Sabine and Neches Rivers and Sabine Lake Bay Basin and Bay Expert Science Team

Environmental Flows Recommendations Report

Final Submission to the Sabine and Neches Rivers and Sabine Lake Bay Basin and Bay Area Stakeholder Committee, Environmental Flows Advisory Group, and Texas Commission on Environmental Quality

November 30, 2009

http://www.sratx.org/BBEST/RecommendationsReport/

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Sabine and Neches Rivers and Sabine Lake Bay Basin and Bay Expert Science Team

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November 2009

The Honorable Kip Averitt, Co-presiding Officer,
Environmental Flows Advisory Group

The Honorable Allan Ritter, Co-presiding Officer,
Environmental Flows Advisory Group

Mark R. Vickery, P.G., Executive Director,
Texas Commission on Environmental Quality

Jerry Lynn Clark, Chairman,
Sabine and Neches Rivers and Sabine Lake Bay Basin and Bay Stakeholder Committee

Dear Senator Averitt, Congressman Ritter, Mr. Vickery, and Mr. Clark:

For your consideration, the Sabine and Neches Rivers and Sabine Lake Bay Basin and Bay Expert Science Team (Sabine-Neches BBEST) hereby submits its final report pursuant to its charge under Senate Bill 3 (80^{th} R, 2007), including environmental flow recommendations with rationale. The Sabine-Neches BBEST members have reached consensus on these recommendations.

Respectfully submitted,

Jack W. Tatum, Chairman

Scott Hall, Vice-Chairman

Gary Graham

Richard Harrel

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Final Submission to the Sabine and Neches Rivers and Sabine Lake Bay Basin and Bay Area Stakeholder Committee, Environmental Flows Advisory Group, and Texas Commission on Environmental Quality

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EXECUTIVE SUMMARY

The Sabine and Neches Rivers and Sabine Lake Bay Basin and Bay Expert Science Team (Sabine-Neches BBEST) was appointed by the Sabine and Neches Rivers and Sabine Lake Bay Basin and Bay Area Stakeholders Committee (Sabine-Neches BBASC) under Senate Bill 3 (Texas Legislature 2007), the third in a series of three omnibus water bills related to the State of Texas meeting the future needs for water. Under its SB 3 charge, the Sabine-Neches BBEST used the "best available science" to develop environmental flow analyses and recommend flow regimes for the Sabine and Neches Basins and the Sabine-Neches Estuary. These recommendations are provided to the Sabine-Neches BBASC, Texas Environmental Flows Advisory Group (EFAG), and the Texas Commission on Environmental Quality (TCEQ).

The Sabine-Neches BBEST held twelve monthly meetings and several workshops beginning with its initial meeting on December 8, 2009. To accomplish this task the Sabine-Neches BBEST established subcommittees for:

- gaging
- hydrology
- biology
- water quality
- geomorphology
- Recommendations Report preparation.

Two consulting firms were retained to provide modeling and research in addition to extensive committee/subcommittee work. The meetings were an open process that benefited from participation and contributions from the resource agencies – TCEQ, Texas Water Development Board (TWDB) and Texas Parks and Wildlife Department (TPWD), environmental groups such as the National Wildlife Federation (NWF), and the public.

The Sabine-Neches BBEST believes the body of work presented and discussed in the Recommendations Report (Report) has enabled it to move the Texas environmental flows process forward and to address the charge to develop environmental flow analyses and recommend an environmental flow regime in a positive manner within the limited time frame and full recognition of the best science available. The Report is comprised of:

- a <u>Preamble</u>, which outlines the charge, goal and objectives;
- <u>Summary of Recommendations, Recognitions and Rationale</u>, which highlights the report findings;
- <u>Basins and Bay Descriptions and Current Conditions</u>, which describes the Sabine River Basin (Texas and Louisiana), the Neches River Basin, Sabine Lake Estuary (Sabine-Neches Estuary, Texas and Louisiana); Regional Water Planning (SB 1 ongoing process), and Sabine-Neches Study Area Unique Issues;
- <u>Texas Environmental Flows Science Advisory Committee</u> (SAC) which provided guidance documents for this process as well as overall direction, coordination, and consistency from the broader state perspective;

- Discipline Reports from the four disciplines – hydrology, biology, water quality and geomorphology;
- Development of Environmental Flows Recommendations/Recognitions/Unresolved Issues which includes instream flow regime application, environmental flow matrices for selected stream flow gages, and inflows to Sabine-Neches Estuary; and
- Appendices which includes the full body of work and references that the Report is based on.

The SAC, an objective body of experts tasked to advise and make recommendations to the Environmental Flows Advisory Group, provided valuable assistance to the Trinity-San Jacinto BBEST and Sabine-Neches BBEST as the two initial BBESTs. To date, the SAC, composed of members with expertise in a number of technical fields including hydrology, hydraulics, water resources, aquatic and terrestrial biology, geomorphology, geology, water quality, and computer modeling, has developed six technical guidance documents for BBEST use. These are as follows:

- Geographic Scope of Instream Flow Recommendations;
- Use of Hydrologic Data in the Development of Instream Flow Recommendations for the Environmental Flows Allocation Process and the Hydrology-Based Environmental Flow Regime (HEFR);
- Fluvial Sediment Transport as an Overlay to Instream Flow Recommendations for the Environmental Flows Allocation Process;
- Methodologies for Establishing a Freshwater Inflow Regime for Texas Estuaries Within the Context of the Senate Bill 3 Environmental Flows Process;
- Nutrient and Water Quality Overlay on Hydrology-Based Instream Flow Recommendations; and
- Essential Steps for Biological Overlays in Developing Senate Bill 3 Instream Flow Recommendations.

Unfortunately, the Sabine-Neches BBEST was unable to take full advantage of all guidance documents since the SAC's development timeline coincided with the Sabine-Neches BBEST timeline. However, the SAC member performing as liaison to the Sabine-Neches BBEST assisted the group by providing the initial drafts of works in progress to allow the process to move forward. This resulted in an evolving process through the twelve months with the Report reflecting a transition of understanding from SAC guidance to the Sabine-Neches BBEST, to its consultants' work, its subcommittees' reports, input from the resource agencies, and the NWF studies. This input and work influenced the understanding and progress along the twelve month timeline. The final Report reflects the evolving and transitional understanding as the year unfolded and additional information and data was brought into the process.

Decision Tree – To help follow this process from start to finish, the Sabine-Neches BBEST developed a DECISION TREE (Figure 4, page 8). The Decision Tree traces the decisions made throughout the process. The decision tree was instrumental in tracking decisions and pathways and the concept should be of great value to future BBESTs.

During the course of the past year, the Sabine-Neches BBEST recognized its recommendation charge required further clarity. Taking its charge from the “theoretical” to the “practical”, the Sabine-Neches BBEST was able to make some specific environmental flow recommendations, while in other cases (for example overbank flows), the group agreed to recognize (recognition) the ecological value of such flows but not recommend them. The Sabine-Neches BBEST was able to move forward with the environmental flow process by agreeing that some issues, due to the severe time constraint and limitations of available science would remain ‘unresolved issues’. These unresolved issues would need ‘future studies’ and, ultimately, as envisioned by the SB 3 process, ‘adaptive management’ to resolve. Thus, over time, the path forward became:

1. Recommendations;
2. Recognitions;
3. Unresolved Issues;
4. Future Studies; and
5. Adaptive Management.

Recommendations and Recognitions

The following recommendations and recognitions are presented in the Report with qualifying language and in some cases remain unresolved issues that will need future study and adaptive management to determine if particular flow components need to be altered. The recommendations and recognitions are presented in the Report with supporting rationale based on information and data summarized from a substantial body of work in the appendices and noted references. They are summarized as follows:

Recommendations:

1. Recommendation 1: Definition of a Sound Ecological Environment.
   The Sabine-Neches BBEST recommends the SAC definition that it adopted (see Section 1.2.4, page 11) for sound ecological environment.
2. Recommendation 2: The Current Conditions of the Sabine and Neches Rivers and the Sabine-Neches Estuary are Sound.
3. Recommendation 3: Acknowledge that Flows in the Sabine and Neches Rivers and Inflow to the Sabine-Neches Estuary will Change Over Time.
4. Recommendation 4: Future Study, Data Gathering, and Adaptive Management are Necessary to Determine Whether or not Changes in Environmental Flows will Maintain a Sound Ecological Environment.
5. Recommendation 5: Applicable Hydrologic Conditions for the Entire Season are Defined on the Basis of an Assessment of Hydrologic Conditions of Storage in Selected Reservoirs at the Beginning of the First Day of the Season Thereby Recognizing Both Drought Persistence and Practical Operations.
6. Recommendation 6: Subsistence Flows.
   The Sabine-Neches BBEST recommends adoption of the seasonal subsistence flows from MBFIT /HEFR, unless:
   i. the seasonal value is less than the summer value in which case the summer value is adopted by default, and

ii. MBFIT/HEFR failed to calculate a value (this occurred usually for winter) in which case the lowest recorded flow value for that season at that gage was adopted by default.

Translation of seasonal subsistence flows into environmental flow standards and permit conditions should not result in more frequent occurrence of flows less than the recommended seasonal subsistence values as a result of the issuance of new surface water appropriations or amendments.

7. Recommendation 7: Base flows.

   Seasonal base flows represent thresholds for environmental protection based on current scientific understanding of fluvial and estuarine ecosystems. As new studies and monitoring information become available, these base flow thresholds may be revised.

8. Recommendation 8: High Flow Pulses.

   Seasonal high flow pulses have recognized ecological benefits and are recommended for protection with certain reservations associated with environmental and operational liability risks.

9. Recommendation 9: Fluvial Matrices Inflow Recommendations are Adequate to Maintain a Sound Ecological Environment in the Sabine-Neches Estuary.

   Recognizing that the Sabine-Neches Estuary is a system in transition (Tatum 2009) and that the Sabine-Neches Estuary receives the freshwater inflows determined by the flow component recommendations for the Sabine-Ruliff, Neches-Evadale, and Village Creek gages (as well as other inflows), the Sabine-Neches BBEST recommends that these inflows are adequate to maintain a sound ecological environment in the Sabine-Neches Estuary.

Recognitions

1. Recognition 1: Overbank Flows Have Recognized Ecological Benefits but are not Recommended.

   Overbank flows may cause extensive damage to private property and endanger the public. Therefore the Sabine-Neches BBEST recognizes the ecological benefits of these events, but cannot recommend such events be produced.

2. Recognition 2: Toledo Bend Reservoir FERC Relicensing.

   The relicensing of the Toledo Bend Project is ongoing at this time. The relicensing will recognize the Project's primary use as a water supply project with the capability of generating hydroelectric power. Since no major changes in operations are planned, a maintenance flow will continue to be maintained from the spillway.

3. Recognition 3: Sabine River Compact.

   The major purposes of the Sabine River Compact are to provide for the equitable apportionment between the States of Louisiana and Texas of the waters of the Sabine River and its tributaries. Texas retains free and unrestricted use of the water of the Sabine River and its tributaries above the Stateline, subject only to the provisions that the minimum flow of 36 cfs must be maintained at the Stateline. All free water (free water means all waters other than stored water) and stored water in the Stateline reach, without reference to origin, will be divided equally between the two states.

4. Recognition 4: Cutoff Bayou.
   Environmental flows as well as the diversions for the water supply canal system in Texas are adversely affected by migration of channel flow to the Old River Channel in Louisiana during low and average flow conditions.

Basins and Bay Descriptions and Current Conditions

The Study Area defined for the Sabine-Neches BBEST is the Sabine River Basin and the Neches River Basin with each having a watershed of approximately 10,000 square miles with the total drainage of some 20,000 square miles being received by the Sabine-Neches Estuary. Detail descriptions and maps are found in the Report and supporting appendices and references. SB 1 Regional Water Planning for this area is presented in Regions I, D and C plans since the geographic footprint extends into all three regions. SB 2, or Texas Instream Flow Program (TIFP), studies include only the lower Sabine River from Toledo Bend Reservoir to tidal. (The State of Louisiana owns half the flow in this stateline reach, but does not have a program similar to SB 2). Unique aspects of the Study Area include:

1. Texas/Louisiana (stateline flows, water supply reservoir and estuary);
2. Texas State Water Quality Flows (Texas – 7Q2/Louisiana – 7Q10);
3. SB 2 priority study – lower Sabine River;
4. Toledo Bend Reservoir Project Joint Operations – Federal Energy Regulatory Commission relicense of Toledo Bend hydropower facility;
5. Sabine River Compact which provides for equitable apportionment of waters between Texas and Louisiana;
6. Lower Neches River Saltwater Barrier - minimum flow requirement;
7. Cutoff Bayou – migration of water to Louisiana's Old Sabine River channel affecting environmental flows and water supply users in Texas; and
8. USACE proposed deepening of existing ship channel through the Sabine-Neches Estuary to upstream ports.

Discipline Reports

The Sabine-Neches BBEST Subcommittees submitted reports –on the disciplines of hydrology, biology, water quality and geomorphology – key components identified by the TIFP Technical Overview.

Hydrology – The Hydrology Subcommittee benefited from outside consultant work which prepared three memoranda:

1. Analysis of Sabine-Neches BBEST Stream Gages;
2. Hydrology-Based Environmental Flow Regime (HEFR) Analyses for Sabine-Neches BBEST; and
3. Water Availability Analyses for Sabine-Neches BBEST.

The subcommittee worked with the consultant in the preparation of these memos and used this baseline work to develop flow regime matrices for each of the selected gages for use by the other disciplines.

Biology – The Biology Subcommittee assisted in the selection of representative focal species for the two river basins and the estuary, and also worked with an outside consultant to prepare reports on Fluvial Focal Species and Estuarine Focal Species. The flow regime matrix produced by the HEFR statistical analyses of the historical stream gage records was used to evaluate the available biological information for the focal species related to subsistence flows, base flows, high flow pulses, and overbank flows. Using SAC guidance, the estuarine ecosystem evaluation was enhanced with the NWF analysis of habitat suitability for key estuarine species under alternative flow regimes. Changes to the estuary including the ship channel, intracoastal waterway, and secondary channels into the marshes were discussed along with a need for habitat restoration in marshes in Texas and Louisiana. Adaptive management as envisioned by the SB 3 process was considered along with the need for future studies to address the unresolved issues in the Report.

Geomorphology (Sediment Transport) – The Geomorphology Subcommittee, utilizing SAC guidance, worked with the TWDB to address sediment transport in the Study Area. The TWDB has conducted studies of sediment transport and geomorphologic characterization within Texas river systems and most recently has worked with Dr. Jonathan Phillips of the University of Kentucky to conduct studies in the lower Sabine River as part of the SB 2 study. TWDB modeling was undertaken for each of the gages as well to determine how these systems are functioning. Estuary sediment delivery was also considered.

Water Quality – The Water Quality Subcommittee evaluated water quality as an overlay application in environmental flows. Water quality is an important aspect of environmental flow recommendation development. Available water quality was compiled and evaluated for the study area along with water quality standards, flow and water quality relationships, and the integration of water quality into environmental flow recommendations.

