kondolf 1997), these effects tend to be limited to the area immediately below the dam (Phillips 2003), and the overall effect of reduced flood peaks are decreased transport capacities. A similar decrease in transport capacities in Yegua Creek downstream of Somerville Dam in south-central Texas has resulted in reduced channel capacities over time (Chin and Bowman 2005, Chin et al. 2002).

Sediment Entrainment

To answer the question of whether sediments present in the channel downstream of Lake O' the Pines are being transported into Caddo Lake, sediment entrainment calculations were performed. Because quantitative particle size data are unavailable for Cypress Creek, these calculations were performed for a series of particle sizes ranging from clay to fine sand, which are known to be typical for this channel reach (Barrett, personal communication). Two sediment samples collected and analyzed in November 2004 by a student at Texas A&M University were also in the fine sand range (median sizes of 0.165 mm and 0.097); they corroborate qualitative estimates of particle size. These samples were collected in the channel close to the banks at locations near Jefferson and at Hwy 43 upstream of Caddo Lake.

Critical shear stresses required to entrain clay, silt, very fine sand, and fine sand were therefore calculated (diameter equal to 0.0015 mm, 0.02 mm, 0.075 mm, and 0.175 mm, respectively). Two equations were used, which produced similar results.

Shield's equation is:

$$\tau_c = 0.045(s-1)\rho g D$$

where τ_c = critical shear stress (N/m2 or Pa)
D = median diameter of sediments (mm)
s = relative density of sediments to water = 2.65
ρg = specific weight of water = 9807 kg m-2 s-2

Church's equation is (Church 1978):

$$\tau_c = 0.89D$$

where τ_c = critical shear stress (N/m2 or Pa)
D = median diameter of sediments (mm)

Table 4 shows that, for sediments ranging from medium sand to clay, flows with shear stresses ranging from 0.274 N/m^2 to 0.001 N/m^2 are required to entrain them.

Table 4 Critical shear stresses required to entrain sediments ranging from medium sand to clay.

Class Name	Diameter (mm)	Shield's τ_c (N/m^2)	Church's τ_c (N/m^2)
Medium Sand	0.375	0.274	0.334
Fine Sand	0.175	0.128	0.156
Very Fine Sand	0.075	0.055	0.067
Silt	0.02	0.015	0.018
Clay	0.0015	0.001	0.001

To determine flow depths needed to generate the critical shear stresses required to entrain sediments, the DuBoy's equation was used:

$\tau_o = \rho g\ ds$

where τ_o = shear stress
(critical shear stress calculated for various sediment sizes using Shield's and Church's equations, Table 4)
ρg = specific weight of water
d = depth (m)
s = slope

Application of the DuBoys equation indicated that, for sediments ranging from medium sand to clay, flow depths of 60 m to ~0.3 m would have sufficient shear stresses to entrain these sediments (Table 5).

Table 5 Average depths required to have sufficient shear stresses to entrain sediments ranging from medium sand to clay.

Class Name	Avg. Depth based on Shield's m (ft)	Avg. Depth based on Church's m (ft)
Medium Sand	59.6 (195.7)	72.7 (238.6)
Fine Sand	27.8 (91.3)	33.9 (111.3)
Very Fine Sand	11.9 (39.1)	14.5 (47.7)
Silt	3.2 (10.4)	3.9 (12.7)
Clay	0.24 (0.78)	0.29 (0.95)

The final step to determine whether sediments are capable of being moved under the present flow regime is to relate the average depths to discharges. Using data available at the channel cross-section immediately downstream of Ferrells Bridge dam, where USGS gauging station 07346000 is located, the relationship between average depth and discharge was established (Figure 15). This relationship enables discharges corresponding to the calculated critical depths for sediment entrainment (Table 5) to be determined.

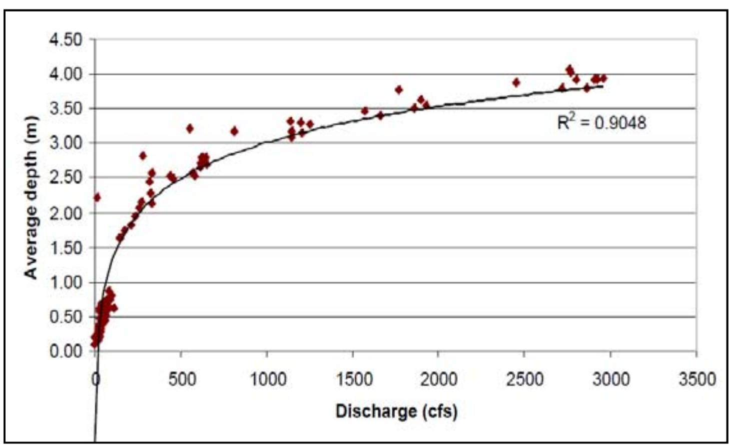

Figure 15 Depth-discharge relationship at cross-section downstream of Ferrells Bridge Dam.

Combining Table 5 and Figure 15, results indicate that the present flow regime is capable of entraining only silts and clays. Clays are mobilized at a discharge of ~25 cfs, whereas silts require a discharge of 1,250 cfs to be entrained (Table 6). Because sands (very fine, fine, and medium) require flow depths corresponding to discharges that exceed 3000 cfs, which is the maximum flow under the present regulated regime (Figures 2 and 5), they are not being mobilized by present flows.

Table 6 Required discharges to entrain sediments ranging from medium sand to clay.

Class Name	Avg. Depth based on Shield's m (ft)	USGS x-sctn cfs
Medium Sand	59.6 (195.7)	>3000
Fine Sand	27.8 (91.3)	>3000
Very Fine Sand	11.9 (39.1)	>3000
Silt	3.2 (10.4)	1250
Clay	0.24 (0.78)	25

Sediment Delivery into Caddo Lake

The last piece of available data to give insight to the issue of sediment delivery into Caddo Lake is analysis of sedimentation rates within Caddo Lake (Barrett 1995, Lisanti 2001). Modern sedimentation rates (1963 to present) were measured using gamma ray spectroscopy at seven sites within Caddo Lake (Lisanti 2001), yielding sedimentation rates ranging from 0.22 cm/year to 0.56 cm/year, with two sites not measurable. Although Caddo Lake receives sediment input from sources other than Cypress Creek, and thus sedimentation rates within the lake are not perfect analogs for sediment delivery through Cypress Creek, variations in sedimentation rates nevertheless give additional information to corroborate previous analyses. It is worthy to note that the two sites located immediately at the outlet of Cypress Creek (Cypress Bayou delta) have the lowest sedimentation rates (both 0.22 cm/year). These sedimentation rates are only half of the rate of 0.56 cm/year at the outlet from James Bayou. Low sedimentation rates at the Cypress Creek outlet support previous conclusions that 1) sediment supplies are reduced downstream of Lake O' the Pines; 2) sediment transport capacities are reduced due to a drastic reduction in flood peaks; 3) only the finest sediments (clays and silts) are being mobilized under the current flow regime.

In summary, both flow regime and sediment regime have been altered by flow regulation at Ferrells Bridge Dam since 1960. The overall result is a river floodplain disconnected from the river channel at present.

The high flow regime does not appear to have changed in Black and Little Cypress Creeks and therefore it is expected that natural sediment transport characteristics remain largely unchanged in these drainages. The caveat to this is that the sediment load characteristics may have changed because of timber and agricultural activities; however, these land use alterations have not been investigated as part of this study.

2.1.1.3 Water Quality and Macrophytes

The analysis of the relationship of flows and water quality relied upon several documents and the work of the Watershed Protection Planning Process. The basic documents included:

- Texas A&M Summary Report Supporting the Development of Flow Recommendations, 2005 (http://www.caddolakeinstitute.us/Docs/TAMU_SummaryReport_April2005.pdf)
- Cypress Creek Basin Summary and Highlights Reports (http://www.netmwd.com)
- Analyses prepared for the Caddo Lake Watershed Protection Plan (http://www.netmwd.com)
- Draft Discussion Paper on Flows and Water Quality by Tim Osting, Espey Consultants, Inc. 2008. (http://www.caddolakeinstitute.us/docs/flows/dec08meeting/draft_discussion_paper_on_flows_and_water_quality.pdf)

The Cypress Creek Basin appears to be at the transition zone between a mesotrophic and eutrophic system. The process of eutrophication seems to be accelerated in some of the subbasins due to anthropogenic activities within the watershed, including nutrient loadings. (NETMWD 2010) Many other water quality parameters, such as dissolved oxygen, bacteria, mercury and pH have become problematic. According to the state's 303(d) listings, the number of impairments in the Cypress Creek Basin continues to increase.

The latest Basin Summary Report for the Cypress Creek watershed, by Water Monitoring Solutions, Inc., in 2009 provides a review of the historical water quality data and trends based on the TCEQ Surface Water Monitoring Information System database. The Basin Summary states that water quality over the period of record has remained relatively stable in the Little Cypress Creek and Black Cypress Creek watersheds. However, significant trends were found in Big Cypress Creek beginning in Lake Cypress Springs and Lake Bob Sandlin and ending in the upper end of Caddo Lake. The report identifies five statistical trends:

- Increasing trends for specific conductance/TDS throughout the Big Cypress Creek watershed,
- Increasing trends for pH in Big Cypress Creek and James Bayou,
- Increasing trends for phosphorus in Big Cypress Creek below Lake Bob Sandlin and corresponding increasing chlorophyll a trends in Lake O' the Pines,
- Decreasing DO in the upper portion of Caddo Lake, and
- Decreasing DO and pH along with increasing chlorophyll a in Black Bayou.

Fourteen stream segments in the Cypress Creek watershed have been listed as impaired or not supportive of water quality criteria for one or more parameters. The number of impairments generally continues to increase with several added by TCEQ in 2010. The most common parameters listed were dissolved oxygen, pH, E. coli, bacteria and mercury in fish tissue. Nutrients and chlorophyll a were also identified in the 2008 Texas Water Quality Inventory as water quality concerns in the watershed.

Table 7 Impairments in the Cypress Basin.

Segment	Description	Parameter
401	Caddo Lake	Low DO, Low pH, High Mercury in Tissue
0401A	Harrison Bayou	Low DO
402	Big Cypress Bayou below Lake O' the Pines	Low pH, High Mercury in Tissue
0402A	Black Cypress Bayou	Low DO, High Bacteria, High Mercury in Tissue, High Copper*
404	Big Cypress Creek below Lake Bob Sandlin	High Bacteria, Low DO*
0404A	Ellison Creek Reservoir	High PCBs in Tissue, High Sediment Toxicity High Copper*
0404B	Tankersley Creek	High Bacteria
0404C	Hart Creek	High Bacteria
0404N	Lake Daingerfield	High Mercury in Tissue
0404O	Dragoo Creek	High Bacteria*
0404P	Unnamed tributary to Tankersley Creek	High Bacteria*
0404Q	Unnamed tributary to Tankersley Creek	High Bacteria*
0404R	Unnamed tributary to Dragoo Creek	High Bacteria*
405	Lake Cypress Springs	Low DO (has been removed)
406	Black Bayou	Low DO, Low pH, High Bacteria
407	James' Bayou	Low DO, Low pH, High Bacteria
409	Little Cypress Bayou (Creek)	Low DO, High Bacteria, High Copper*
0409B	South Lilly Creek	High Bacteria

*Added in 2010.

Located at the bottom of much of the Cypress watershed, Caddo Lake receives contaminants from a wide variety of activities. In addition to the trends toward eutrophication, a major concern has been the rampant growth of macrophytes, especially in the upper reaches of Caddo Lake. These have created significant problems for use of the Lake and, with decay, they increase the accumulated biomass, which adds to the conditions of low dissolved oxygen and may fuel summer phytoplankton blooms and fish kills. Levels of mercury in bass and some other large fish has lead to fish consumption advisories, warning of the risks of eating too much of these fish.

High inflows during the summer months when temperatures are highest and dissolved oxygen and pH are lowest appear to be the most beneficial to water quality problems, including nutrients, in the Lake. It is unclear from available data whether high flushing during winter and spring months will have a strong impact on summer months.

High inflow and lake-level lowering are possible strategies that should be examined to address water quality and macrophytes. There are not likely to alleviate the problems entirely. Control options involving mechanical removal and the application of chemicals and biological controls are also likely to be needed.

Lower inflows will not flush nutrients from Caddo Lake as quickly as higher inflows. For the same reasons mentioned above, intermediate and low flows will be more effective at flushing nutrients from the system during the summer months. Low inflows would likely have very little impact on alleviating potential problems associated with low dissolved oxygen and pH. In other words, during conditions of low inflow Caddo Lake will likely continue to be plagued by periodic conditions of poor water quality. It is not clear, however, whether these were characteristic traits of the system which occurred during historical (i.e. pre-Lake O' the Pines Dam) low flow periods.

Lake drawdown has been an effective tool to help control growth of submerged and floating macrophytes in some lakes. For Caddo Lake this might not be a viable option in the future, but releases from the current dam only occur as water flows over the spill way.

2.1.1.4 Floodplain Vegetation

In the Cypress Creek Basin and around the greater Caddo Lake area, bottomland hardwood and bald cypress forests occupy areas of the floodplain ranging from low areas that are permanently inundated to higher areas that are infrequently inundated, yet may still have saturated soils. It is widely accepted that the structure and function of these alluvial river swamps is tightly coupled with hydrologic energy. In fact, hydrologic variability may be the single most important factor affecting the local distribution of bottomland tree species within their natural ranges. In alluvial settings such as the Big Cypress Creek floodplain, these forested wetlands receive periodic disturbances in the form of a flood pulse that is important in delivering nutrients and altering soil physico-chemical properties to the point that upland species are excluded. The high flows typical of these events are also important in scouring and dispersing many of the seeds produced in alluvial river swamps.

The key to the establishment and long-term maintenance of these wetland forests is through seedling recruitment. Without periodic, successful recruitment of new seedlings, these systems may become more even-aged and more susceptible to human perturbations. For most of the species found in these forests, seeds are released in late summer/early fall—usually between September and October. For the Caddo Lake region, this period historically was the dry season and corresponded with low flows in the Big Cypress Creek basin. Rapid growth—from seed germination–seedling stage—up to the next flood pulse (usually in late winter/early spring) is needed for the successful establishment of a new cohort of saplings in the forest. These hydrologic conditions prevailed up to the installation of the dam for Lake O' the Pines in the 1950s. In fact, it has been suggested that seedling recruitment has been depressed in some areas of the Big Cypress and Caddo Lake region because of these hydrologic alterations. Still other past impacts such as logging and drainage and fill of adjacent floodplain area and nutrient enrichment need to be considered in addition to biotic processes such as herbivory and exotic species invasion.

Recommendations are for high flows to occur during the historic early spring flood pulse period. These high flows will scour and distribute seeds to a large area of the floodplain and should start to decline into late spring, bottoming out in early summer. Low flows in Big Cypress Creek during the historical dry summer will then be needed to allow for the establishment (i.e. germination) of seeds and growth to a level at which many will be able to survive the following year's spring high water period. Periodic draw down in Caddo Lake will also likely be important in recruiting a new generation of bald cypress to this perennially lentic environment.

2.1.1.5 Aquatic Fauna

Fishes obviously depend on in-stream flows to provide aquatic habitats in which to live, but there are many other direct and indirect effects of water availability, flow characteristics, and water quality on fish behavior and ecology. In lowland floodplain rivers, such as the major tributaries that deliver water to Caddo Lake, the annual hydrological regime greatly influences the quantity, quality, and connectivity of aquatic habitats that are required by the various fish species during each stage of their life cycles. The fish fauna of the Cypress Basin can be divided into four groups: 1) fishes directly dependent on flowing channel habitats, 2) fishes directly dependent on non-flowing backwater habitats, 3) fishes not directly dependent on flowing or backwater habitats but which may use either to varying degrees, and 4) migratory fish.

Rather than develop an exhaustive assessment of each fish species, we have developed a list of “indicator” species under each category that may be useful in establishing targets for restoration. Some of these species are threatened, in a few instances are now locally extinct, as a result of hydrologic modifications and perhaps other impacts.

The paddlefish (*Polyodon spathula*) has been greatly reduced in abundance and distribution throughout its range due to pollution and especially construction of dams that block migration routes, regulate flow, and alter channel geomorphology and substrate composition. Paddlefish spawn in the spring when water levels rise rapidly. After the larvae develop within deep pools of the main channel, the juveniles move into backwater (lentic) habitats. Spring floods have been greatly curtailed in Big Cypress Creek, and this may have eliminated cues and conditions needed for spawning. In addition, the lack of floods has likely resulted in the degradation of shoal habitats that are critical spawning habitat for this species.

The chain pickerel (*Esox niger*) spawns during late February and early March and requires lentic habitats for all stages of its life cycle, even during the egg-laying stage when eggs are typically scattered in littoral vegetation. In terms of its in-stream flow requirements, the chain pickerel would benefit from flow regimes that maintain permanent aquatic habitat in the floodplain. Periodic pulsed flows would be important for dispersal of juvenile and adult pickerels among lentic (backwater) habitats along the margins of the main channel as well as within the floodplain.

The largemouth bass (*Micropterus salmoides*) nests in backwater areas lacking current, either along river or stream margins or in floodplain habitats such as oxbow lakes. It spawns from April until June, with spawning initiated when the water temperature rises above 65°F. Caddo Lake provides an outstanding habitat for this species, which would only be enhanced by maintenance of a flow regime on Big Cypress Creek that maintains oxbows and other permanent lentic habitats in the floodplains and facilitates dispersal.

The freshwater drum, or gaspergou, (*Aplodinotus grunniens*) occurs in pools where it feeds on benthic invertebrates. The drum spawns during April or May near the surface of the water column and buoyant eggs float with the current before hatching into larvae, that also float. At the post-larval stage, they move to the bottom where they begin feeding as juveniles. The freshwater drum has flow requirements for spawning and dispersal of early life stages that are very similar to those described for paddlefish. It might also benefit from extended periods of low flow during summer, as this should enhance benthic foraging opportunities.

The bluehead shiner (*Pteronotropis hubbsi*) is a threatened species that schools in backwaters and marginal areas away from significant current and seems to spawn from early May to July. It appears that late spring and early summer low flow conditions may be most conducive to successful spawning and recruitment by this rare species, but its presence in oxbow lakes reveals a necessity for periodic overbank flows allowing dispersal between channel and oxbow habitats.

The Bigmouth buffalo (*Ictiobus cyprinellus*) and smallmouth buffalo (*Ictiobus bubalus*) do not seem to be strictly dependent on flow regime, but may show enhanced recruitment under appropriate flow regimes. Both species initiate spawning around April in shallow, lentic backwaters after spring floods raise water levels. Therefore, pulsed flows during spring or other periods of the year would allow dispersal of immatures and adults between channel and floodplain habitats.

The ironcolor shiner (*Notropis chalybaeus*) spawns from mid April until late September, and eggs are scattered in stream pools over sand substrate. It seems unlikely that reproduction and recruitment by this small streamdwelling minnow are highly dependent on pulse flows during spring. One could even hypothesize that extended periods of low flow over the summer could enhance recruitment in this spring-summer spawning species.

Big Cypress Bayou and other associated drainages are home to a very diverse freshwater mussel assemblage with a least 26 species identified since 1913 (Howells 1996). One species, the Louisiana pigtoe (*Pleurobema riddellii*), documented by Mather and Bergmann (1994) is one of the rarest Texas unionids and has a state ranking of S1 (critically imperiled). Another S1 ranked unionid, the sandbank pocketbook (*Lampsilis satura*), is thought to inhabit the Cypress Bayou system (Marsha Mays, personal communication), but has never been documented. Howells (1996) suggested that, while the Cypress Bayou systems still support relatively abundant unionid populations, habitat alteration and degradation have reduced populations from historic levels. In addition, he states that many species tolerant of soft bottom habitats and eutrophication were represented by multiyear classes indicating successful reproduction. In contrast, heavily shelled species were represented by older adults only and no signs were found of recent reproductive success in these species. Because many mussel species require a host fish for their parasitic glochidial stage of development, and rely on flow for dispersal of offspring and settlement of juveniles, environmental flows that favor fishes will also favor mussels.

2.1.1.6 Terrestrial and Semi-Aquatic Wildlife

The streams, wetlands, open water bodies, and bottomland forests of the Cypress Basin support a rich and abundant herpetofauna, with 45 species documented by a study that surveyed a relatively small area. Many, perhaps most species, would respond to restoration of aquatic floodplain habitats with enhanced populations. In some cases, this population enhancement would result from creation of additional breeding and rearing habitats, and in other cases, it would be a response to additional food availability and foraging opportunities. In addition, pulse flows provide connectivity of aquatic habitats that permit dispersal by semi-aquatic species.

Two of the state's "threatened" reptiles occur within the basin—alligator snapping turtle (*Macrochelys timminckii*) and the timber rattlesnake (*Crotalus horridus*). The bird assemblage of the basin is estimated to contain 313 species. Two of the state's threatened bird species are likely to use habitats present in the basin—whitefaced ibis (*Plegadis chihi*) and woodstork (*Mycteria americana*). The region is an important migratory corridor for many species, with several lakes in the basin used by wintering waterfowl for foraging and resting. Degradation and losses of wetland habitat are considered the major threats to waterfowl. Although many waterfowl now obtain significant food resources from flooded agricultural fields, forested wetlands are required to meet the full biological requirements of most species. Little research has been conducted on mammals of the Caddo Lake region. Historically, the red wolf (*Canis rufus*) and Louisiana black bear (*Ursus americanus luteolus*) would have inhabited the region. A two-year survey of the Longhorn Army Ammunition Plant recorded 10 species, with taxonomic diversity greatest in the pure pine areas, and abundance greatest in the mixed pine-hardwood. Semi-aquatic mammals in the basin include the beaver (*Castor candadensis*) and river otter (*Lutra canadensis*).

2.1.1.7 Summary of Environmental Flow Relationships

A major alteration of the natural flow regime in the basin occurred when Ferrells Bridge Dam was constructed on the main stem of the upper Big Cypress Creek in the late 1950s. Flow regulation results in elimination of flood flows during late winter-early spring and greatly reduced pulse flows year-round and increased summer low-flows. This in turn results in reduced bed scouring (yielding loss of structural habitat diversity within the channel and creation of backwater habitats), sediment delivery, sediment deposition on floodplains, and over-bank flooding. All of these changes have detrimental effects on aquatic and riparian population dynamics, which ultimately results in reduced species diversity and smaller populations of species of plants, and animals that depend on the natural flow regime for creation of essential habitat for foraging and reproduction, maintenance of ecosystem productivity, and/or dispersal. For example, the paddlefish (breeding population was extirpated in the early 1960s) required flood flows to maintain shoals and to provide cues for spawning. This species also required periodic pulse flows to allow movement between channel and backwater habitats used by juveniles and adults for foraging. Similarly, the major bottomland hardwood tree species required high flows for seed dispersal and to limit encroachment of upland tree species into floodplains. Flow regulation also results in higher daily flow fluctuations and higher late spring and early summer flows, which result in lower water temperatures. These changes impact benthic ecosystem productivity in the channel, foraging opportunities for benthivorous organisms, fish growth rates, and spawning by aquatic species that depend on stable, low flows during summer. These impacts result in degraded fisheries, decline of sensitive and rare species, alteration of aquatic and riparian communities and ecosystems. Although it provides about a third of the total inflow to Caddo Lake, flow regulation in Big Cypress Creek probably has major effects on the lake ecosystem. Sufficiently high inflows would influence nutrient concentrations and phytoplankton dynamics. During periods of low flow, internal nutrient dynamics (involving sediments, bacteria, water column, macrophytes and algae) would be prevalent. Prolonged periods of low-flow, uninterrupted by pulse flows, during late summer result in acute aquatic hypoxia in the shallow (deltaic) upper segment of the Lake.

2.1.2 Flows Workshops and Building Blocks (Preliminary Flow Regime Matrices)

Flow regime matrices were developed and revised at three multi-day flow workshops and at numerous subgroup meetings, which occurred between the full workshops.

First Workshop - May 2005

At the first workshop, three days in early May 2005, the initial work was the development of a first cut at building blocks for Big Cypress Creek downstream of Lake O’ the Pines and for Caddo Lake. The goal was to develop proposals that could be tested with releases from Lake O’ the Pines, while the CFP gathered additional information, including information on whether building blocks for other rivers and streams could be based on the approach taken with Big Cypress Creek. The building blocks were intended to enhance the ecological structure and function of Big Cypress Creek, its floodplain, and Caddo Lake, with the ultimate goal of providing benefits to local flora, fauna, and stakeholders in the region. Document reports on the historical flow conditions (i.e., pre-dam) in Big Cypress Creek and their role in shaping the lotic, lentic, and floodplain ecosystems of this region.

Over eighty scientists, water managers, and local community members participated in the first workshop. After reviewing the data and analysis included in the literature survey and summary report, including presentations on each of the major disciplines, participants worked together in breakout groups to qualitatively define necessary dimensions of the flow component patterns including magnitudes frequencies, durations and timing for a full range of hydrologic conditions and inter and intra-annual variation. The workgroup also identified knowledge gaps and prioritized research tasks that would be necessary to validate or, if necessary, refine these preliminary recommendations.

Second Workshop - October 2006

The second multi-day workshop was held in October 2006, and the work focused on developing building blocks for Little and Black Cypress Creeks, after considering possible changes to the building blocks for Big Cypress and Caddo Lake. Because of drought conditions, the CFP had not had the opportunity to test assumptions and the building blocks with releases from Lake O’ the Pines. The needed rains came in January 2007. Thus, the building blocks developed in the May 2005 workshop were not changed.

To prepare for the work on Little and Black Cypress Creeks, a supplement to the literature survey was completed, including IHA and recurrence interval flow statistics for these streams. There was first a discussion of whether the building blocks for Black and Little Cypress could be developed by using the approach used for the building blocks for Big Cypress Creek. The consensus was that this approach was appropriate.

Third Workshop - December 2008

A third flows workshop was held in December 2008 at which time the results of targeted research facilitated an environmental flow regime analyses (application of overlays) leading to several refinements of the preliminary flow regime matrices. The working group also decided to make a significant adjustment to the form of the flow recommendations on the unregulated sites on Little and Black Cypress by adopting a narrative approach for Black Cypress and hybrid (part Building Block, part narrative) approach for Little Cypress. This decision was motivated by the recognition that the wetlands associated with Caddo Lake have very high resource value and the concern expressed at the second workshop that the limited high flow events defined by the building blocks might not be satisfactory to maintain the ecological health of these streams that currently experience largely unaltered flow regimes. At this third flows workshop, the working group also made recommendations to develop flow regimes at ungaged sites based on drainage area adjustment. Having reached consensus on the science-based environmental flow regime recommendations; the CFP began the process of developing flow standards and strategies. The results of this process will be presented in a subsequent report.

2.1.2.1 Big Cypress Creek

The initial building blocks for Big Cypress Creek, developed in May 2005, are presented in Figure 16. (The revised final flow recommendations are in Figure 32) The flows portrayed in this figure include magnitudes, duration and seasonal timing as well as a prediction of the ecological outcome that would be expected if the flow condition were attained.

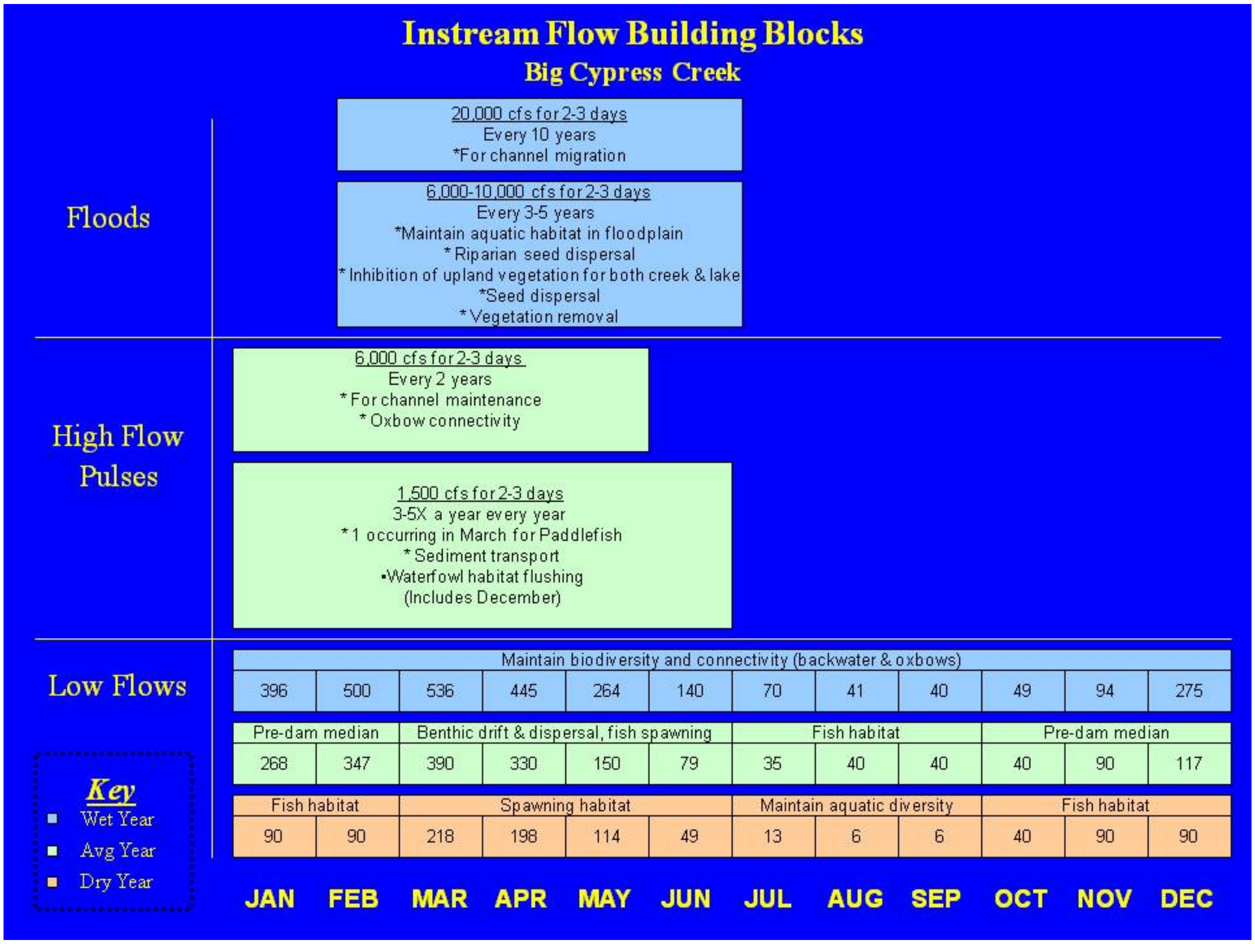

Figure 16 Initial building blocks for Big Cypress Creek, May 2005.

The low-flow targets are based upon a variety of ecological objectives. The fish habitat objectives are based upon on overlay of fish habitat simulation modeling performed by the USFWS and USACE (Cloud, 1984, USACE 1994). Other targets were based upon the fish habitat modeling results as well as a review of the pre-dam low-flow conditions for each month, as derived from the "Indicators of Hydrologic Alteration" (IHA) software. For instance, the 25th percentiles of the pre-dam flows were largely used as a basis for the July-September flows in dry years, medians were used for setting the October-February average flows, and the 75th percentiles were used as a reference in setting wet year flows.

The high-pulse flows in December-June were based upon pre-dam flow records, ecological information provided in the Summary Report, and professional judgment. Based on analysis of pre-dam flow data, historical durations and frequencies of these high flow events were somewhat larger than what is recommended by this matrix, however biologists participating in these discussions felt that fish and other mobile aquatic and amphibious organisms would be able to move into or out of secondary channels and oxbow lakes fairly quickly (e.g., during a single day) during these high-flow pulses. The duration of these events was set at 2-3 days to allow for some ramping time on the rising and falling limbs of these high-flow pulses. Fluvial geomorphologists similarly felt that necessary sediment transport could also occur during these short pulses. After some discussion about the fact that the median duration of high-flow pulses was 11 days during the pre-dam period, workshop participants agreed that the high-flow pulse duration deserved close attention during the implementation and adaptive management phase of the project. Similarly, because high-flow pulses occurred with a median frequency of seven times per year in the pre-dam period, the number of pulses to be targeted should be closely examined.

The 6,000 cfs target for channel maintenance is based upon the assumption that the pre-dam 2-year flood magnitude approximates the bankfull discharge level. It is well established in the geomorphic literature that the bankfull discharge is the level at which the majority of sediment transport occurs, and is therefore a primary determinant of channel geometry (i.e., width and depth of the river channel). An accurate determination of the bankfull discharge level has been identified as a top-priority research need (Appendix B). Based upon this research, the flow magnitude and necessary recurrence interval for this building block was later refined.

Somewhat less frequently (i.e., at 3-5 year intervals), a flow of 6,000-10,000 cfs would be needed to provide additional ecological benefits including riparian seed dispersal, maintenance of aquatic habitats in the floodplain, and maintenance of riparian vegetation diversity. Even less frequently (10 year intervals), a flood of 20,000 cfs would be needed to drive channel migration across the floodplain, which is an important mechanism for creating or maintaining habitat for both aquatic and terrestrial organisms.

2.1.2.2 CADDO LAKE

Caddo Lake received special attention because of its location at the bottom of the Cypress Basin. It also has been designated as a “Wetland of International Importance” under the Ramsar Convention, now signed by 160 nations. (see caddolakeinstitute.us/ramsar.html)

One outcome of the first workshop was an initial finding that management of flows in Big Cypress Creek may not need to be adjusted to benefit Caddo Lake. This was based largely upon the fact that Big Cypress contributes about one-third of the total inflow to Caddo Lake. The other two-thirds entering Caddo Lake comes from other tributaries that are currently largely unaffected by dams or diversions. These relatively natural inflows from other tributaries result in a considerable rise in lake levels during floods and can provide flows to Caddo sufficient to inundate most of the wetlands around the lake.