Development of Environmental Flows Recommendations/ Recognitions/ Unresolved Issues

As illustrated in the Report's Decision Tree (Figure 4, page 8), the decision process and statistical analyses created, in effect, a statistical river which resulted in HEFR output matrices for each of the twelve gages (six in the Neches Basin and six in the Sabine Basin). These are listed with descriptions of each location and the corresponding matrix (for example – HEFR Matrix for Big Sandy Creek near Big Sandy) which presents the numbers associated with these decisions on a seasonal basis (Sabine-Neches BBEST selected Jan-Mar for winter, Apr-Jun for spring, and so on) for subsistence, base, high flow pulses and overbank flows with qualifying language regarding the interpretation of these flow components. For base flows, seasonal numbers were generated for dry, average and wet conditions which were arbitrarily chosen to be 25^{th} /50^{th} /75^{th} percentiles.

The Sabine-Neches BBEST developed an example application of a flow regime to focus on key elements of a HEFR output matrix and considerations in order to understand how such flow regimes might be applied to new surface water appropriations and/or diversions. The group's understanding of potential flow regime application is summarized in a series of examples for Big Sandy Creek near Big Sandy, Texas.

The Sabine-Neches Estuary current status is summarized from the discipline reports, appendices, and reference documents. The SAC guidance, Sabine Lake history, State Methodology, percent inflow schematic documenting inflows (from the Sabine River, the Neches River, and coastal inflows), and HEFR as an estuary inflows recommendation tool are presented. The USACE's project to deepen the ship channel includes extensive studies. Hydrodynamic salinity modeling, water supply planning using the 2007 Texas Water Plan (Texas Water Development Board. 2007) data modeling current and future water use (50 year) conditions, and marsh habitat mitigation/restoration in Texas and Louisiana are included.

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1 PREAMBLE

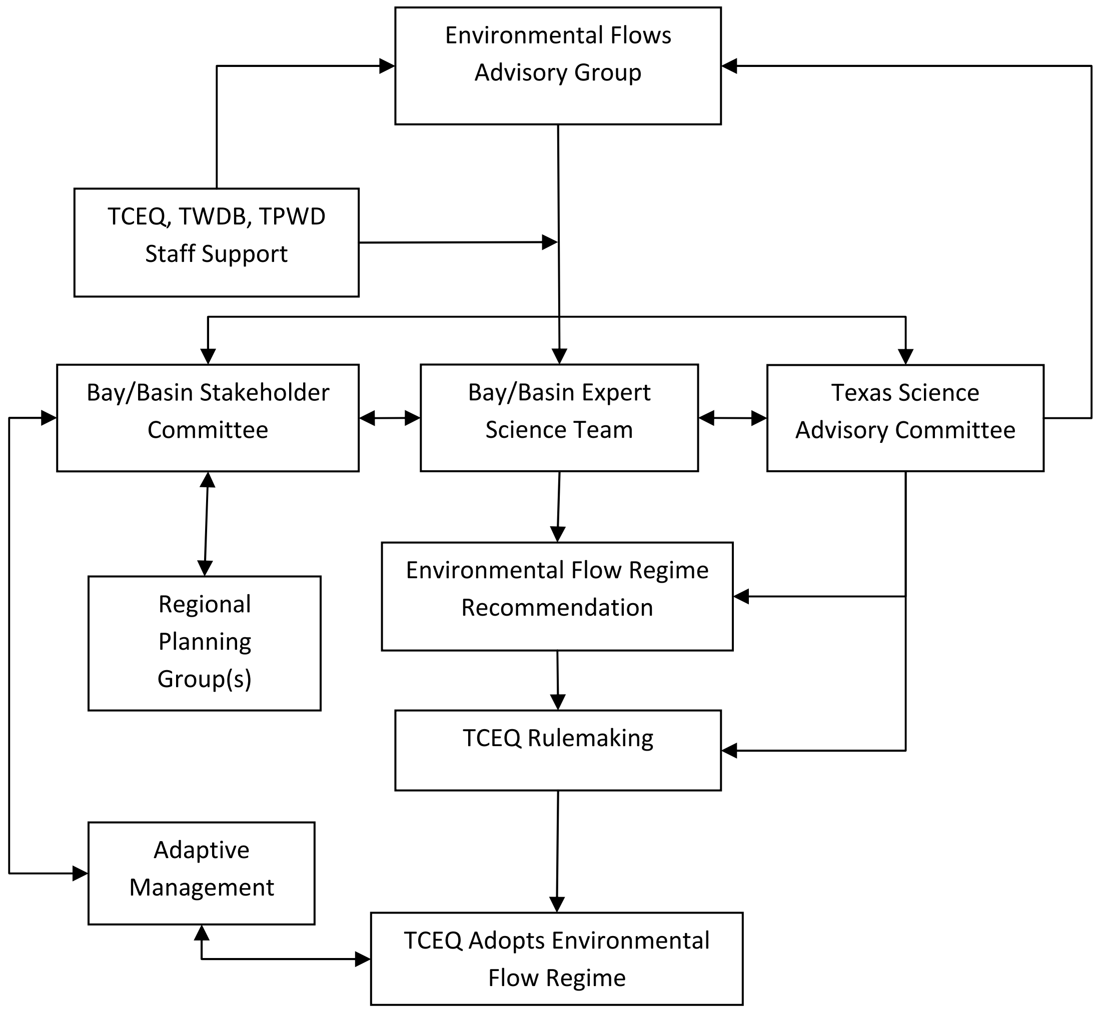
The Sabine and Neches Basin and Sabine Lake Bay Expert Science Team (Sabine-Neches BBEST) is pleased to provide this *Environmental Flows Recommendation Report* to the Sabine and Neches Rivers and Sabine Lake Bay Basin and Bay Area Stakeholder Committee (Sabine-Neches BBASC), Texas Environmental Flows Advisory Group (EFAG), and the Texas Commission on Environmental Quality (TCEQ). The Sabine-Neches BBEST fully understands its primary charge for developing environmental flow analyses and arriving at these final recommendations, as well as the constraints on making this determination. The Sabine-Neches BBEST believes the body of work discussed herein has enabled it to move the Texas environmental flows process forward and to address this charge in a very positive manner, in full recognition of the best science available and limited time frame. The Sabine-Neches BBEST has worked very hard over the past twelve months to provide this *Environmental Flows Recommendations Report* within the allotted time frame with recommendations and supporting rationale that will lay the necessary groundwork for the Sabine-Neches BBASC to balance environmental flows with the needs of the people of Texas in the Sabine and Neches River Basins and the Sabine-Neches Estuary (Sabine Lake) area with full recognition of the State of Louisiana's co-ownership of Toledo Bend Reservoir and the portion of the Lower Sabine River that forms the state line (see Section 3.5, page 36).

1.1 SENATE BILL 3

Texas lawmakers passed Senate Bill 3 (SB 3) in the 2007 80th Regular Session of the Texas Legislature. SB 3 is the third in a series of three omnibus water bills related to the State of Texas' meeting the future needs for water. Senate Bill 1 (SB 1) established a "bottom-up" approach to water resource planning. The Senate Bill 2 (SB 2) instream flow program was established in recognition of the lack of data to determine how much water is needed for the environment. SB 3 created a basin-by-basin process (see Figure 1, page 2) for developing recommendations to meet the instream flow needs of rivers as well as freshwater inflow needs of affected bays and estuaries and required TCEQ to adopt the recommendations in the form of environmental flow standards. Such standards will be utilized in the decision-making process for new water right applications and in establishing an amount of unappropriated water to be set aside for the environment. (Texas Legislature 2007)

Prior to SB 1, SB 2, and SB 3, Texas law recognized the importance of balancing the biological soundness of the state's rivers, lakes, bays, and estuaries with the public's economic heath and general well-being. The Texas Water Code (TWC) requires the TCEQ, while balancing all other interests, to consider and provide for the freshwater inflows necessary to maintain the viability of Texas' bay and estuary systems in TCEQ's regular granting of permits for the use of state waters. Unfortunately, even though Texas has long been the leading state at documenting existing and historical flows, the information needed to determine the instream flows and freshwater inflows needed to support ecologically sound river and bay systems is limited. Prior to SB 3, the balancing of the effect of authorizing a new use of water with the need for that water to maintain a sound ecological system was done on a case-by-case basis as part of the water rights permitting process. This resulted in an enormous roadblock for the SB 1 water planning process.