The dam for Caddo Lake, which is a weir, is fixed with the lowest spillway at an elevation of 168.5 NGVD. Under present conditions, the lake level will drop below that elevation during low flows, but these reduced levels of the lake do not often exceed 2 feet.

The workshop participants recommended an evaluation of the option of installing an outlet that would allow lowering lake levels for a number of purposes, including nutrient management, cypress regeneration, and invasive species control. (In 2010, the U.S. Army Corps of Engineers announced a plan to begin a study that would include the feasibility of replacing the weir with a dam that includes an outlet for lowering lake levels.)

The consensus was also that nutrient levels in Caddo Lake are contributing to the undesirable abundance of aquatic plants, phytoplankton blooms and conditions of low dissolved oxygen. The participants concluded that lake flushing could more efficiently be accomplished by drawing down the lake and that any such nutrient removal effort should be carried out adaptively, using monitoring to inform decisions about the necessary design and duration of the Project.

Another potential benefit of lake lowering could be bald cypress regeneration in areas that presently do not dry sufficiently to allow seed germination and seedling recruitment. Such a drawdown might need to occur in at least two consecutive growing seasons for this goal, and, thus, could have significant impacts on use of the lake and the local economy.

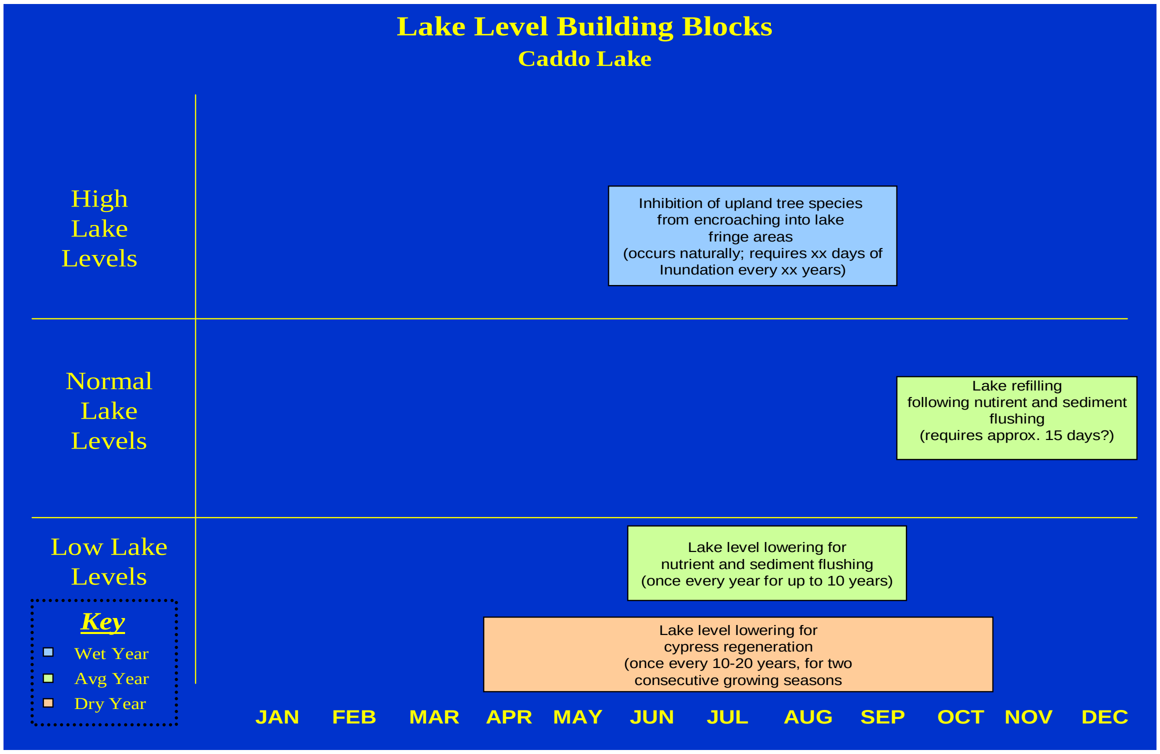

Figure 17 Initial building blocks for Caddo Lake, May 2005.

2.1.2.3 Little Cypress and Black Cypress Creeks

The second Flows workshop expanded the geographic scope of the CFP to include the other major gaged tributaries to Caddo Lake. There was a consensus that the building blocks for Black and Little Cypress could be developed by using the approach used for the building blocks for Big Cypress Creek. The original summary report included data from the entire basin and was again used to inform workshop participants' decisions. A supplemental report was prepared to include a hydrological analysis of the historical data from these tributary gages using the IHA software. Breakout groups were again relied upon to facilitate discussions.

One breakout group proposed that Black Cypress Creek be designated an "untouchable" stream, essentially setting a narrative flow regime on top of the building blocks that would assure adequate pulse and flood flows for the Creek and to help protect Caddo Lake. The group felt that Black Cypress Creek should remain in the as pristine a state as possible to serve as: (1) a source of unregulated flows to Caddo Lake; (2) a reference state for other creeks; and (3) a refuge for biota. (In 2010, The North East Texas Regional Water Planning Group recommended that Black Cypress Creek also be designated an Ecologically Unique Stream Segment.)

This breakout group also proposed that historically large flood events should still occur on Little Cypress, to maintain the wetlands associated with Caddo Lake, however there was also a consensus that this segment may not require the same level of protection was recommended for Black Cypress.

There was consensus on the use of the IHA-EFC 25th, 50th and 75th monthly low flow percentile values as reasonable starting values for the base flows. There was some discussion of augmenting the IHA-derived monthly percentiles with values developed in the Physical HABitat SIMulation (PHABSIM) study conducted by the USFWS (USFWS 84) and it was suggested that the same could be done for Little Cypress. The recommended flow from PHABSIM for Black Cypress in September was 75 cfs while the monthly median flow was 3 cfs and for Little Cypress the PHABSIM recommended September flow was 75 cfs while the median was 11 cfs. Stipulating an August and September low flow of 75 (seven to twenty times greater than the median flow) would change the creeks from ones that frequently had intermittent flow during the dry season to ones that had consistent elevated base flows. Therefore, the flows recommended by that study were not adopted in the Building Blocks.

It was recognized that very low flows, specifically the 25th percentile flows for August-October, might result in a series of disconnected pools. In order to maintain the connectivity between pools, it was proposed that the absolute minimum flows for Little and Black Cypress should not be less than 5 and 4 cfs, respectively.

While there was a consensus to follow the Big Cypress approach for the high-flow pulse target at the 2-year flood, there was again considerable discussion about what this flow represents, e.g. whether it reflected the bankfull flow or the effective discharge. Based on the USGS's preliminary analysis on Big Cypress, it was felt that the 2-year flood may overestimate the physical bankfull flow. Therefore the lower bound on the 95th percentile confidence interval of the 1.5-year flood, which in Big Cypress was close to the bankfull observed by the USGS, was selected as a lower range and an upper range, to ensure that the water will get up steep banks in some areas.

There was also consensus to develop building blocks for large floods in a manner similar to the approach used for as the building block for Big Cypress. For Big Cypress, a building block for a large flood stipulated that a flood of 20,000 cfs (approximately 10-year recurrence interval) should occur once every ten years on average. Thus, for Little and Black Cypress, floods of approximately 13,000 and 8,000 cfs for 2-3 days every ten years were proposed for late winter or spring.

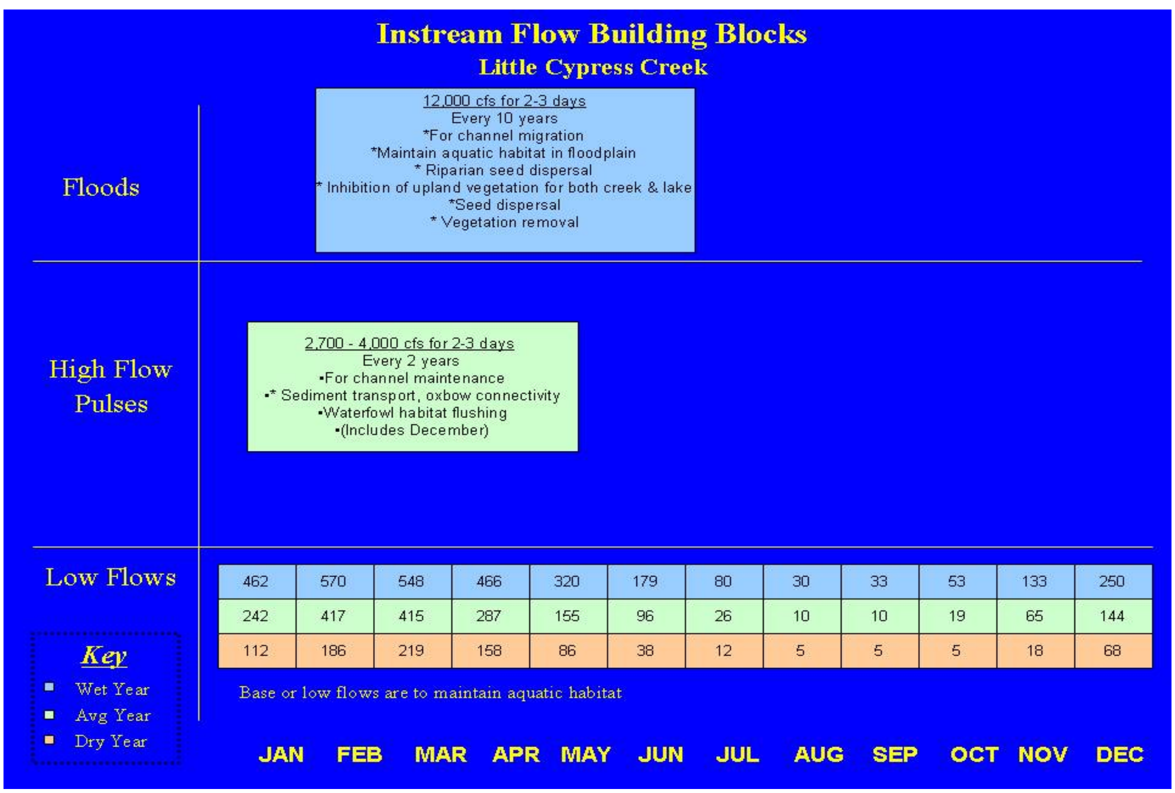

Figure 18 Initial building blocks for Little Cypress Creek, October 2006.

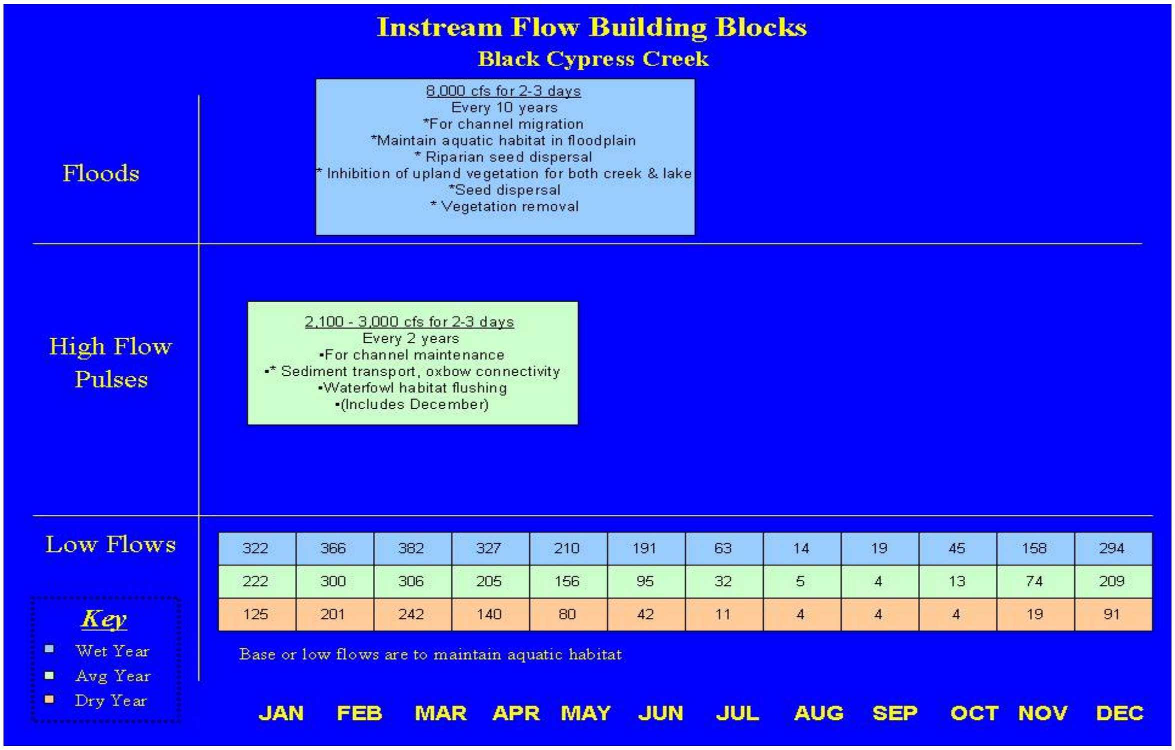

Figure 19 Initial building blocks for Black Cypress Creek, October 2006.

2.1.2.4 Knowledge Gaps and Research Priorities

At each workshop, after preliminary flow matrices were developed, participants identified knowledge gaps and prioritized research tasks. These issues were grouped under the various instream flow disciplines and workplans were developed to address the highest priority issues (Appendix B).

The CFP has been able to initiate work on some of these workplans in order to address high priority research needs. This has been due to the participation in the CFP of water managers that have been willing to facilitate some limited implementation experiments that are probably beyond what might be expected in a regular BBEST process. To the extent possible, the workgroup has used these experiments to inform further environmental flow analysis and overlays.

2.2 Environmental Flow Analysis (Overlays)

"Environmental flow analysis" "means the application of a scientifically-derived process for predicting the response of an ecosystem to changes in instream flows or freshwater inflows." [§Sec. 11.002 (15)] In the CFP, the environmental flow analysis has included all reasonably available science described in Section 2.1.1 and the collection and additional data and development of predictive models.

Beginning in 2008, the SAC produced a number of guidance documents describing the application of overlays relating to biology, geomorphology, and water quality (SAC 2009a-e). Although some CFP study elements had already been initiated when this guidance was produced, an effort was made to incorporate and, to the extent possible, adapt the CFP to follow the direction provided in these documents. The essential direction from SAC guidance has been to develop a preliminary flow matrix including a full regime of flow components employing hydrological statistics as a starting point. The SAC then proposes that the BBESTs apply knowledge from other scientific disciplines to refine this preliminary flow regime matrix by overlaying information from other disciplines.

The application of overlays in the CFP is described in the following sections. The section on **Biology** focuses on the relationship between base flows and instream aquatic habitat. This relationship was determined based on site-specific data collections and instream habitat modeling. The section on **Water Quality** reviews existing water quality data and known impairments, describes the relationship between flow and water quality issues of concern and describes the judgment as to whether the recommended flow would likely cause the stream to fail to maintain water quality standards. The section on **Geomorphology** is focused primarily on high flow events and their ability to transport sediments and maintain the channel and riparian areas. Finally, the **Connectivity** section relates primarily to overbank flows needed to inundate riparian and wetland areas associated with the creeks. The primary tools used to address this issue have been the collection of elevation discharge data, modeling and analysis using Geographic Information Systems (GIS) tools. The overlay process in the CFP was developed in several stages. Initial overlay information was compiled in the Texas A&M report and was used to refine a subset of flow matrix numbers at the 2005 workshop. Subsequently, fieldwork and flow experiments addressing information needs identified at the 2005 workshop have provided additional information that has been overlain to refine the initial building blocks. These overlay steps are detailed below.

2.2.1 Biology

The SAC guidance document for conducting biological overlay provides a five-step process for applying biological information to refine or validate preliminary environmental flow recommendations.

STEP 1. Establish clear, operational objectives for support of a sound ecological environment and maintenance of the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies.

The objective of the environmental flow regime recommendations is defined by the legislation and the CFP interpretation of that legislation is provided in Section 1.2. With reference specifically to the habitat requirement of the biological community found in the Cypress basin, the operational objective is to provide instream "habitat conditions, including variability, to support the natural biological community" and "include ranges of flow appropriate for wet, average and dry hydrologic conditions." (TIFP 2008) This section, Section 2.2.1, will address instream aquatic habitat needs that are the primary function of base flows. The section on connectivity addresses biological issues as related to riparian and watershed communities and the flows needed to maintain their health.

STEP 2. Compile and evaluate readily available biological information and identify a list of focal species.

Compilation and evaluation of readily available biological information occurred in four areas:

1. Literature survey and summary report produced by Texas A&M,
2. Review and analysis of the site specific instream flow studies that have been conducted in the basin including correspondence and meetings with their principle authors,
3. New basin and reach level biological sampling, and
4. Review of all available historical fish collections to analyze historical trends in the fish community.

In the literature review and summary report section on aquatic fauna (Winemiller and others 2005), indicator species were identified based on their flow dependency and whether they were of conservation or economic concern. (Table 8)

Table 8 Indicator species with flow dependencies.

Scientific Name	Common Name	Flow Dependency
Polyodon spathula	paddlefish	Dependent - T&E
Esox niger	chain pickerel	Dependent - Sport
Micropterus salmoides	largemouth bass	Dependent - Sport
Aplodinotus grunniens	freshwater drum	Dependent - Sport
Pteronotropis hubbsi	bluehead shiner	Responsive - T&E
Ictiobus bubalus	smallmouth buffalo	Responsive - non T&E
Ictiobus cyprinellus	bigmouth buffalo	Responsive - non T&E
Notropis chalybaeus	ironcolor shiner	Responsive - non T&E

Basic life history information, especially reproduction and spawning, was provided as well as life cycle relationships to intra-annual variation in flow magnitude. These relationships were depicted for each of the indicator species in figures similar to Figure 20. A complete Cypress basin species list including their general flow dependencies was provided in the appendix to the literature survey. A general conclusion of this survey is that the Cypress basin contains a very diverse fish community that exploits a wide range of instream habitat conditions.

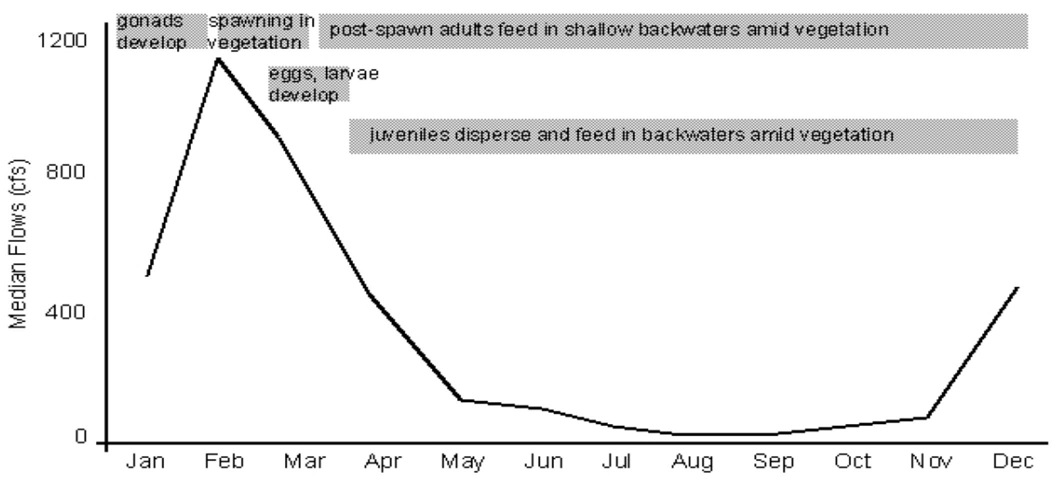

Figure 20 Chain pickerel (backwater-dependent species) life cycle relation to seasonal flow (portrayed relative to pre-1957 median flows in Big Cypress Creek) (Winemiller and others 2005).

In 1994, the USACE's Engineer Research and Development Center (ERDC) produced the most comprehensive site-specific evaluation of the aquatic community in the Cypress basin to date (USACE 1994). In addition to the development of one-dimensional hydrodynamic habitat models, discussed below, habitat specific fish collections were made at 21 sites in Big Cypress Creek from April to August 1992. Based on these and other historical collections, fish guilds were derived from categories along two dimensions: preferred velocity (swift water, slack water, and generalist) and spawning substrate (open water, sand and gravel, vegetation, and crevice). Habitat suitability criteria for the dominate species within these guilds (bold in red) were developed and used in the habitat modeling. (Figure 21) These curves allowed the Corps to model habitat responses to flows for species representative of the various guilds.

Table 9 Habitat guilds for Cypress and Twelve-mile Creek fishes, based on preferred velocities (horizontal axis and spawning substrate (vertical axis). Evaluation species are indicated in red bold. (USACE 1994).

		Prefered Velocities		
Spawning Substrate		Lacustrine/Generalist	Slack Water	Swift Water
	Open	Gizzard shad	American eel	Skipjack herring
		Mosqultoflsh	Threadfin shad	Emerald shiner
			Cypress minnow	Mimic shiner
			Silvery minnow	Freshwater drum
			Ribbon shiner	
	Sand and Gravel	Red shiner	Redfin shiner	Chestnut lamprey
		Green sunfish	Pallid shiner	Blackspot shiner
		Orangespotted	Bluehead shiner	Striped shiner
		Bluegill sunfish	Pugnose minnow	**Ironcolor shiner**
		Redear sunfish	River carpsucker	Sand shiner
		Largemouth bass	Creek chubsucker	Weed shiner
		White Crappie	**Spotted sucker**	Yellow bass
		Black crappie	Blacktail redhorse	White Bass
			Golden topminnow	Scaly sand darter
			Flier	Harlequin darter
			Warmouth	Goldatripe darter
			Redbreast sunfish	Redfin darter
			Dollar sunfish	River darter
			Longear sunfish	**Blackside darter**
			Spotted sunfish	Dusky darter
			Bantam sunfish	
			Spotted bass	
			Mud darter	
	Vegitation	Bowfin	Spotted gar	Longnose gar
		Common carp	Shortnose gar	Black buffalo
		Golden shiner	Alligator gar	
		Brook silverside	**Grass pickerel**	
			Chain pickerel	
			Taillight shiner	
			Lake chubsucker	
			Smallmouth buffalo	
			Bigmouth buffalo	
			Starhead topminnow	
			Blackstripe topminnow	
			Blackspotted topminnow	
			Inland silverside	
			Banded pygmy sunfish	
			Bluntnose darter	
			Swamp darter	
			Slough darter	
	Cervic	Bullhead minnow	Blue catfish	**Blacktail shiner**
		Black bullhead	Tadpole madtom	
		Yellow bullhead	**Flathead catfish**	
		Channel catfish	Pirate perch	
			Cypress darter	

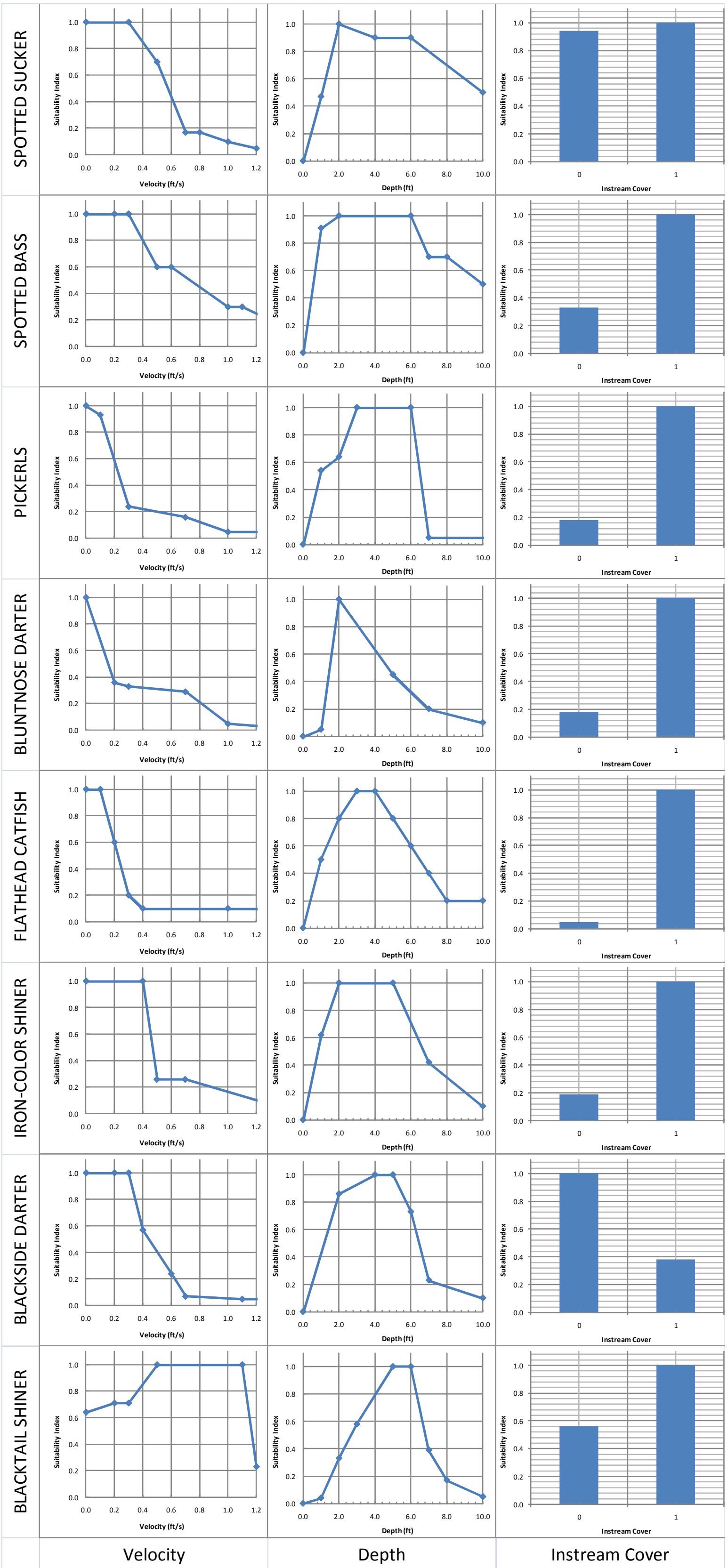

Figure 21 Habitat suitability criteria. (USACE 1994).

A research priority identified at the first flows workshop was to assess the current biological status of the Cypress Basin fish assemblage. Synoptic fish surveys as well as reach-based surveys were conducted throughout the lower segments of Big Cypress, Little Cypress and Black Cypress Creeks. Synoptic surveys are intended to provide a complete picture of the existing community and are therefore not limited to a strict protocol designed to produce a consistent level of sampling effort per site. The reach-based evaluations are intended to produce comparable levels of effort per site thus allowing comparisons across time and space between different sampling efforts. Reach-based sampling following TCEQ protocols were conducted on Big Cypress Creek by the USGS and recent comparable sampling efforts were undertaken on Black Cypress (Crowe and Bayer 2005) and Little Cypress (TSU unpublished data). Species richness, relative abundance, diversity, and a regional index of biotic integrity (IBI) were determined for the fish assemblages from each reach (Linam and others 2002).

Finally, regional and national museums (including the Smithsonian National Museum of Natural History, Texas Natural History Collection (University of Texas), Tulane University Museum of Natural History, University of Kansas Museum of Natural History and the Texas Cooperative Wildlife Collection (Texas A&M) and past monitoring activities (primarily conducted by universities and state and federal agencies, including the recent sampling efforts undertaken as part of the current CFP effort (USGS 2006) were surveyed. The Fishes of Texas project at the Texas Natural History Museum was a particularly rich source of quality-controlled data. Historical collections throughout the basin going back to the 1950s were compiled and organized in a geodatabase. Following the approach used in the TIFP for the SB2 priority basins (Bonner and Runyan. 2007), these data were analyzed to determine fish species composition and abundances in Big Cypress, Little Cypress and Black Cypress Creeks and to determine if changes through time have occurred within each. The analysis also looked for these trends based on habitat, reproductive and trophic guilds. Given the rather patchy nature of this data through time, definitive findings are not possible, however the preliminary finding from this analysis found that for Big Cypress several species appear to be increasing or decreasing through time and that as a group, reproductive guilds that include riverine obligate species appear to be declining while more generalist species appear to be increasing.

Table 10 Trends in reproductive guilds in terms of relative abundances. (Pelagophils: Obligate riverine species, broadcast-pawn buoyant eggs within current, Lithophils: Includes most Centrarchidae, spawn elliptical egg envelopes over rock or gravel nests.)

Reproductive Guild	1953-54	1995	2006
Non guarders			
Open Substratum			
Pelagophilis	22.49	7.25	0.072
Guarders			
Nest Spawners			
Lithophils	7.38	42.58	56.15

After conducting this analysis, the preliminary conclusion was confirmed by the discovery of an unpublished manuscript by Jan Hoover and Jack Kilgore at ERDC. (Kilgore and Hoover have been studying the Cypress Basin since the 1980s.) Their report concluded that “the ichthyofauna of the Cypress Creek basin appears to have shifted from assemblages dominated by cyprinids, percids, and cyprinidontids in the 1950s to assemblages dominated by centrachids, other cyprinids, clupeids, and atherinids in the 1980s.” This shift in the community from riverine specialists to generalist is a well-documented response to altered flow regimes.

In summary the general life history information, provided by Texas A&M, for species with different flow dependencies suggest the value of a varied flow regime with a particular need for high flow pulses and overbank connectivity to riparian and oxbow areas. The instream flow study produced by ERDC in 1993 suggests the need for habitat diversity to provide for the needs of the whole community and the historical trend analysis suggests that riverine-dependent species may be declining relative to a more generalist-dominated community.

STEP 3. Obtain and evaluate geographically-oriented biological data in support of a flow regime analysis.

This section in the SAC guidance addresses the task of producing maps that might be used to describe the various river types that are encountered in the basin. Section 1.3 (Geographic scope) includes much of this information. This task seems particularly important for larger basins with a wider range of ecoregions and river types. The sites identified for the development of instream flow recommendations by the CFP all fall within the same ecoregion and the group concluded that they are sufficiently similar that different sites do not require the development of analysis that are fundamentally different.

However the CFP is in the enviable position, given the time and resources that have been devoted to this project and the long history of instream flow evaluation conducted in the Cypress basin, of having site-specific habitat data including new data that was collected as part of this study and data collected previously as part of earlier studies in the basin.

Among the knowledge gaps and research priorities identified during the development of the preliminary flow recommendations were the need to assess instream habitat availability at different low-flow levels. Beginning in 2006, the USGS led the field effort to collect data to fill in these knowledge gaps (USGS field work and analysis also included investigations related to geomorphic characterizations and quantification of riparian connectivity discussed below).

In October 2005, a site reconnaissance was undertaken to determine the location of adequate points of access to Big Cypress Creek over this segment, and to complete a rapid evaluation of habitat conditions and geomorphic features of the channel. The reconnaissance provided critical information in support of the selection of a set of candidate sites for baseline assessment of reach-based geomorphic features, fish assemblages, and for the installation of pressure transducers for monitoring stage and water temperature. Three sites were selected on Big Cypress upstream of Jefferson. An additional site downstream of Jefferson, as well as a site on Black Cypress, was added subsequently.

At each site, a channel reach was established based on a multiple of mean wetted channel width (20X) at low flow (Leopold 1964 and Fitzpatrick and others 1998). The upstream and downstream extents of each reach were selected to include at least two of each geomorphic channel units (GCUs) such as riffle, runs, or pools. GCUs are fluvial geomorphic descriptors of channel shape and scour patterns widely used in stream habitat assessments (Orth 1983; Ohio Environmental Protection Agency 1989). The GCU sequence was duplicated at each reach to facilitate comparisons between sites.

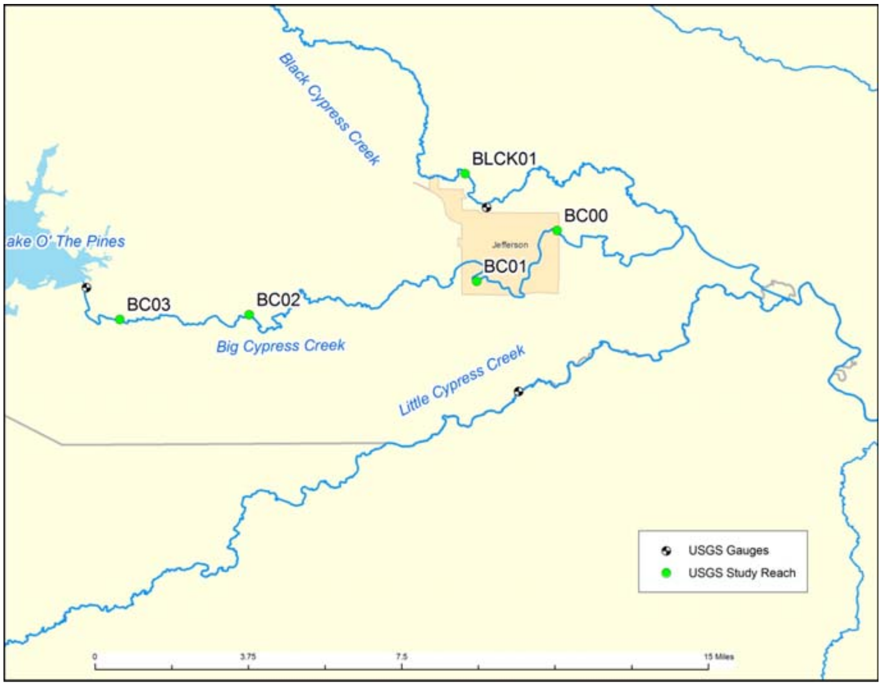

Figure 22 Map of USGS study sites.