FIGURE 1. SB 3 ENVIRONMENTAL FLOW PROCESS



(Environmental Flows Advisory Committee 2006)

1.2 SABINE-NECHES BBEST

The Trinity and San Jacinto Rivers and Galveston Bay system and the Sabine and Neches Rivers and Sabine Lake Bay system are the priority river basin and bay systems of the state for the purpose of developing environmental flow regime recommendations and adopting environmental flow standards. Therefore, the Sabine-Neches BBEST is one of two initial basin and bay expert science teams in Texas.

In accordance with SB 3, the Sabine-Neches BBEST members were appointed by the Sabine-Neches BBASC (Texas Commission on Environmental Quality 2008a). Table 1 provides a list of the Sabine-Neches BBEST members and the Sabine-Neches BBASC representatives that nominated them. The Sabine-Neches BBEST held twelve monthly meetings and several workshops beginning with its initial meeting on December 8, 2009. During the course of this time, the Sabine-Neches BBEST established subcommittees for:

- Gaging
- Hydrology
- Biology
- Geomorphology (sediment transport)
- Water Quality
- Recommendations Report Preparation

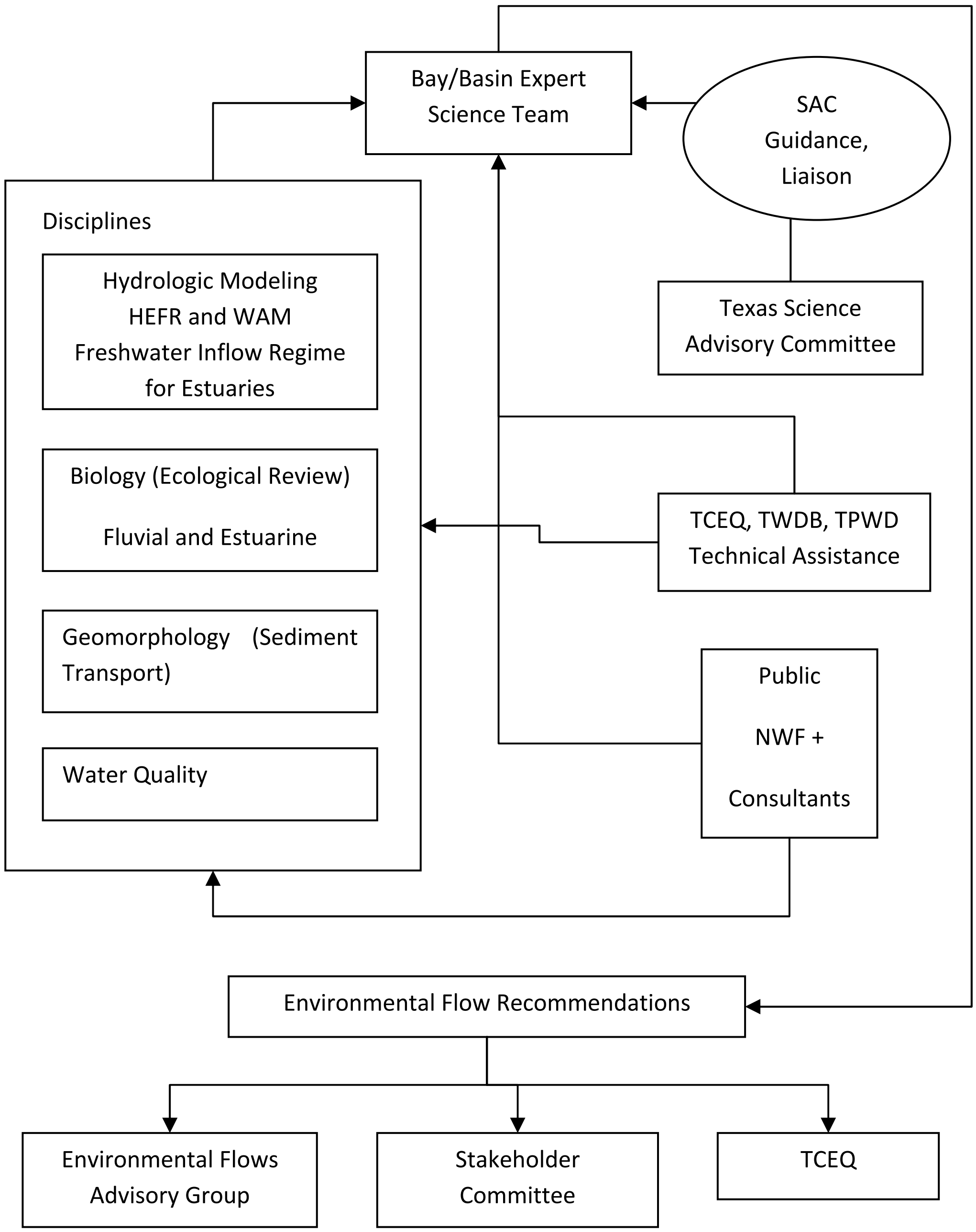
Subcommittee work has included numerous meetings and conference calls in addition to the monthly meetings as the Sabine-Neches BBEST has moved forward to define the available science in the study area shown in Figure 5 on page 25. The Sabine-Neches BBEST meetings were an open process that benefited from the resource agencies -- TCEQ, Texas Water Development Board (TWDB) and Texas Parks and Wildlife Department (TPWD), environmental groups such as the National Wildlife Federation (NWF), and the public. All the contributions of these have been constructive to the process (conceptualized in Figure 2, page 5) and have been carefully considered.

To assist the subcommittees, the Sabine-Neches BBEST retained the services of Freese-Nichols, Inc., (FNI) and BIO-WEST, Inc., for hydrologic modeling and ecological review, respectively.

TABLE 1. SABINE-NECHES BBEST MEMBERSHIP

Member	Affiliation	Nominated by
Graham, Gary	G.E. Walker & Associates, L.L.C.	Jerry Clark
Hall, Scott (Co-Chair)	Lower Neches Valley Authority, General Manager	Robert Stroder
Harrel, Richard	Lamar University, Clean Air & Water, Inc.	Bruce Drury and Robert Stroder
Hunt, Rex H.	Alan Plummer Associates, Inc., Principal	Kelley Holcomb
Kelley, J. Roger	LBG, Inc., General Manager - Environmental	Ken Dickson
McBroom, Matthew	Stephen F. Austin State University, Assistant Professor	Baker Pattillo
McCullough, Jack D.	Stephen F. Austin State University, Research Scientist	Baker Pattillo
Parkhill, David L.	AECOM Water, Vice President	Jerry Clark
Tatum, Jack W. (Chairman)	Sabine River Authority of Texas, Water Resources Manager	Jerry Clark
Vaugh, Samuel Kent	HDR Engineering, Vice President	Monty D. Shank
Winemiller, Kirk	Texas A&M University, Professor	David Roemer

FIGURE 2. SABINE-NECHES BBEST PROCESS



1.2.1 Primary Charge

The Sabine-Neches BBEST Primary Charge is taken directly from SB 3 (Texas Legislature 2007):

> ***Primary Charge*** *to the Texas Environmental Flows Bay Basin and Science Expert Science Team (BBEST) is found in SB3, Section 11.02362 (m). "Each basin and bay expert science team shall* ***develop environmental flow analyses*** *and a recommended* ***environmental flow regime*** *for the river basin and bay system for which the team is established through a collaborative process designed to achieve a consensus." In developing the analyses and recommendations, the science team must consider all reasonably available science, without regard to the need for the water for other uses, and the science team's recommendations must be based solely on the best science available.*

SB 3 defines an **"environmental flow analysis**" as the "application of a scientifically derived process for predicting the response of an ecosystem to changes in instream flows or freshwater inflows."