Habitat and geomorphic data were collected at the segment, reach and transect scales (Table 11). At the segment scale (Big Cypress and Black Cypress segments), length and curvilinear length were measured and from these measures, gradient and sinuosity were determined (Fitzpatrick and others 1998). In addition, side-slope gradient was measured at ten regularly spaced intervals to provide an indication of the variability in the valley slope over the length of the segment. At the four study reaches on Big Cypress (BC00, BC01, BC02, and BC03) and the one on Black Cypress (BLCK01), water-surface gradient and the sequence, type and length of GCUs were determined. The horizontal and vertical extent of physical features such as undercut banks and woody snags were also surveyed. Within each study reach, eleven cross-section transects were distributed equidistant from the upstream to the downstream. Each transect extended from the high-bank terrace on one bank to an equivalent height on the opposite bank. For each transect, a number of measurements, including bank slope and bank height, were recorded. Within the stream and in alignment with each transect, stream depth, velocity, bed substrate composition, and habitat cover were measured at three points including the channel thalweg, and two additional points each one one-half the distance from the thalweg to the water's edge of each bank.

Table 11 Segment, reach, and transect-scale geomorphic and stream habitat measures.

Segment	Reach	Transect (n = 11 per reach)
Segment length (m)	Reach length	Bankfull height
Curvilinear segment length (m)	Curvilinear reach length	Bank slope
Segment gradient	Reach gradient	Bankfull width
Side-slope gradient	GCU type and length	Bank vegetative coverage
	Thalweg profile	Wetted channel width
		Depth
		Velocity
		Dominant and sub-dominant substrate
		Habitat cover
		Canopy closure
		Riparian buffer width and density

A number of site-specific instream flow studies have been conducted in the Cypress basins since the early 1980s. These studies generally followed the Instream Flow Incremental Methodology (IFIM), which produces predictive relationships between flow and an ecological response, namely the amount of habitat available to specific species generally selected to represent larger habitat guilds. There were two studies undertaken simultaneously on Little and Black Cypress (Cloud 1984, USACE 1987) in response to reservoir proposals on those tributaries and a more recent one to evaluate a proposal to extend navigation on Big Cypress (USACE 1994).

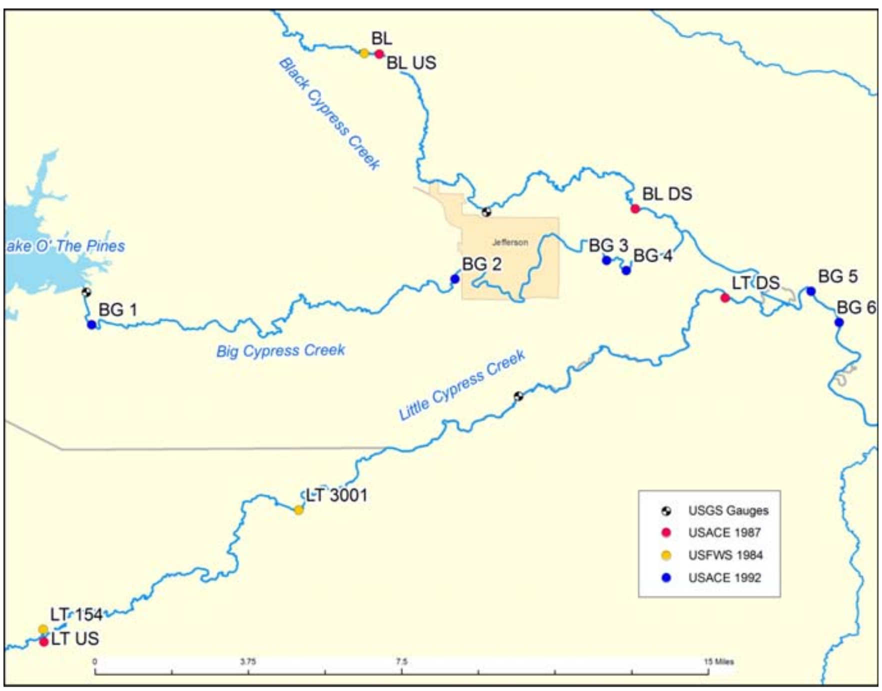

Figure 23 Map of previous Instream flow study sites.

The results of these studies were used in an overlay process to inform the development of the preliminary building blocks (Section 2.1.2.1). However, these studies were not specifically designed to address the same objective as SB 3, and in fact, the methods and findings reached by these studies are not entirely consistent with one another. The science of instream flows, while rooted in the same basic approaches to instream habitat modeling, has also evolved in the last two decades. Perhaps just as important as the findings from these studies, is the fact that much of the original data used to conduct these studies including cross-section surveys, flow versus water surface elevation rating curves, habitat suitability criteria and the computer input files for the 1-dimensional Physical Habitat Simulation Models (PHABSIM) is available and has been reviewed and in some cases reanalyzed as part of the CFP.

STEP 4. Parameterize the flow regime hydrological analysis using ecological and biological data.

The preliminary hydrologic analysis for Big Cypress was conducted by Texas A&M using the Indicator of Hydrologic Alteration (IHA) software. IHA is a forerunner to the HEFR, the hydrological statistics tool used in other BBESTs as part of SB 3. While both of these tools include functions not available in the other, the results produced by IHA appear to be very similar to what would have been produced had HEFR been available. Texas A&M provided the workshop participants complete IHA results including statistics for the pre-Lake O' the Pines period (1924-1936) and the more recent period (1980-2003). A similar analysis was produced based on gage data for Little and Black Cypress for the second flows workshop. The workshop participants agree to base the preliminary building blocks on the Pre-impact period for Big Cypress. This is consistent with TIFP and most of literature related to the science of instream flows. The technical approach of the TIFP, much of which has since been adopted in the SAC technical guidance documents, received a favorable external review by the NAS (NRC 2005). The NAS (2005) report noted that "state-of-the-science programs use natural flow characteristics as a reference for determining flow needs." Discussions of analysis provided in the summary report (Winemiller and others 2005), focused on the differences between the pre- and post Lake O' the Pines records. Since there have been no major flow quantity alterations on Little and Black Cypress, the entire period of record was used for each of these gages.

The approach utilized in the CFP follows current worldwide consensus regarding theory and tools for understanding and managing flow regimes. Over the last 30 years, river scientists have learned quite a bit about the functioning of rivers and the influence of flow regime on aquatic organisms, geomorphology, and other characteristics of rivers (NAS 1992; Gordon et al. 2004; Dyson et al. 2003; NRC 2005; Thorp et al. 2006; Locke et al. 2008). Through extensive research, river scientists and biologists have developed a “natural flow regime paradigm” which states that in general, the ecological integrity of river ecosystems depends on their natural dynamic character, especially their natural flow variability. River flow regime, which many ecologists consider the key driver of river ecology and function, influences habitat, biota, water quality and geomorphology of the rivers (Poff et al. 1997; Bunn and Arthington 2002; Cushing et al. 2006; Poff and Zimmerman 2009). For example, Bunn and Arthington (2002) conducted a literature review focused around four key principles to highlight the important mechanisms that link hydrology and aquatic biodiversity and to illustrate the consequent impacts of alterations to natural flow regimes. Tables 12-15 summarize their findings.

Table 12 Summary of biotic responses to altered flow regimes in relation to flow-induced changes in habitat (principle 1). (Bunn and Arthington 2002).

Flow variables affected	Biotic responses	Sources
Increased stability of baseflow and reduction of flow variability	Excessive growths of aquatic macrophytes	Rørslett 1988, Røslett and others 1989, Walker and others 1994, French and Chambers 1996, Blanch and others 2000
	Proliferation of nuisance larval blackflies	De Moor 1986
	Reduction in fish populations	Converse and others 1998
	Increased standing crop and reduced diversity of macroinvertebrates	*Armitage 1977, Ward and Short 1978, Lillehammer and Saltveit 1979, Williams and Winget 1979*
Erratic (diurnal) patterns in flow below hydroelectric dams	Reduction in species richness of benthic macroinvertebrates	Munn and Brusven 1991, *Mullan and others 1976, Trotzky and Gregory 1974*
	Reduction in standing crop of benthic macroinvertebrates	Layzer and others 1989, *Mullan and others 1976, Trotzky and Gregory 1974, Radford and Hartland-Rowe 1971*
	Stranding of macroinvertebrates	*Kroger 1973*
	Stranding of fish	Bradford 1997, Bradford and others 1995
Conversion of lotic habitat to lentic	Decline of populations of riverine crayfish and snails	Walker and others 1992
	Elimination of salmonids and pelagic spawning fishes and dominance of generalist fish species	Copp 1990
	Loss of fishes adapted to turbid river habitats	Stanford and Ward 1986a
	Loss of fishes due to inundation of spawning grounds	*Hubbs and Pigg 1976*

Table 13 Summary of life history responses to altered flow regimes (principle 2). (Bunn and Arthington 2002).

Flow variables affected	Biotic responses	Sources
Rates of water level fluctuation	Aquatic macrophyte growth rates and seedling survival	Blanch and others 1999, 2000, Froend and McComb 1994, Rea and Ganf 1994
Timing of spates	Reduced survivorship of larval atyid shrimps following early summer spates	Hancock and Bunn 1997[b]
	Stable low flows required for spawning and recruitment of riverine fish	Milton and Arthington 1983[b], 1984, 1985, Humphries and Lake 2000
Reduced seasonality	Reduced synchrony of breeding in gammarid shrimps	Bunn 1988[b]
Timing of rising flows	Loss of cues for fish spawning and migration	Lowe-McConnell 1985, Nesler and others 1988, King and others 1998
Short-term fluctuations in flows	Adverse effect on species of stoneflies with long larval development times (autumn/winter)	*Henricson and Müller 1979*
Modified temperature regimes below dams	Delayed spawning in fish	Zhong and Power 1996
	Disrupted insect emergence patterns	*Lehmkuhl 1972, Gore 1977,* Ward and Stanford 1982
	Reduced benthic standing crop	*Lehmkuhl 1972*
	Elimination of temperature-specific species of fish	*Trautman and Gartman 1974*

Table 14 Summary of biotic responses to loss of longitudinal or lateral connectivity (principle 3). (Bunn and Arthington 2002).

Flow variables affected	Biotic responses	Sources
Water abstraction	Reduction in migrating shrimp larvae	Pringle and Scatena 1999
Presence of in-stream barriers	Increased predation on juvenile migrating shrimp	Pringle and Scatena 1999
	Loss of migratory fish species	*Hubbs and Pigg 1976, Welcomme 1979,* Harris 1984a,b, Dauble and Geist 2000, Kareiva and others 2000, Reyes-Gavilan and others 1996, Joy and Death 2001
Reduced frequency, duration and area of inundation of floodplain wetlands	Reduced spawning areas and/or recruitment success of lowland river fish	*Jubb 1972, Whitley and Campbell 1974, Lake 1975, Welcomme 1979,* Geddes and Puckridge 1989, Cadwallader and Lawrence 1990
	Decline in waterbird species richness and abundance	Kingsford and Thomas 1995
	Decline in wetland vegetation	Kingsford 2000

Table 15 Summary of biotic responses to altered flow regimes in relation to invasion and success of exotic and introduced species (principle 4) (Bunn and Arthington 2002).

Flow variables affected	Biotic responses	Sources
Loss of wet-dry cycles and increased stability of water levels	Reduced growth and survival of native aquatic macrophytes and increased invasion of exotics	Kingsford 2000, Mitchell and Gopal 1991
Reduced flow variability and increased seasonal stability	Favor populations of exotic fish species (carp, mosquitofish)	*Edwards 1978,* Faragher and Harris 1994, Walker and others 1995, Gehrke and others 1999
Conversion of lotic to lentic habitat	Proliferation of exotic fish species	Arthington and Bluhdorn 1994, Davies and Day 1998
Interbasin transfers of water	Transfer of schistosomiasis; translocation of fish species	Pitchford and Visser 1975, Skelton 1986, Cambray and others 1986

This extensive body of research has established strong support for the links between biological processes and aspects of flow variability. The safest and simplest approach to insure that both natural variability and threshold conditions are restored or conserved is to mimic the natural flow pattern as closely as possible including variability patterns (wet, dry and average years, seasonal), and associated duration and magnitude of flows. One way of doing this, which the CFP utilized, is by using software such as IHA and HEFR that provides quantifiable endpoints that describe this distribution and recommends flow regimes that attempt to duplicate these endpoints as closely as possible.

These types of desktop hydrologic tools have been widely utilized in this application across the world. In one review of the use of such tools, Ogden and Poff (2003) reviewed 171 hydrologic indices from 420 sites across the USA and showed that the IHA method successfully characterizes all the major components of the flow regime. The results from their study showed that the IHA method adequately represented the majority of the variation explained by the entire population of 171 indices and thus captured the majority of the information available. Furthermore, the IHAs represent almost all of the major components of the flow regime, and therefore provide a good balance between objective selection of high information indices and accessibility in terms of computation.

STEP 5. Evaluate and refine the initial flow matrix.

Flow recommendations were evaluated at a third flows workshop in October 2008, based on analysis of the recent data collection efforts and of the physical habitat models available from previous studies. Data collected by the USGS in 2006-07, indicates that the base flow recommendation provide a range of habitat diversity relative to available instream structure. The dominant instream structures in the system are snags and cypress knees. During dry conditions, the lowest flows recommended are 8-13 cfs (Jul-Sep). Water surface elevations were surveyed at flow of 16.7 cfs and compared to surveys of instream snags (Figure 24). This comparison indicates that that these low flows provide good access to this patchy but important instream habitat. In the range of flows from 40-90 cfs, the base dry targets for October to February, these snags would begin to be inundated.

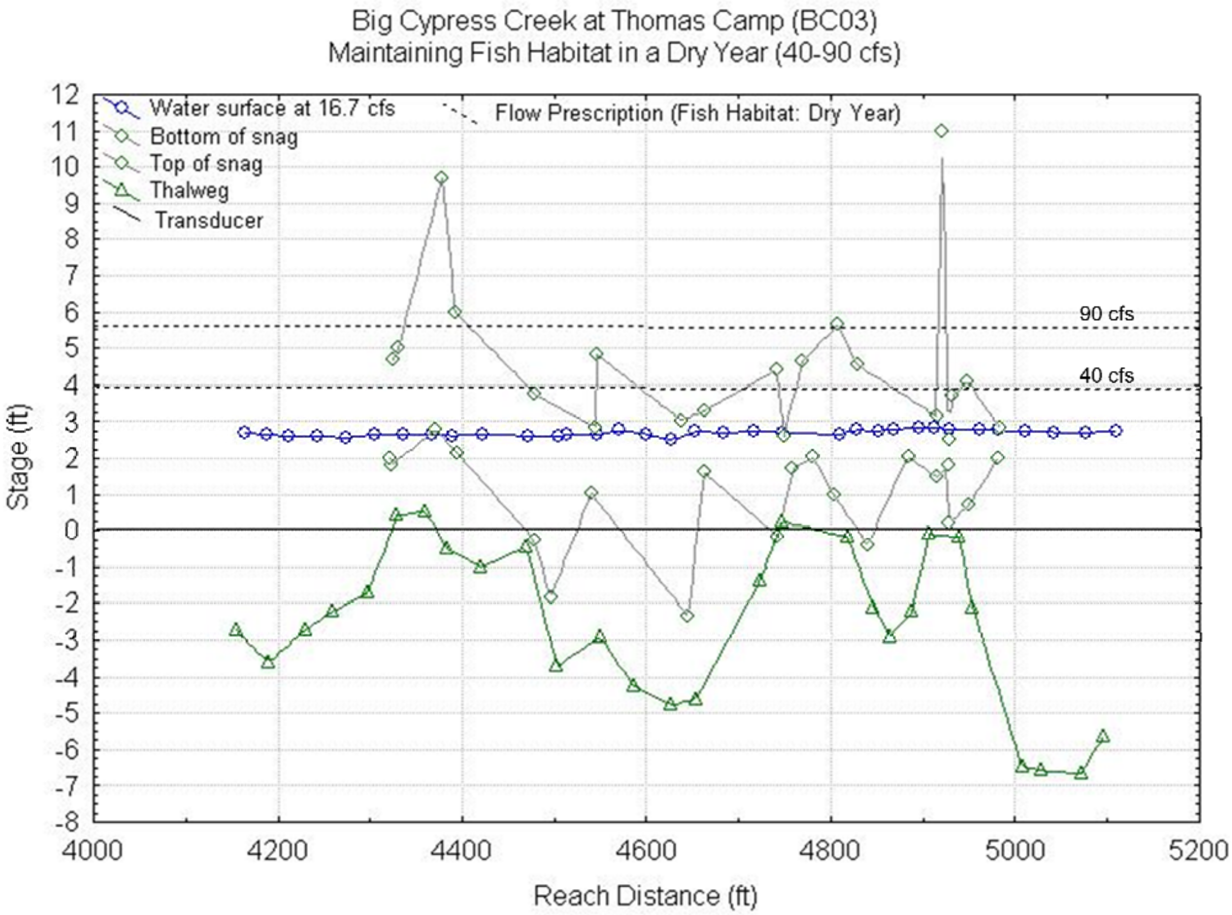

Figure 24 Comparison of water surface elevations produced by base dry flows to instream structure (snags) at BC03.

During wetter conditions, the dominant instream structure is cypress knees, which are only slightly inundated at low flows and progress through a full range of inundation as flows increase to the highest base flow recommendation of 536 cfs (Figure 25).

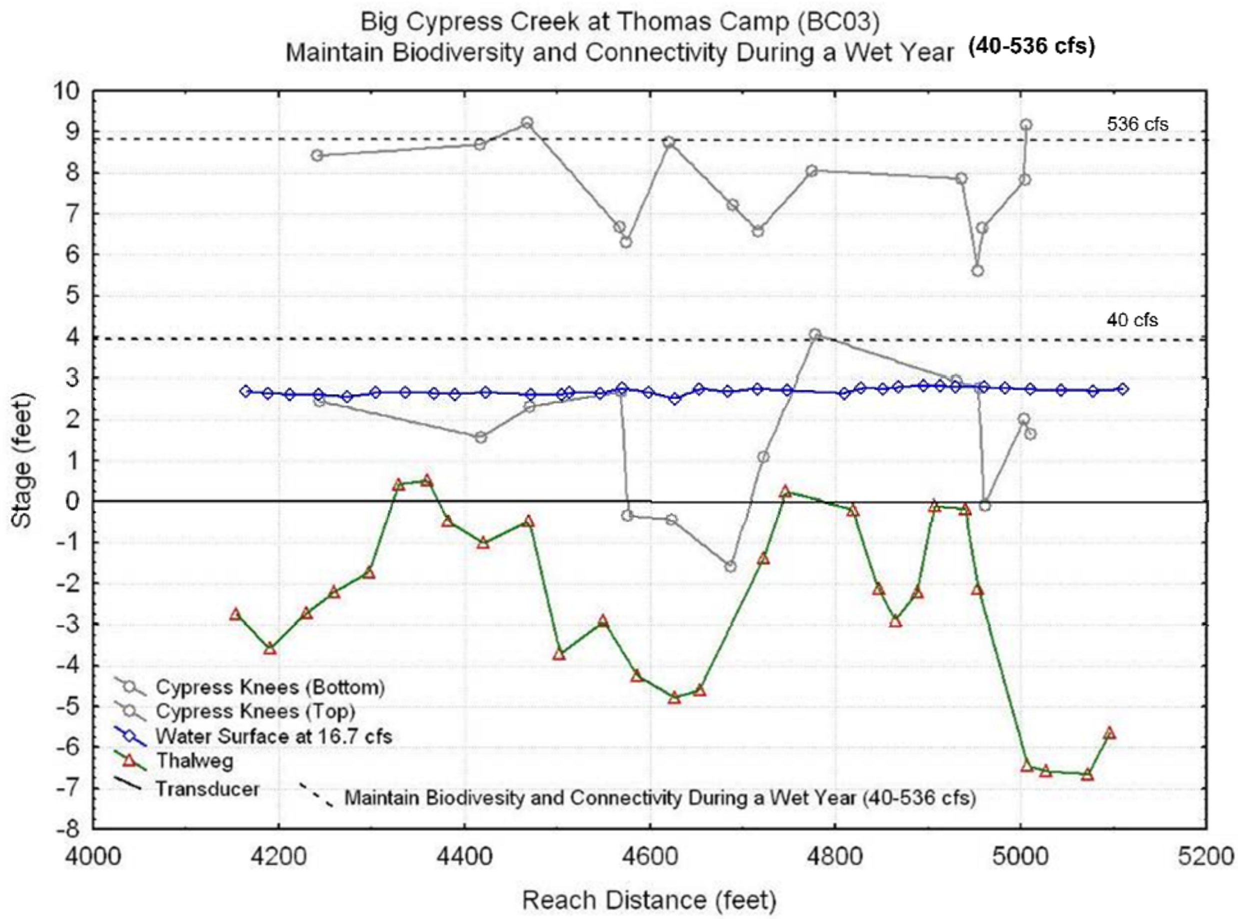

Figure 25 Comparison of water surface elevations produced by base wet flows to instream structure (Cypress knees) at BC03.

Physical habitat models were used to evaluate the availability of preferred habitat as defined by velocity, depth and instream cover suitability criteria. The primary output from these model simulations are Weighted Usable Area (WUA) versus flow curves, which depict availability of preferred habitat conditions for species representative of the habitat guilds present in the stream. Figure 26 and Table 16 present WUA results for BG 02. At the third flow workshop in December 2008, the working group reviewed results from habitat models for other sites including two more on Big Cypress (BG 1 and BG 3) and two on Little (LT 3001 and LT 154) and one on Black (BL). For the sites on Big Cypress monthly percent of maximum WUA was also calculated for building blocks derived solely from the hydraulic analysis (IHA) and building blocks that would have resulted from statistics derived from the flow record after Lake O' the Pines (Post). These results are provided in Appendix C.

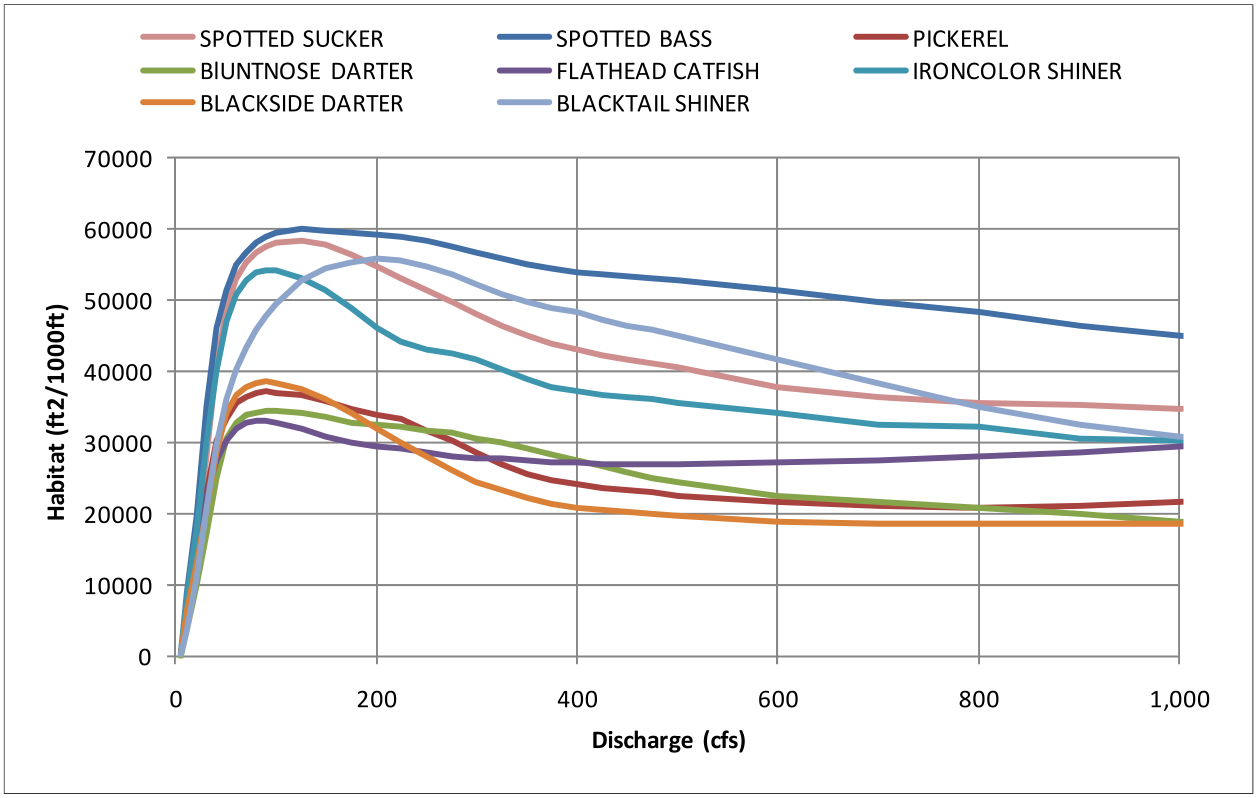

Figure 26 Weighted usable area versus discharge at BG 02.

Based on the WUA results, the amount of habitat (expressed as a percent of the maximum possible area) produced by the initial building blocks is presented in Table 16. The table is color coded to provide a quick visual to the percent of maximum available habitat showing greater than 90% in green, 75-90% in blue and 50-75% in red. Based on these results we see that very little habitat is available for any of the fish guilds at the low summer (Jul-Sep) base dry flows. Conversely, good to excellent conditions are produced by the base dry targets for much of the rest of the year. During average years, there is somewhat more available habitat in the summer and a slight decrease in the rest of the year as compared to the dry conditions targets. The wet base flow targets produce the most habitat in the summer but these higher flows tend to decrease available habitat in the rest of the year (relative to dry and average base flows). Similar results were produced by considering an alternative period of record, one more reflective of current management of Lake O' the Pines, to develop a flows matrix. It should be noted that while a great deal of quantitative results from a predictive model was reviewed by the working group, there is no formula for determining exactly how to select a flow recommendation from these results.

Table 16 Percent of maximum habitat BG 02 produced by building blocks recommended flow.

		SLACK WATER					SWIFT WATER		
		SAND AND GRAVEL		VEGITATION		CREVICE	SAND AND GRAVEL		CREVICE
		SPOTTED SUCKER	SPOTTED BASS	PICKEREL	BIUNTNOSE DARTER	FLATHEAD CATFISH	IRONCOLOR SHINER	BLACKSIDE DARTER	BLACKTAIL SHINER
Dry									
Jan	90	99%	98%	100%	100%	85%	100%	100%	86%
Feb	90	99%	98%	100%	100%	85%	100%	100%	86%
Mar	218	92%	98%	90%	94%	75%	83%	79%	100%
Apr	198	94%	99%	92%	94%	76%	86%	83%	100%
May	114	100%	100%	99%	100%	83%	99%	98%	92%
Jun	49	82%	85%	89%	87%	77%	85%	87%	64%
Jul	13	18%	20%	21%	16%	20%	21%	22%	10%
Aug	8	9%	10%	10%	7%	9%	11%	11%	4%
Sep	8	9%	10%	10%	7%	9%	11%	11%	4%
Oct	40	70%	77%	82%	73%	70%	74%	75%	53%
Nov	90	99%	98%	100%	100%	85%	100%	100%	86%
Dec	90	99%	98%	100%	100%	85%	100%	100%	86%
Avg									
Jan	268	86%	96%	83%	91%	72%	79%	69%	97%
Feb	347	78%	92%	69%	85%	71%	72%	58%	90%
Mar	390	74%	90%	66%	81%	70%	69%	55%	87%
Apr	330	79%	93%	72%	86%	71%	74%	60%	91%
May	150	99%	100%	97%	98%	79%	95%	93%	98%
Jun	79	97%	97%	100%	99%	85%	99%	99%	82%
Jul	35	59%	68%	72%	61%	64%	65%	64%	45%
Aug	40	70%	77%	82%	73%	70%	74%	75%	53%
Sep	40	70%	77%	82%	73%	70%	74%	75%	53%
Oct	40	70%	77%	82%	73%	70%	74%	75%	53%
Nov	90	99%	98%	100%	100%	85%	100%	100%	86%
Dec	117	100%	100%	99%	99%	82%	99%	98%	93%
Wet									
Jan	396	74%	90%	65%	80%	70%	69%	54%	87%
Feb	500	69%	88%	61%	71%	69%	66%	51%	81%
Mar	536	68%	87%	60%	69%	69%	65%	51%	79%
Apr	445	72%	89%	63%	75%	69%	67%	53%	84%
May	264	87%	97%	84%	92%	73%	79%	70%	97%
Jun	140	99%	100%	98%	98%	80%	96%	95%	97%
Jul	70	95%	95%	98%	98%	84%	97%	98%	78%
Aug	41	71%	78%	82%	74%	71%	75%	76%	54%
Sep	40	70%	77%	82%	73%	70%	74%	75%	53%
Oct	49	82%	85%	89%	87%	77%	85%	87%	64%
Nov	94	99%	99%	100%	100%	84%	100%	100%	87%
Dec	275	85%	96%	82%	91%	72%	78%	68%	96%

At the third flows workshop (October 2008), participants reviewed the information presented in Figure 26 and Table 16 and addressed the following issues.

- Does the change in habitat based on pre vs. post LOP conditions suggest a refinement?
- Should the group re-evaluate modifications to the flow matrix from IHA outputs that were made based on reference to other studies?
- Should there be refinements made to compensate or mediate for habitat for fishes that appear to be declining?

- Are all three base flow levels (wet/average/dry) necessary?
- Are the base flows needs upstream and downstream of Jefferson the same?
- Does the analysis suggest other areas of concern?

The discussion first focused on if and how this analysis could be used to validate or refine the preliminary flow recommendations. Generally, the analysis showed that the building blocks provide variability in stream habitat conditions. Although the area of some habitat types would be relatively lower than others, this was assumed to be reflective of the natural habitat conditions of the stream, which the recommendations are intended to protect. One clear conclusion from the analysis was that habitat in the lower reach of Big Cypress Creek is less sensitive to changes in flow than in the upper reach.

The participants agreed that this type of evaluation is useful in providing insight into what the base flow recommendations would produce in terms of instream habitat. However, given the lack of any outstanding concerns arising from this analysis, tempered by uncertainty associated with biological data and hydrodynamic models developed 15-25 years ago, the workgroup concluded that the results of this evaluation supported the basic approach taken for low flows in the building blocks for the three rivers and that the results did not suggest further revisions to the approach or prior recommendations for those flows.

2.2.2 Geomorphology

Geomorphic investigations are conducted as part of instream flow studies to evaluate how the movement and transport of sediments maintain river channels. The most widely referenced, though not universally accepted, hypothesis that addresses this issue is that river channels are in a state of dynamic equilibrium that is governed by a number of factors, including flow rate, sediment characteristics and channel morphology that interact and respond to adjustment from one another (Lane 1955). Many studies suggest that channel instability can result in significant deleterious impacts including:

- Increased erosion,
- Undercutting banks,
- Less succession riparian vegetation which can lead to reduced loading of course woody debris, an important component of instream habitat,
- Straightening and narrowing of channels,
- Removal of hydraulic controls for upstream reaches, inducing scour of upstream riffles,
- Typically wider, shallower stream beds, leading to increased temperature,
- Modification of pool-riffle distribution and
- Altered flow paths.

Given the multiple interactions that can affect sediment transport, guidance provided by the SAC has been to use effective discharge as an indicator of sediment transport. The idea being that as long as the effective discharge is not changed dramatically, then there is reason to suspect that sediment transport processes will continue to function as they should. The basic framework is to:

1. Describe existing or historical conditions and calculate effective discharge,
2. Develop a reasonable approximation of a future hydrograph resulting from the implementation of the flow recommendations, and
3. Evaluate potential impacts resulting from the changed flow regime.

Information provided in the literature survey addressed the first issue and provided an evaluation of the change in effective discharge based on the closure of Ferrells Bridge Dam and filling of Lake O' the Pines. Based on this analysis the working group recommended as part of the initial building blocks, several high flow events at the effective discharge (6,000 cfs). At the same time, they recognized that these estimates would benefit from targeted research including:

- Collection of baseline geomorphologic data to assess the responses during and following flow releases (including sediment characteristics, channel cross-section and general assessment of channel condition), and
- Estimate sediment budget and develop better characterization of sediment composition along entire creek.

These two tasks address two of the functions that relate geomorphic processes to a sound ecological environment. The first task directly addresses channel characteristics that are maintained by the current sediment transport. This task is being addressed as part of a contract with the USGS that is assessing channel morphology in the regulated segment of Big Cypress Creek and compare these conditions with the channel morphologies observed in the unregulated Little and Black Cypress Creeks. Some of the data and analysis conducted under this effort is discussed in Section 2.2.1. The second task evaluates the ability of the stream flow to move sediments through the system. This ability was quantified by a calculation of stream power and effective discharge based on available information provided in the summary report. (Bankfull flow is often used as an initial estimate of effective discharge. Refinements to the bankfull estimates based on field studies are address below under connectivity in Section 2.2.4.) The SAC provided guidance on an approach to refine these estimates by collecting sediment samples and undertaking a modeling exercise (SAM). While a scope of work was developed to perform these tasks, the work has yet to be completed. However, it is expected that a more thorough evaluation of effective discharge will be completed prior to the next flows workshop.

2.2.3 Water Quality

Although the initial building blocks for Big Cypress did not explicitly consider water quality issues, the absolute minimum flows (summer dry base) were revised to provide a conservative estimate of flows necessary to maintain water quality standards. The water quality concerns have been the focus of the development of building blocks for Caddo Lake, with the proposal that lake levels be lowered periodically for management of nutrients and sediments.