SB 3 defines **"environmental flow regime"** as "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."

1.2.2 Accomplishment of Primary Charge and Decision Tree

The two components of the Sabine-Neches BBEST's Primary Charge under SB 3, develop environmental flow analyses and develop a recommended environmental flow regime, could be considered independently: develop environmental flow analyses then use the resulting analyses to recommend an environmental flow regime (Figure 3, below). However, the Sabine-Neches BBEST found them to be tightly coupled and accomplished both components of the Primary Charge together through an iterative process of decision making that is shown in Figure 4. Sabine-Neches BBEST Decision Tree.

1.2.3 Recommendation Report Evolution

The Sabine-Neches BBEST Recommendations Report is composed of a main body, which is a summary of the BBEST process, the study area, the work that was done in the development of recommendations; and the appendices, which include the full text of reports that were assembled through the process. Work reflected in the appendices was done throughout the twelve months the Sabine-Neches BBEST had to finish its charge and reflects a transition of understanding. Opinions and recommendations by the discipline report authors were generally agreed upon by consensus of the Sabine-Neches BBEST. ***The body of this Environmental Flows Recommendations Report is intended to be an assembly of the information that best reflects the consensus of the Sabine-Neches BBEST at the time the Recommendations Report was written.***

FIGURE 3. SABINE-NECHES BBEST - ACCOMPLISHMENT OF PRIMARY CHARGE

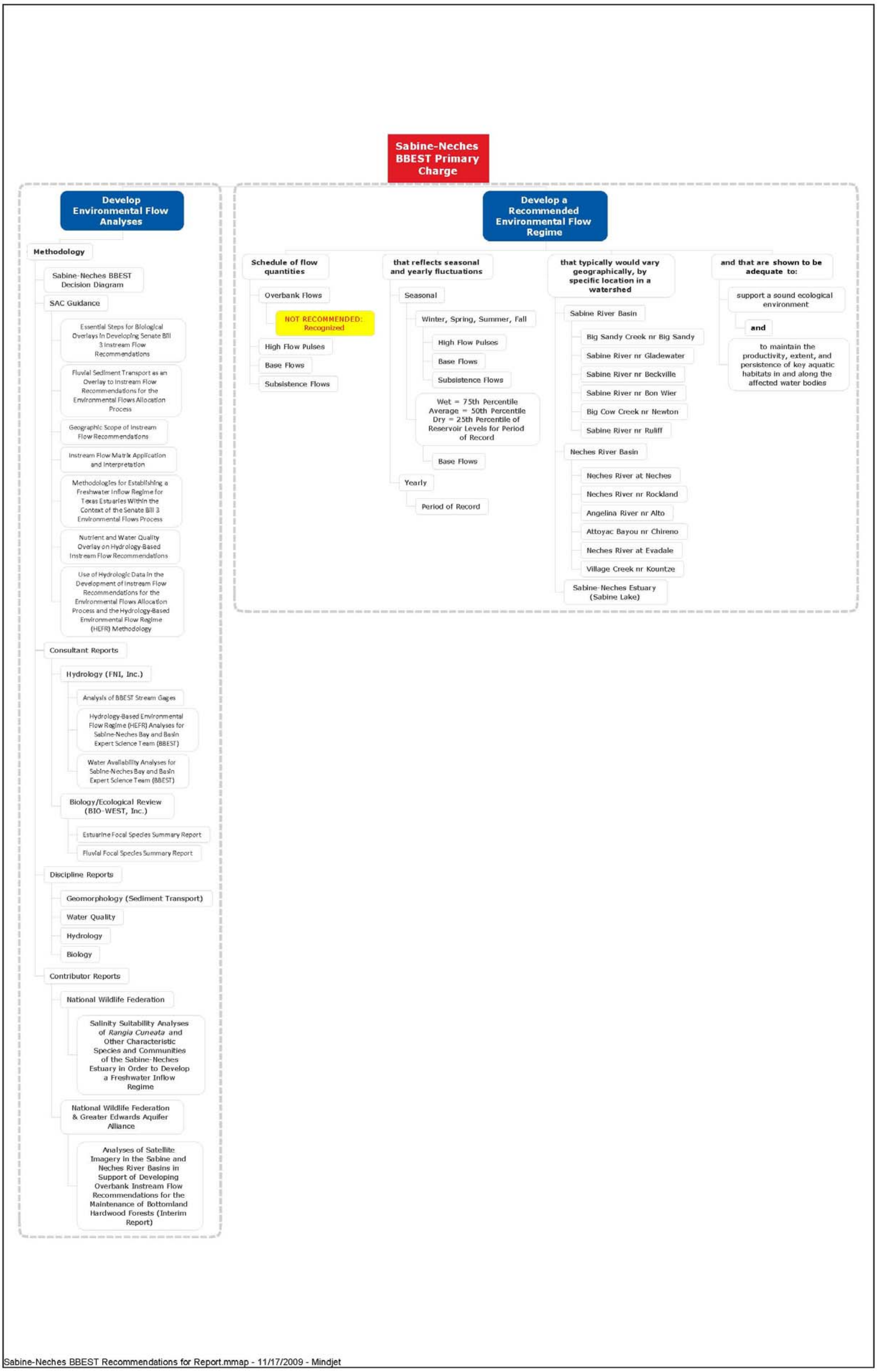
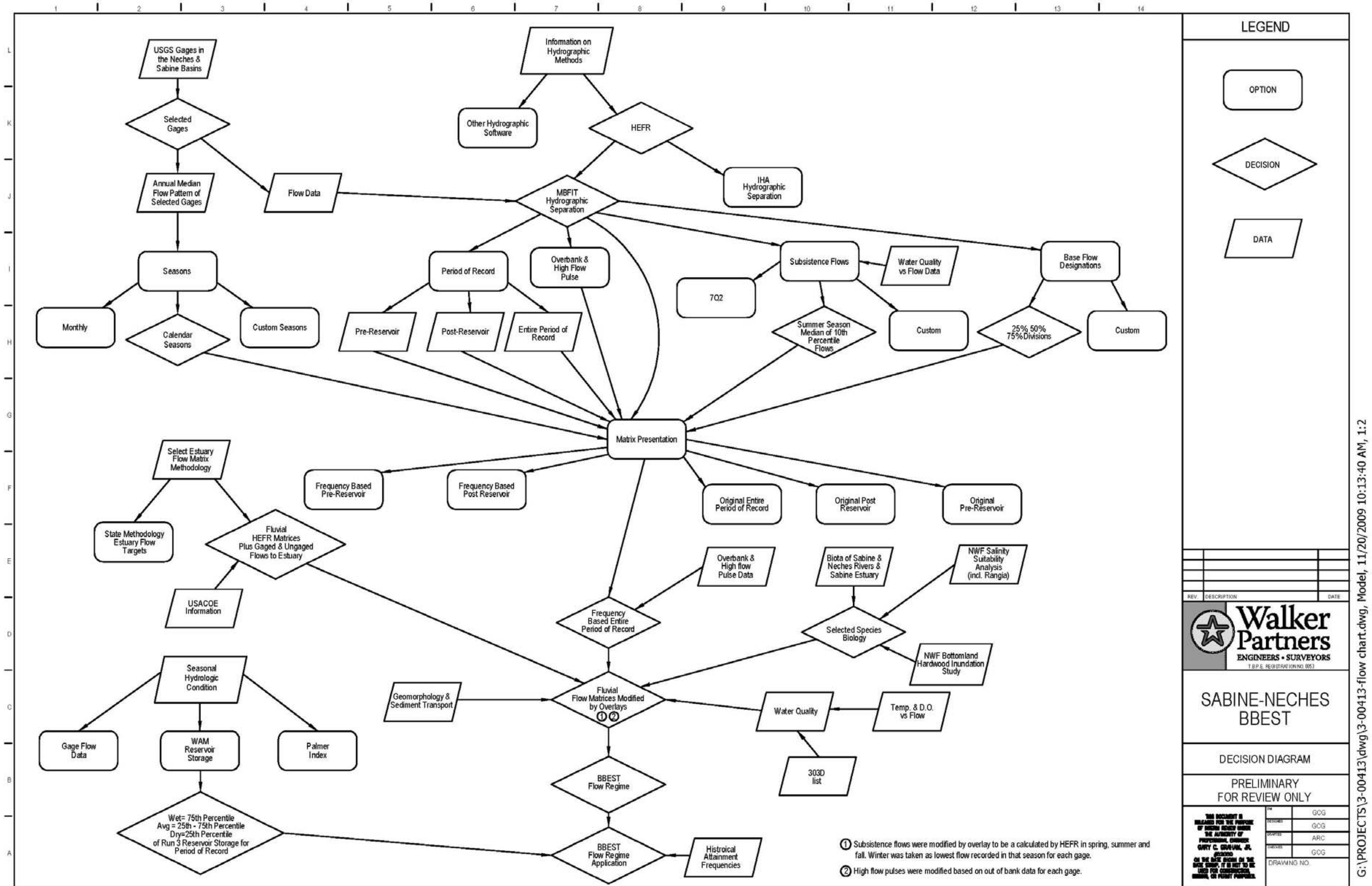