The SAC guidance on the application of water quality overlays to refine preliminary flow matrices includes the following steps:

- Identifying current conditions and trends in water quality, mainly in relation to the state water quality standards,
- Evaluating the relationship between flow and the water quality parameters of concern, and
- Determining whether changes are needed to the building blocks to address water quality issues.

The first step was included in the literature survey (Winemiller and others 2005) and in the review of the water quality impairment list (303d) included in the Cypress Basin Highlights report (NETMWD 2010). (Section 2.1.1.3). Of these identified water quality issues, dissolved oxygen (DO) has the greatest potential for impact through prescriptive flow building blocks because increased velocity provides re-aeration and mixing to increase DO concentration.

The dissolved oxygen concentration of a water body has historically been considered one of the most important water quality parameters to measure. High dissolved oxygen concentrations have been linked to high aquatic life use, and low dissolved oxygen concentrations have been linked to low aquatic life use. Dissolved oxygen concentrations in water can be affected by many factors, especially water temperature and rates of re-aeration. In streams, re-aeration rates are often closely associated with stream flow. TCEQ considers Black Cypress Bayou in the Big Cypress Watershed as a least-impacted stream and reference stream within the South Central Plains ecoregion because of limited human disturbance and minimal point and non-point pollution sources. A study of Black Cypress Bayou by TCEQ during 2000 and 2001 was conducted to determine how the flow of the stream related to the aquatic life of the stream (Crowe and Bayer 2005). During both summers, the flow of the stream was below 7Q2 and flow intermittently with perennial pools. During August of 2001, 24 hr dissolved oxygen means were generally below 3 mg/L which is lower than the Texas Surface Water Quality Standard. Despite low dissolved oxygen concentrations during this critical period, the aquatic life was rated as high to exceptional. A Rapid Biological Assessment (RBA) of the benthic macroinvertebrate community scored in the intermediate to high categories, while an Indicators of Biotic Integrity (IBI) of the fish community scored in the high to exceptional categories. The report concluded that the fish assemblage in the watershed has the ability to withstand periodic low summertime dissolved oxygen conditions of short durations.

Given the finding that naturally occurring low DO conditions do not appear to have significant detrimental effect on the biological community, the CFP did not include a category to the building blocks for subsistence flows, though this issue was discussed at some length. There was considerable discussion that very low flows occur naturally in the unregulated streams and the general consensus that these conditions are an acceptable component of the sound environment of this system. Note the workgroup did recommend minimum base flows of 5 and 4 cfs for Little and Black Cypress to ensure that the frequency of occurrence of pools becoming disconnected is not increased. The workgroup also decided to increase the minimum flow recommendation in Big Cypress Creek up from 6 cfs to the 7Q2 value of 8.2. This was done to provide a slightly more conservative estimate of the flow needed to maintain the DO standard in this segment.

Watershed Protection Plan

Concerns raised about the water quality impairments in the CFP led to an agreement with TCEQ for the development of a Watershed Protection Plan (WPP) in 2006 to address water quality issues in a more comprehensive process. The Northeast Texas Municipal Water District has served as the watershed coordinator for the project. The WPP has provided new sources of information. It also helped expand the participation by scientist and stakeholders in the CFP. There has been a significant effort to coordinate the work of the WPP and CFP. The CFP, for example, serves as the hydrology work group for the WPP, which has two other work groups.

While there has been important collaboration, the two processes are somewhat different. Both provide for participation by scientists and stakeholders, but the work of the WPP is guided to a larger degree by the stakeholder goals and TCEQ's interests. Thus, at TCEQ's request, the WPP has not been used to address mercury impairments. It has instead focused on bacteria and DO impairments. During the first two years of the WPP, work focused on identifying potential short-term solutions to the problems of giant salvinia (*Salvinia molesta*); a floating invasive aquatic plant, first discovered in Caddo Lake in 2006.

In any case, water quality problems in most of the watershed have appeared to be more dependent upon sources than on flows. The solutions, therefore, may depend more upon reductions in the loading of pollutants than on flow regimes. The possible exception is Caddo Lake where flushing flows and lake level adjustments may be needed. The WPP process may provide a basis for refinements, but the preliminary modeling of loadings, flows and impacts together with proposals for load reductions will not be available until late 2010.

The WPP and CFP have recognized the need to evaluate changes to pulse and flood flows and in levels of Caddo Lake for water quality and control of aquatic vegetation in the Lake. The evaluation of options for changes to the dam at Caddo Lake will be part of a new study begun by the U.S. Corps of Engineers in 2010. That work will not be completed, however, for several years. Changes to the dam and options for significant lake lowering are not likely to be made for many years.

2.2.4 CONNECTIVITY

The issue of riparian and wetland connectivity is of great importance in the Cypress Basin. The creeks in the basin support valuable bottomland hardwood and Cypress forests (Figure 27). As noted in the biological section, many of the fish that inhabit this area rely on access to riparian and watershed areas for part of their life cycle.

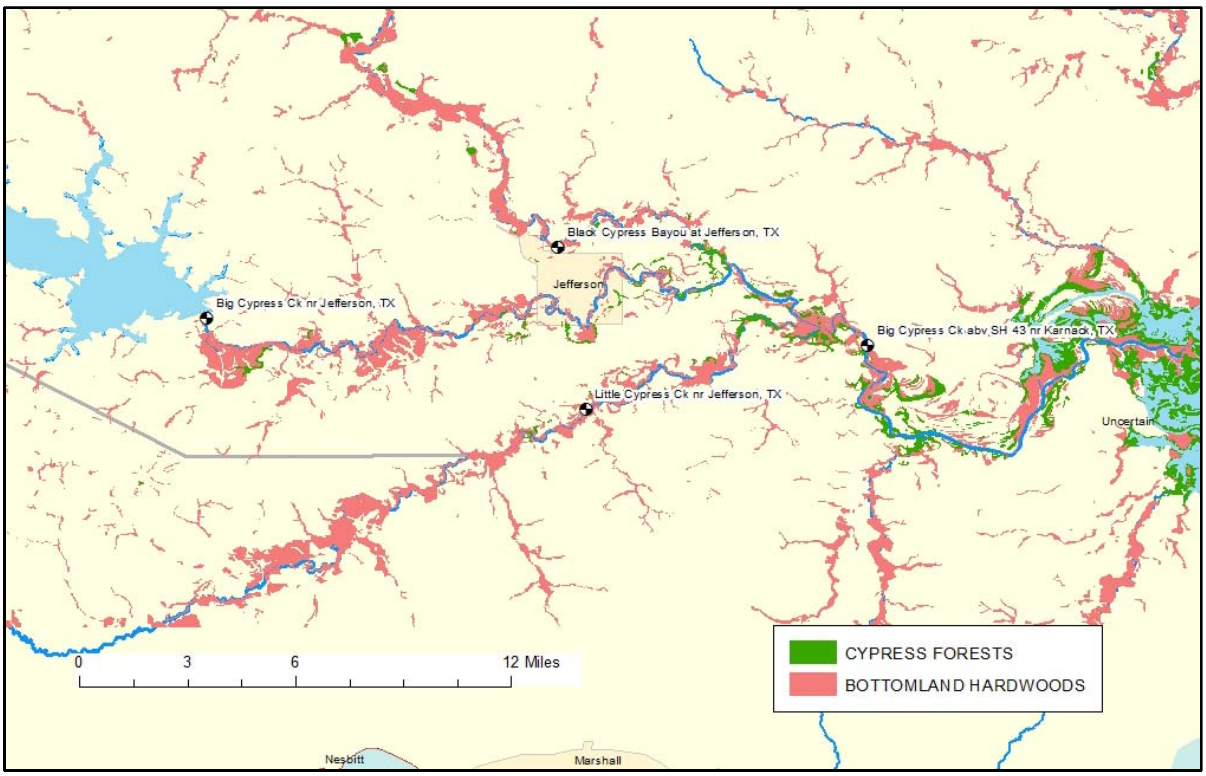

Figure 27 Bottomland Hardwood and Cypress forests associated with Cypress Creeks.

Estimates of the flows needed to maintain this connectivity formed a critical component of the initial building blocks and evaluation of these estimates has been the focus of considerable effort over the last several years. These efforts have included experimental releases from Lake O' the Pines to test whether the flow prescribed in the initial building blocks achieves desired overbank results, refinements to water surface elevation models (HEC-RAS) to produce coarse but larger scale inundation maps, and, most recently and still in process, work analyzing high resolution satellite imagery to develop relationships between flow and area inundated and thus predict ecological benefits of higher flows to spatially explicit wetland communities.

Collection of high flow and stage data was the primary tool used to evaluate the high flow targets. The first step in this process was to install pressure transducers, which measure water elevation, at ten locations on Big Cypress and three each on Little and Black Cypress.

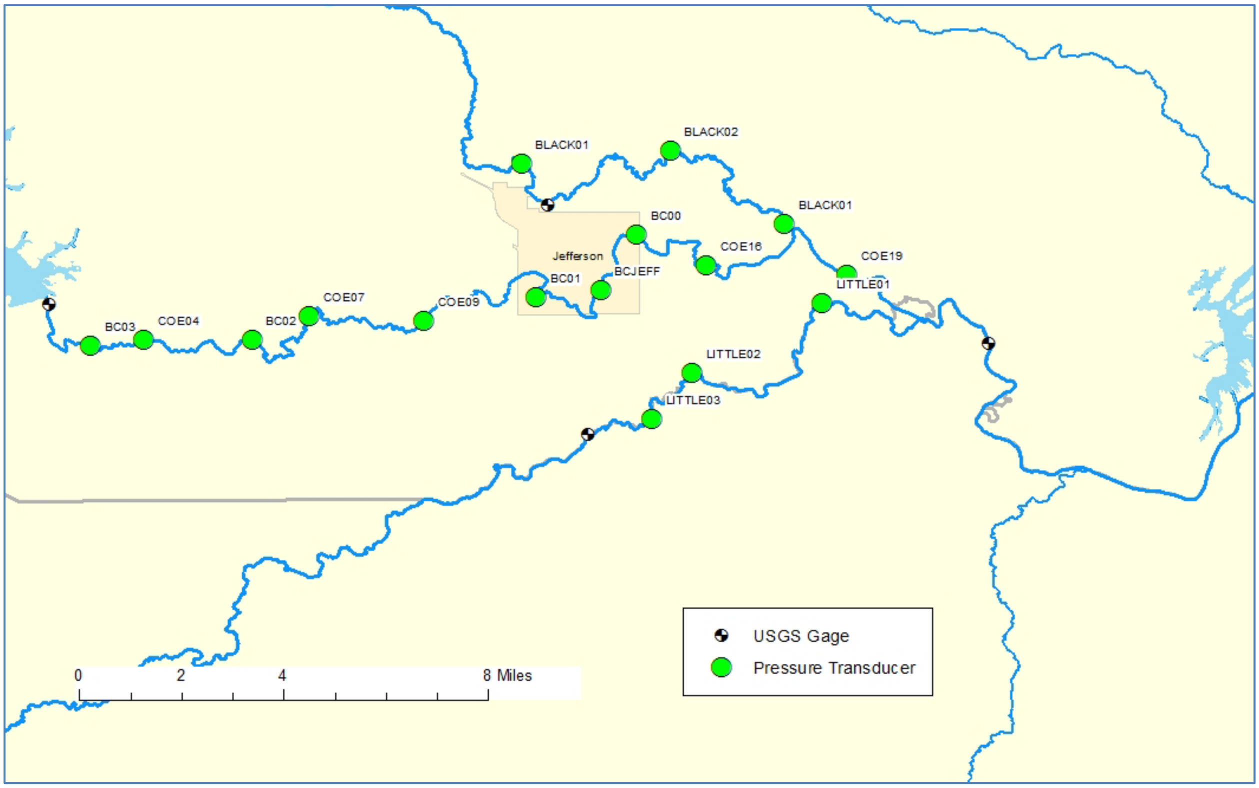

Figure 28 Pressure Transducers installed to measure water surface elevations.

These instruments remained in place for up to a full year on Big Cypress and captured a full range of flows. They were specifically deployed in advance of experimental releases made from Lake O' The Pines to test the overbank and connectivity that results from high flow events. From January 25th to February 3rd, 2007 the Corps stepped up releases from about 100 cfs to 500 cfs to 1800 cfs. (Figure 29)

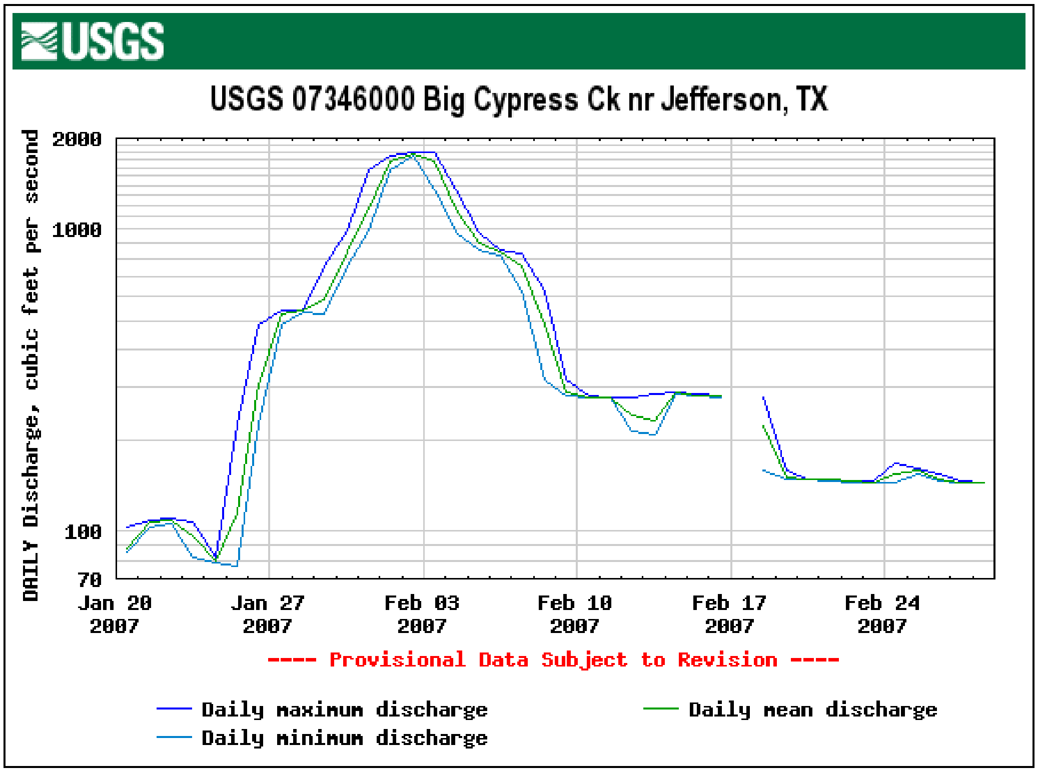

Figure 29 Flow rate measured at nearby gage during experimental releases from Lake O' the Pines.

Releases were held constant for several days to allow for a relatively static flow condition past each of the pressure transducers allowing the direct observation of water surface stage to flow rate. Throughout the rest of the year, the PTs recorded flow up to the maximum release from Lake O' the Pines equal to 3,000 cfs. After processing the raw data and georeferencing their exact positions, a longitudinal profile of water surface elevation for a range of flows was developed. (Figure 30)

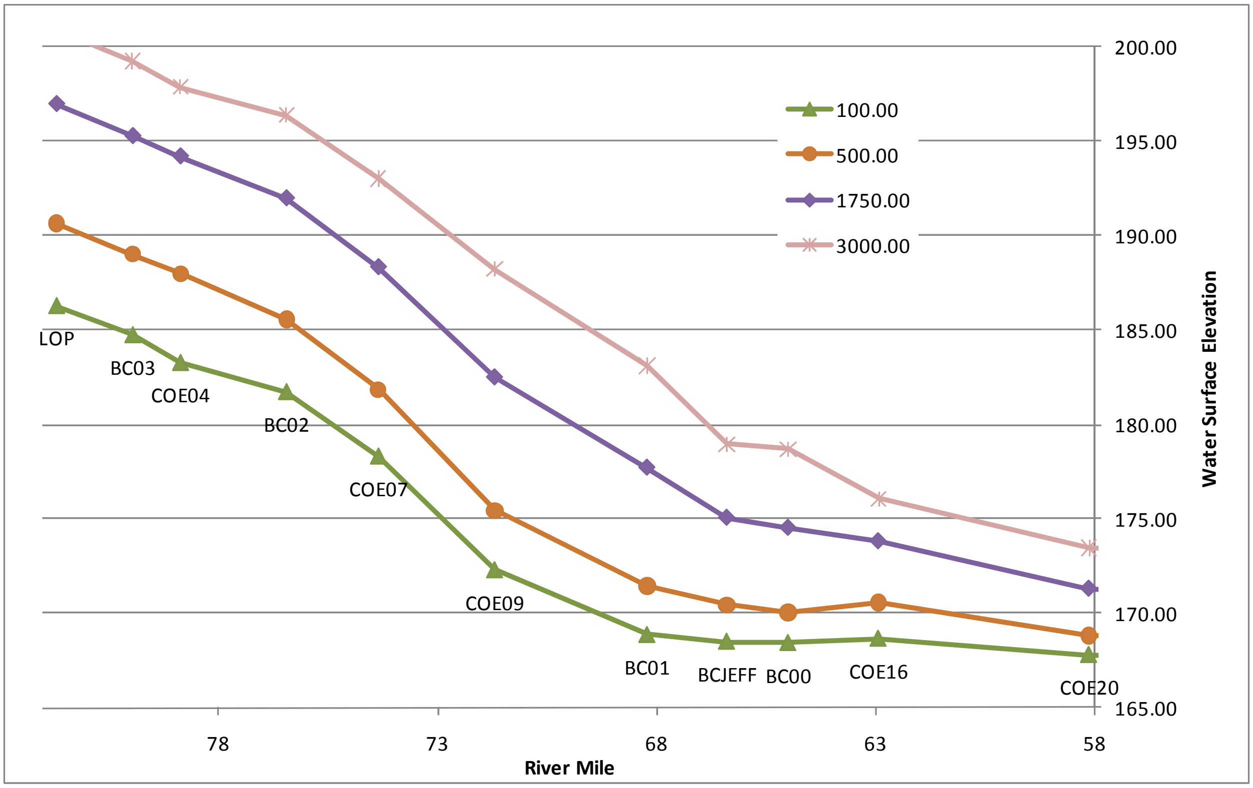

Figure 30 Longitudinal profile of water surface elevation in Big Cypress Creek.