FIGURE 4. SABINE-NECHES BBEST DECISION TREE



1.2.4 Sound Ecological Environment

SB 3 did not define "sound ecological environment"; therefore, the Sabine-Neches BBEST adopted the definition of "sound ecological environment" stated by the Texas Environmental Flows Science Advisory Committee (SAC) in its "Methodologies for Establishing a Freshwater Inflow Regime for Texas Estuaries Within the Context of the Senate Bill 3 Environmental Flows Process" (SAC 2009d):

> *A **sound ecological environment** is 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.*

(SAC 2009d) further notes:

Underlying each of these is the need to establish relationships between elements of the environment, including flows, and the native species and their functions.

1.2.5 Goal

> *The goal of the Sabine-Neches BBEST is to maintain a **sound ecological environment** in the Sabine and Neches Basin and the Sabine-Lake Estuary as defined above.*

1.2.6 Objectives

> *Objectives: To meet the Criterion of a **sound ecological environment***
>
> - *Characterize system hydrology and hydraulics*
> - *Examine status of geomorphic processes within the system*
> - *Characterize system water quality*
> - *Evaluate biological communities*
> - *Define the influence and relationship of other riverine environmental components relative to biology of the system*

The "Texas Instream Flow Studies: Technical Overview" (Texas Commission on Environmental Quality 2008b) provided the basis for these objectives.

1.2.7 INSTREAM FLOW REGIME COMPONENTS

Variations in the magnitude, frequency, duration, timing, and rate of change of stream flows are all critical components of a natural flow regime (Poff, Allan et al. 1997). Variability in stream flow is manifested to stream biota as a change in habitat availability. Consequently, the life histories of stream fishes and other aquatic organisms are adapted to the seasonal and interannual variability of low, base, and high flow components. Hydrologic pattern and variability are therefore key determinants of aquatic community structure and stability (Poff and Ward 1989; Richter, Baumgartner et al. 1996; Poff, Allan et al. 1997; Dilts, Leonard et al. 2005).

Alterations to a natural flow regime may result in decreased richness, diversity, and abundance of aquatic species inhabiting lotic systems. While the elimination of high flows can result in reduced species densities and community diversity (Robinson, Clarkson et al. 1998), stable flow regimes that lack seasonal and interannual variability may favor generalist and non-native species (Tyus, Brown et al. 2000). In addition, seasonal and interannual flow variability may benefit native species that have developed life history strategies in response to natural flows. Thus, providing a flow regime based on the natural flow paradigm should provide ecological benefits in stream systems (Dilts, Leonard et al. 2005).

To date, most instream flow recommendations in Texas have used a single "minimum" flow standard, which may vary by month and location (see discussion on Lyons Method in Section 5.1 Hydrology, below). Conversely, instream flow recommendations based on a flow regime concept, such as the regime concept found in SB 3, consist of multiple flow regime components, or levels, with specific characteristics. Following the recommendation of the National Research Council (National Research Council Committee 2005), and consistent with "Scientific Principles for Definition of Environmental Flows" (Maidment, Montagna et al. 2005) , the Texas Instream Flow Program[1] (TIFP) (Texas Commission on Environmental Quality 2008b) uses a framework that consists of a set of four components of a flow regime intended to support a sound ecological environment. These instream flow regime components and their definitions as adopted by the Sabine-Neches BBEST are described in Table 2. Instream Flow Regime Components Definitions, below.

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[1] Senate Bill 2, 77th Texas Legislature, 2001

TABLE 2. INSTREAM FLOW REGIME COMPONENTS DEFINITIONS

Component	Definition
Overbank Flows	the component of an instream flow regime that represents infrequent, high flow events that exceed the normal channel. These flows maintain riparian areas and provide lateral connectivity between the river channel and active floodplain. They may also provide life-cycle cues for various species.
High Flow Pulses	the component of an instream flow regime that represents short-duration, in-channel, high flow events following storm events. These flows maintain riparian areas and provide lateral connectivity between the river channel and active floodplain. They may also provide life-cycle cues for various species.
Base Flows	the component of an instream flow regime that represents normal flow conditions (including variability) between precipitation events. Base flows provide a range of suitable habitat conditions that support the natural biological community of a specific river sub-basin.
Subsistence Flows	the component of an instream flow regime that represents infrequent, naturally occurring low flow events that occur for a seasonal period of time. They maintain sufficient water quality and provide sufficient habitat to ensure organism populations capable of recolonizing the river system once normal, base flows return.

The instream flow regime flow regime components are discussed in more detail in Section 5.1.4, Instream Flow Regime Components (page 45).

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2 SUMMARY OF RECOMMENDATIONS, RECOGNITIONS, AND RATIONALE

SB 3 established an aggressive schedule for determining environmental flow standards in Texas' river basins and bay systems. (Texas Water Code § 16.059 (Vernon 2008)). The BBESTs are to develop a flow regime recommendation. These recommendations must consist of a schedule of flow quantities, reflecting seasonal and yearly fluctuations that may vary by location. The SB 3 schedule does not allow for the development of multi-year site-specific instream flow studies to determine the ecological flow needs mandated by SB 2. Instead, SB 3 requires that environmental flow standards be predicated upon the best science and data currently available and intends that adaptive management be employed to refine the flow standards in the future. The timing constraints in SB 3 dictate that "desktop methods" be utilized which are primarily based on statistical evaluations of historical flows and therefore establish the flows that have occurred rather than a determination of the flows that are needed to support a sound ecological environment.

The immediate task for developing the flow standards required under SB 3 is to identify an environmental flow regime at particular locations on a stream that will support a sound ecological environment and maintain the productivity, extent, and persistence of key aquatic habitats. The extent to which such an environmental flow regime conforms to the basic structure of that being proposed for application in the TIFP studies is an important consideration. Incorporating the results of TIFP studies into SB 3 environmental flow regimes may be greatly facilitated if the initial environmental flow regime recommendations are consistent with the TIFP flow regime components.

2.1 RECOMMENDATIONS

SB 3 charged each BBEST with recommending an environmental flow regime. While the Sabine-Neches BBEST has met its SB 3 charge, its recommendations are not limited to an environmental flow regime only. Defining *recommendation* as "a course of action that is recommended as advisable", the Sabine-Neches BBEST was very careful to limit its recommendations to those flow regimes for which the group agreed that implementation is advisable. For those environmental flow regime components it did not deem advisable for implementation, the Sabine-Neches BBEST *recognized*, or acknowledged, the ecological benefits of the component.

Following are nine recommendations adopted by the Sabine-Neches BBEST regarding an environmental flow regime for the Sabine and Neches Basins and the Sabine-Neches Estuary. Each recommendation includes a brief summary of the rationale associated with the recommendation.

2.1.1 RECOMMENDATION 1: DEFINITION OF A SOUND ECOLOGICAL ENVIRONMENT

The Sabine-Neches BBEST recommends the SAC definition that it adopted (see Section 1.2.4, page 9) for **sound ecological environment**.

Rationale The Sabine-Neches BBEST recognizes that the ecology of the rivers and estuaries in Texas is a dynamic system, in that what exists today differs from what existed in the past. Further, current ecological conditions will naturally change over time under the forces of nature and other external influences (hurricanes, floods, ship channel deepening, land use changes, etc.) unrelated to and unaffected by instream flows. Therefore, while instream flow regimes may have a direct and immediate influence on the ecologic system of the rivers and estuaries, mankind does not have the ability to fully control these systems or render them static.

2.1.2 Recommendation 2: The Current Conditions of the Sabine and Neches Rivers and the Sabine-Neches Estuary are Sound

Rationale Appendix XII-1 summarizes Sabine and Neches Basin water quality impairments appearing on the 2008 Texas 303(d) List.[2] None of the segments including the 12 gages are listed as impaired for any water quality parameter that would be significantly affected by the level of environmental flow in the stream at the gage, or by future diversions of water from the stream at these locations. The Sabine-Neches Estuary is generally sound, exhibiting good overall water quality and diverse fish and wildlife communities (see Section 6.2.3, page 141) despite the influence that the Sabine-Neches Waterway (SNWW) and Gulf Coast Intracoastal Waterway (GIWW) have on salinity in the estuary. Also, although no other specific instream flow studies have been completed in the Sabine-Neches Basins, the Sabine-Neches BBEST evaluation of biological/ecological responses to flow variation was greatly aided by data collected over broader spatial and temporal scales (Evans and Noble 1979; Moriarty and Winemiller 1997; Bonner and Runyan 2007; Bart 2008) and other studies summarized in (BIO-WEST 2009b).

2.1.3 Recommendation 3: Acknowledge That Flows in the Sabine and Neches Rivers and Inflows to The Sabine-Neches Estuary will Change Over Time

Rationale The Sabine-Neches BBEST acknowledges that the flow regimes recommended herein are based upon analysis of historical streamflow gages at specific locations and that the current state of the environment is sound. Furthermore, the Sabine-Neches BBEST acknowledges that over time, changes in utilization of existing water rights, and issuance of future water rights, climate change, land use changes, and other outside factors will undoubtedly change stream flows from those seen in the past. Consequently, the Sabine-Neches BBEST believes that the flow regime matrices provided in this report are representative of a flow regime necessary to support a sound ecological environment but by no means do they represent the only flow regime that could do the same.

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[2] TCEQ, 2008 Texas Water Quality Inventory and 303(d) List, http://www.tceq.state.tx.us/compliance/monitoring/water/quality/data/08twqi/twqi08.html, retrieved November 7, 2009

2.1.4 Recommendation 4: Future Study, Data Gathering, and Adaptive Management are Necessary to Determine Whether or Not Changes in Environmental Flows will Maintain a Sound Ecological Environment

Rationale SB 3 envisions an adaptive management process for revisiting the environmental flow standards and environmental flow set-asides derived through the TCEQ rulemaking procedure. The SB 3 adaptive management process envisions that additional data, information, and studies will be necessary to make informed decisions regarding future changes to environmental flow recommendations. The on-going TIFP studies and Toledo Bend Project Federal Energy Regulatory Commission (FERC) Relicensing will provide useful information, but more research will be needed. In particular, dependence upon hydrology-based environmental flow recommendations, which is required to meet the aggressive time frames specified in SB3, highlights the need for future adaptation of the adopted flow standards. While application of the pre- and post-biological overlay process and other overlay disciplines can substantively improve the hydrology-based recommendations, future refinements and validation will accrue only from the use of new and better science developed through the adaptive management process.

2.1.5 Recommendation 5: Applicable hydrologic conditions for the entire season are defined on the basis of an assessment of hydrologic conditions of storage in selected reservoirs at the beginning of the first day of the season thereby recognizing both drought persistence and practical operations

Rationale The Sabine-Neches BBEST considered instantaneous or cumulative flow, Palmer Drought Severity Indices, and reservoir storage as potential means of defining hydrologic conditions. The Sabine-Neches BBEST chose hydrologic conditions at any specific location to be defined on the basis of cumulative storage in major reservoirs located upstream and the frequency of occurrence of such storage subject to full use of authorized water rights (TCEQ Run3). Wet, average, and dry are represented by 25th, 25th – 75th, and 75th percentile conditions.

2.1.6 Recommendation 6: Subsistence Flows

The Sabine-Neches BBEST recommends adoption of the seasonal subsistence flows from MBFIT /HEFR, unless:

1. ***the seasonal value is less than the summer value in which case the summer value is adopted by default, and***
2. ***MBFIT/HEFR failed to calculate a value (this occurred usually for winter) in which case the lowest recorded flow value for that season at that gage was adopted by default.***

Translation of seasonal subsistence flows into environmental flow standards and permit conditions should not result in more frequent occurrence of flows less

than the recommended seasonal subsistence values as a result of the issuance of new surface water appropriations or amendments.

Rationale **H**ydrology-**B**ased **E**nvironmental **F**low **R**egime (HEFR; Opdyke 2009; SAC 2009f) outputs were used to estimate subsistence flows based on historical streamflow data and manipulation of the **M**odified **B**ase **F**low **I**ndex with **T**hreshold (MBFIT; Opdyke 2009) option. Historical streamflows represent a sound ecological environment, and this recommendation is consistent with the subsistence flow definition of the component of an instream flow regime that represents infrequent, naturally occurring low flow events that occur for a limited period of time (Table 2, page 11). See Section 5.2.2.1, page 63, for more detailed discussion of the biological overlay evaluation of subsistence flows.

Subsistence flows lower or higher than those recommended for the basins could be justified if sufficient water quality data were available for evaluation. It is important, therefore, to prioritize additional sampling trips to better characterize water quality conditions during extreme low flow periods; and, as such, additional water quality study (e.g. TCRP Special Studies) at low and subsistence flow is recommended.

After review of Environmental Protection Agency (EPA) DFLOW biologically-derived low flow statistics documentation[3] (i.e., 4B3, or more generally xBy) and sources on hydrologically derived low flow statistics (i.e., 7Q2, 7Q10, or more generally xQy), the Sabine-Neches BBEST concluded that none of these methods determine what the ecological subsistence flow should be for a specific stream. 7Q2 in particular has a two-year expected return period which is frequent and isn't consistent with the adopted definition of subsistence flow. Some BBEST members supported use of the 5th percentile as the subsistence flow criterion due its current widespread support within the environmental flows arena. Recent studies and reviews have concluded that the 5th percentile marks a significant point below which already stressful conditions in the river change rapidly. Hence, the Sabine-Neches BBEST acknowledges that new studies and findings may warrant revision of these subsistence flow thresholds (Recommendation 6).

2.1.7 Recommendation 7: Base Flows

Seasonal base flows represent thresholds for environmental protection based on current scientific understanding of fluvial and estuarine ecosystems. As new studies and monitoring information become available, these base flow thresholds may be revised.