This data was then used to produce an inundation map based on an available digital elevation model of the watershed. (Figure 31) These results were consistent with observations made during the experimental releases. Namely, that riparian areas in the segment of Big Cypress upstream of Jefferson are inundated at flows well below the initial overbank estimate of 6,000 cfs. Downstream of Jefferson where the channel is much wider and deeper, there is no overbank until below the confluence with Little and Black Cypress.

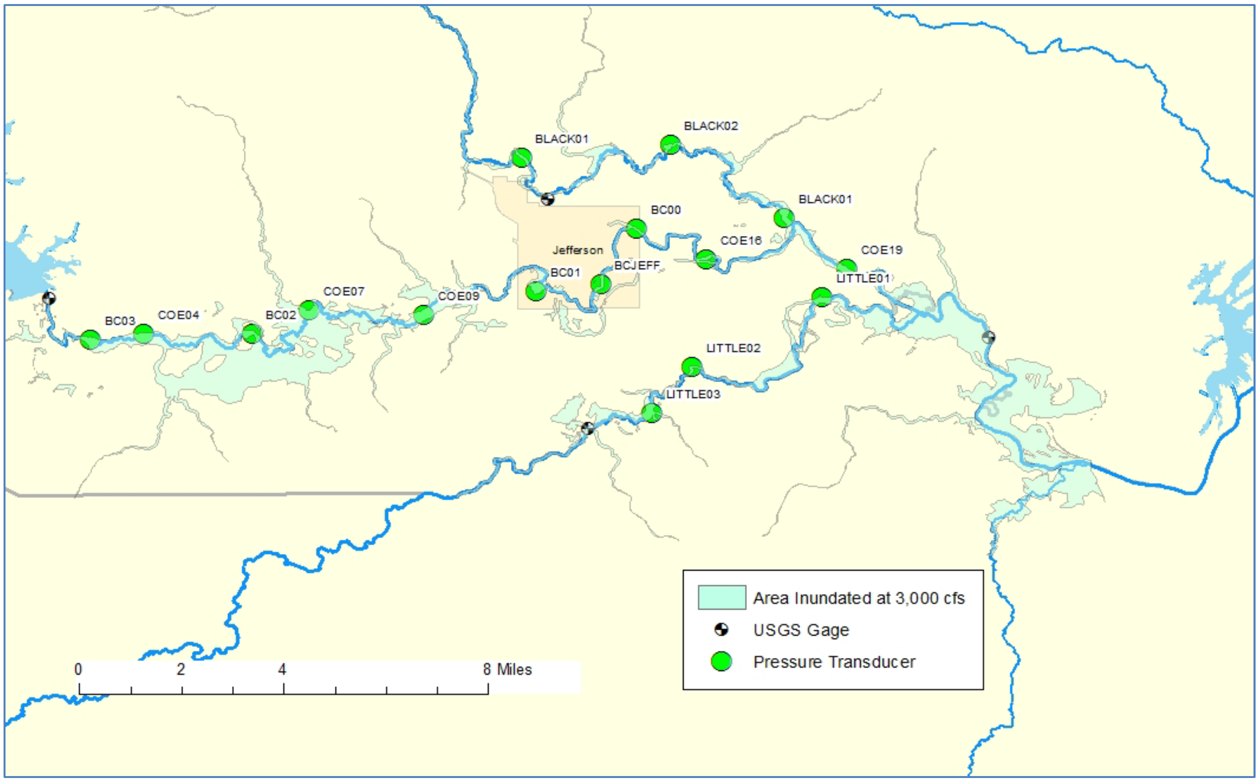

Figure 31 Area inundated at 3,000 cfs release.

Additional work to more precisely quantify riparian connectivity is currently underway on two fronts. First, as part of the work undertaken by the USGS and the Corps of Engineers, 24 cross-section s were surveyed in Big Cypress Creek. These along with the PT data are being used to calibrate a HEC-RAS model that will be used to make a more accurate prediction of water surface at flows not observed directly and potentially to facilitate additional analyses related to sediment transport and water quality. Finally, a study has recently been initiated similar to the work done by the Sabine Neches BBEST to analyze satellite imagery and more directly relate inundation areas to wetland plant communities.

2.3 Environmental Flow Regime Recommendation

The building blocks developed at the first two flow workshops (May 2005, October 2007) were revised at the third workshop in December 2008 based on additional data that had been collected and the environmental flow (overlays) analysis that had been conducted. With respect to the recommendations for Big Cypress Creek, the consensus was to largely adopt the preliminary matrices. It is important to note that these values had already been modified from a purely hydrologic analysis in considering the other riverine disciplines as part of the literature survey and summary report. Nonetheless, the subsequent additional environmental flow analysis did result in the modification of several recommended flows. Values in red are those that were not calculated as part of the hydrologic analysis using IHA, but are refinements and adjustments to the building blocks based on the application of overlay analysis. Some these adjustments were made in the development of the preliminary building blocks by considering the information presented in the literature survey, while others were modified based on the analysis that has been preformed subsequently.

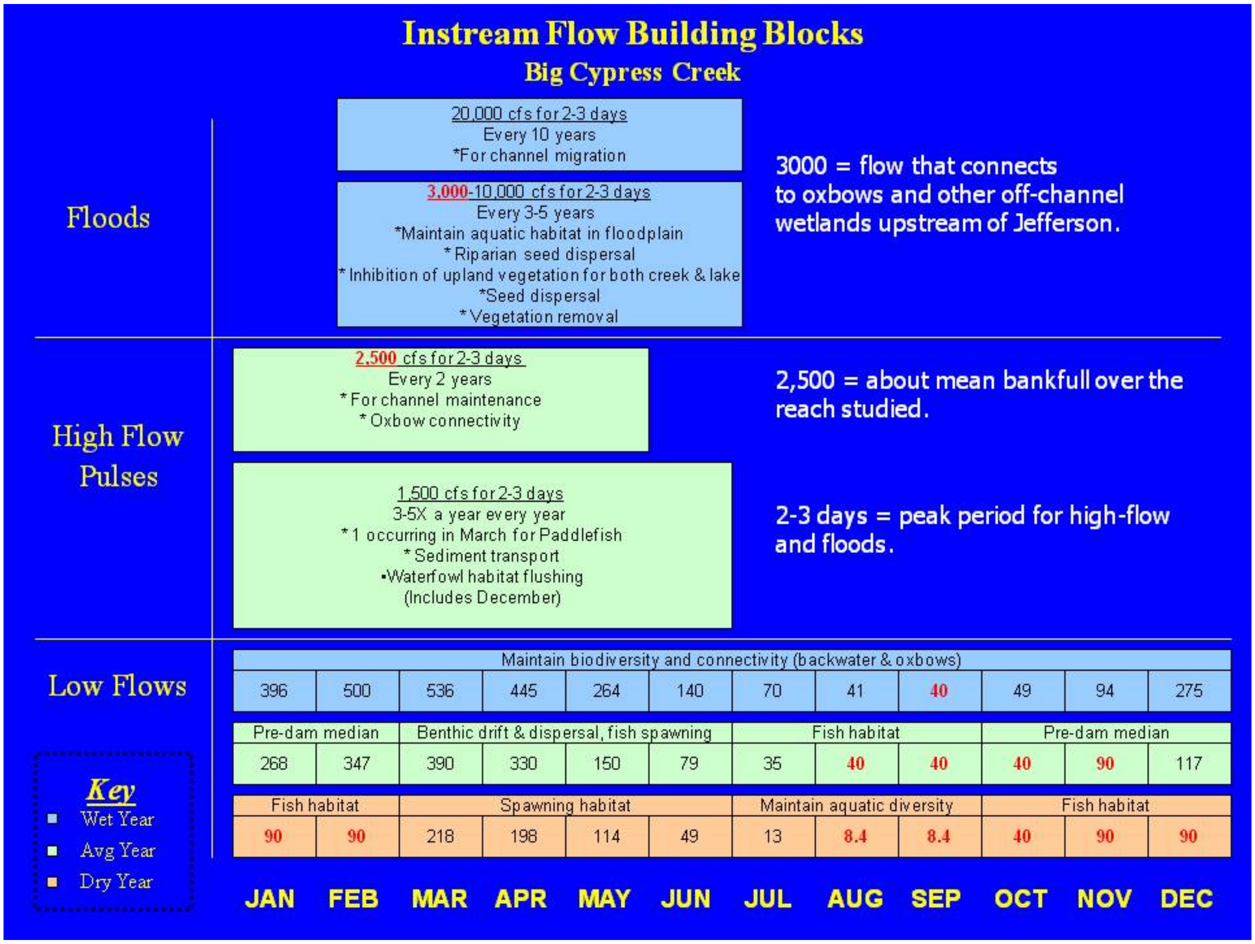

Figure 32 Big Cypress Creek Flow Regime Recommendation.

With respect to base flows, the workgroup agreed that the results of the analyses performed as part of the biological overlay (Section 2.2.1) confirmed the basic framework of developing a range of base flow recommendations based primarily on historical pre-development flow records. Generally, the analysis showed that the building blocks derived primarily from pre-impact flow records, provide variability in stream habitat conditions. Although the area of some habitat types would be relatively lower than others, this was assumed to be reflective of the natural habitat conditions of the stream, which the recommendations are intended to protect. One conclusion from the analysis was that habitat in the lower reach of Big Cypress Creek is less sensitive to changes in flow than in the upper reach. This is due to the fact that Big Cypress Creek has been channelized and deepened downstream of Jefferson. While flow recommendations derived from a pre-development period of record appear to be supportive of ecological functions in river segments that have not experienced significant structural modifications (e.g. Big Cypress upstream of Jefferson and the unregulated tributaries), these flows may not be sufficient to restore this variability to a segment that has undergone significant structural modifications. The workgroup agreed that this type of evaluation is useful in providing insight into what the base flow recommendations would produce in terms of instream habitat, however there was also some reluctance to make adjustment to the building blocks based on biological data and habitat models that are 15-25 years old, without first providing a more recent validation of these results. A Clean River Program special study has since been initiated that will include mesohabitat specific sampling to further validate or refine results from these models.

Regarding low flows, the workgroup decided to adopt a slightly more conservative approach to ensure that for dry conditions in Big Cypress Creek during July through September flows are adequate to protect water quality. The workgroup decided to adopt the 7Q2 flow value developed by the state water quality standards and permitting system equal to of 8.4 cfs for this segment of Big Cypress Creek until additional data or analysis indicates another value should be used. This is higher than the low flow proposed in the building block of 6 cfs. For Little and Black Cypress Creek the absolute minimums were adjusted up from the purely hydrologic (IHA) analysis, to 5 and 4 cfs respectively.

Field work and other analysis was performed by USGS to evaluate the preliminary high flow recommendations for Big Cypress Creek. The analysis of observed high flow releases from Lake O' the Pines by the USGS (Section 2.2.4) resulted in changes to the recommendation for pulse flows for Big Cypress Creek. This analysis indicated that bankfull flows occur below 3,000 cfs. The flows needed for bankfull conditions also changed from the upper reach (generally above Jefferson) to the lower reach (below Jefferson). While valuable wetland resources depend on overbank flows in the lower segment, it seems clear that for the near future these events will be driven by inflows from the unregulated Black and Little Cypress Creeks. The workgroup decided to change the larger high flow pulse from 6,000 cfs to 2,500 cfs, which appears to provide a good approximation of bankfull flow in the upper reach. The lower flood flow was then changed to a range from 3,000 cfs to 10,000 from the prior range of 6,000 to 10,000 to reflect that there was good connectivity occurring at flows as low as 3,000 cfs. It is worth noting that while these adjustments reflect new understanding related to overbank flows, additional analysis will be necessary to evaluate their effect on sediment transport.

Concern was also raised about the lack of building blocks for James Creek and a number of small streams in the basin. Because these streams do not have gages, it was agreed that the IHA approach used for Big, Little and Black Cypress Creeks could not be applied. Instead, the group agreed that flow regimes for these creeks should be based on the building blocks for Big Cypress Creek with a proportional adjustment for the different sizes of the watersheds.

In addition to describing the flow magnitudes necessary to achieve desired ecological outcomes, an SB 3 flow standard, and ultimately the rule developed by TCEQ, should also include the attainment frequencies at which the various flow components must be met. Although attainment targets were not explicitly defined by the CFP, the guiding principal behind the project, as discussed in Section 2.2.1, is the natural flow paradigm, which says that the best way to maintain a sound ecological environment is to mimic the natural flow pattern as closely as possible including variability patterns (wet, dry and average years, seasonal), and associated duration and magnitude of flows. With that concept in mind, historical frequencies of the various recommendations were calculated as well as the predicted attainments under potential future flow scenarios. A discussion paper describing the process in determining attainment goals and the issues that need to be considered as part of this process was prepared and presented at the December 2008 flows workshop and it is included in Appendix D. Appendix E (also presented at the December 2008 workshop) extends further into the realm of implementation with an example of how the various flow conditions (dry, average and wet) could be triggered.

The most significant revision to the recommendations relates to the adoption of narrative standards for Black and Little Cypress Creeks; a concept which had been proposed in the 2006 workshop. The confluences of Little and Black Cypress Creek with Big Cypress Creek are just upstream of Caddo Lake and high flows in Black and Little Cypress can provide relatively high flows to the wetlands and lake, even with the reduced flows from Big Cypress due to the existence of Lake O' the Pines. These high flows are needed for inundation of wetlands associated with Caddo Lake. Although no specific numbers or limitations were proposed by the workgroup, a consensus was reached that a significant proportion the entire population of overbank flows, not just those at the specific magnitudes depicted in the building blocks, should be excluded from future diversions. Consistent with the resource values of the two tributaries, a greater level of protection was stipulated for the regionally least impacted stream, Black Cypress, than for the relatively more modified Little Cypress.

While not done before or at the December 2008 flows workshop, several options exist for a quantitative approach for implementing these narrative standards based on riverine and wetland science. This is an area where the line between pure science and the value that stakeholders associate with these resources is less sharp. In any case, after the 2008 meeting, an example of an implementation approach was developed and it is provided in Appendix F. While developed after the third flows workshop, it has been reviewed by some workgroup members. It is just one example of how a narrative standard could be implemented.

3 CONCLUSIONS

Among the many similarities shared by the SB3 and SPR approaches is the acknowledgement that data limitations and incomplete understanding of ecological processes leads to the development of imperfect environmental flow recommendations. In order to address these shortcomings both of these processes have adopted the approach of employing adaptive management so that new information can be incorporated into subsequent recommendations. The adaptive management process is developed in several steps including the establishment of a schedule to review recommendations, the application of targeted research to gain a higher level of certainty in the recommended flows, and development of ecological indicators to monitor the efficacy of the recommendations. In the SB 3 legislation these steps are required as part of the development of a workplan. [§Sec. 11.02362 (p)] The CFP has established a three-year schedule to review the current recommendations, by which time they should have additional information from targeted research including:

1. Water quality work from the Watershed Protection Plan,
2. Mesohabitat specific monitoring of recommended base flows via a CRP special study,
3. Application of sediment transport modeling (SAM),
4. Analysis of digital imagery data to relate areas of wetland inundation to flows,
5. Additional experimental releases from Lake O' the Pines,
6. Application of daily timestep reservoir operations model to evaluate impact of flow targets on reservoir storage, and
7. New projections on water needs in the region by the Region D Water Planning Group.

Finally, the CRP is in the process of establishing ecological indicators and process for evaluating the efficacy of the flow recommendations. An early draft of this effort is included in Appendix G.

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LIST OF AVAILABLE APPENDICES