Rationale For the Sabine-Neches BBEST ecological analysis, the HEFR base flows for dry-year (25th percentile of upstream reservoir storage for period of record), average-year (25th – 75th percentile of upstream reservoir storage for period of record), and wet-year (75th

[3] DFLOW: A Tool for Low Flow Analysis | Water Quality Models and Tools | US EPA, http://www.epa.gov/waterscience/models/dflow/, retrieved November 3, 2009

percentile of upstream reservoir storage for period of record) estimates from each gage were compared with our information on the ecology of focal species (BIO-WEST 2009a, Appendix VIII) and, when appropriate, findings from the BIO-WEST instream flow study of fishes in the lower Colorado River (BIO-WEST 2008a). Adoption of base flow benchmarks for dry years (low precipitation years when reservoir pools are low), average years, and wet years (high precipitation years when reservoir pools are high) was deemed critical for protecting populations of aquatic organisms within the various diverse habitat guilds.

2.1.8 Recommendation 8: High Flow Pulses

Seasonal high flow pulses have recognized ecological benefits and are recommended for protection with certain reservations associated with environmental and operational liability risks.

Seasonal in-channel high flow pulses with historical frequencies of two smaller-magnitude pulses (defined by the frequency-based method in HEFR as 2-per season) and one larger magnitude pulse (defined as 1-per season) were calculated using the frequency-based method in HEFR. Under average or wet hydrologic conditions (Recommendation 5), up to two pulses would be passed each season for the needs of a sound ecological system. A single larger magnitude in-channel pulse must be passed when produced by precipitation and runoff under wet hydrologic conditions. Two pulses, smaller-magnitude seasonal pulses, must be passed when produced by precipitation and runoff under average hydrologic conditions. Under dry hydrologic conditions (Recommendation 5) during spring and summer (defined in this instance as Spring: March – May; and Summer: June–August), one of the smaller-magnitude pulses must be passed during each season for critical ecological functions, including cues for synchronized fish spawning, passive transport of fertilized eggs and larvae into retention zones, and resuspension of silt. This latter recommendation assumes high flow pulses of the prescribed magnitude and duration to be naturally rare events based on the historical record. Other flows exceeding these environmental pulse targets would be eligible for impoundment or diversion. There would be no memory (carry over) between seasons and no requirement for a storage project to create any flow pulses not delivered by natural precipitation and runoff in the watershed.

Translation of seasonal pulse flows of specified frequencies into environmental flow standards may result in frequencies of occurrence of high flow pulses that are lower than historical frequencies as a result of the issuance of new surface water appropriations or amendments. This reduced frequency of occurrence is deemed a crudely calculated environmental risk at this time, subject to review as new studies and information become available. The Sabine-Neches BBEST recommends further evaluation of the ecological functions of alternative categories of in-channel high flow pulses having lower magnitudes but greater frequencies of occurrence. The ecological functions of small but more frequent high flow pulses can be critical, especially during spring spawning seasons, and under Recommendation 8, these are not protected for support of a sound ecological environment.

At several reference gage locations, winter and spring high flow pulses with historical frequencies of one (1) per season approach were deliberately limited to peak flow rates associated with the approximate bankfull stage condition. Hence, extreme caution is warranted in the passage of high flow pulses to ensure that concomitant downstream runoff does not cause overbank flooding, particularly under wet hydrologic conditions. This potential liability is deemed an acceptable operational risk at this time, subject to BBASC review, logical translation of pulse flows into environmental flow standards and permit conditions by TCEQ, and indemnification of present and future water rights holders operating in accordance with permit conditions specifying high flow pulses.

Rationale As discussed in Section 5.1.4, Instream Flow Regime Components, high flow pulses serve to maintain important physical habitat features and connectivity along a stream channel. And as discussed in Section 5.2.2.3, High Flow Pulses and Overbank Flows, the Sabine-Neches BBEST evaluated HEFR-derived pulse flows in the context of available ecological information and concluded that certain categories of high flow pulses need protection (2-per-season and 1-per-season; see Section 6.2 for specific recommendations). Available hydrologic, biologic, geomorphologic, water quality data, and professional judgment suggest that these recommended pulses are currently perceived that they may be adequate to provide high in-channel flows of short duration, recruitment events for organisms, lateral connectivity, channel and substrate maintenance, limitation of riparian vegetation encroachment, and in-channel water quality restoration after prolonged low flow periods as necessary for long-term support of a sound ecological environment. However, the Sabine-Neches BBEST recognizes that, within certain stream segments, high flow pulses of certain magnitudes might pose potential liability issues (for example, prescribed high flow pulse releases from a reservoir project could exacerbate flooding caused by uncontrollable rainfall events downstream from the project).

2.1.9 Recommendation 9: Fluvial Matrices Inflow Recommendations are Adequate to Maintain a Sound Ecological Environment in the Sabine-Neches Estuary

Recognizing that the Sabine-Neches Estuary is a system in transition (Tatum 2009) and that the Sabine-Neches Estuary receives the freshwater inflows determined by the flow component recommendations for the Sabine-Ruliff, Neches-Evadale, and Village Creek gages (as well as other inflows[4]), the Sabine-Neches BBEST recommends that these inflows are adequate to maintain a sound ecological environment in the Sabine-Neches Estuary.

Rationale

1. The Sabine-Neches Estuary, like all coastal estuarine ecosystems, is spatially heterogeneous, physically and biologically dynamic, and highly complex owing to

[4] Ungaged inflows and gaged inflows at Pine Island Bayou and Cow Bayou that were not included in this analysis.

interactions among numerous environmental variables, manipulations by man, and diverse species spanning a range of salinity tolerances and ecological niches.

2. The Sabine-Neches Estuary, which includes Sabine Lake, is highly influenced by over 100 years of man-made alterations which have and continue to influence the estuary's current salinity structure (see Section 6.2.3, page 141).
3. The U.S. Army Corps of Engineers (USACE) is currently completing the Sabine-Neches Waterway Feasibility Study – a feasibility study for deepening the existing Sabine-Neches Waterway in Sabine Lake. The study includes a Hydrodynamic-Salinity Model and an analysis of Hydrologic Units in existing marshes/cypress-tupelo swamps in both the Texas and Louisiana portions of the Sabine-Neches Estuary for mitigation and habitat restoration related to the incremental changes of the proposed modifications to the Sabine-Neches Waterway.
4. The Sabine-Neches Estuary is generally sound, exhibiting good overall water quality and diverse fish and wildlife communities (Tatum 2009). The Sabine-Neches Estuary receives more freshwater than all other estuaries on the Texas Gulf Coast (see Table 17, page 143) and provides enough freshwater to Sabine Lake for the focal species studied there (NWF 2009). Sediment transport and concentration are within a range that is indicative of a sound ecological environment (Section 5.3, page 86); and
5. The Sabine-Neches BBEST's fluvial-derived environmental flow recognitions fall within the range of values that should provide sufficient freshwater inflows to maintain a sound ecological environment in the Sabine-Neches Estuary under the estuary's current geomorphologic configuration (Section 5.2.3 Estuarine Ecosystem Realm, page 72).

2.2 Recognitions

2.2.1 Recognition 1: Overbank Flows Have Recognized Ecological Benefits but are not Recommended

Overbank flows may cause extensive damage to private property and endanger the public. Therefore the Sabine-Neches BBEST recognizes the ecological benefits of these events, but cannot recommend such events be produced.

Rationale Overbank flows are infrequent, high flow events greater than bankfull that result in the inundation of the adjacent floodplain habitats. Overbank flows are ecologically important and can beneficially restructure the channel and floodplain, recharge groundwater tables, deliver nutrients to riparian vegetation, and connect the channel with floodplain habitats that provide additional food for aquatic organisms. By providing linkages with the stream channel and wetland areas, overbank flows contribute to the creation of waterbird habitat and breeding grounds, fish community diversity, invertebrate colonization, and provide for significant carbon returns to the river. Inclusion of overbank flows as part of a regulatory requirement will be subject to considerations of ecological benefit and issues of liability and the practicality of managing such flows (Texas Parks and Wildlife Department 2008). The Sabine-Neches BBEST recognizes that legal challenges may arise including liability for the damage resulting from managing for environmental flows that must be addressed (Dyson, Bergkamp et al. 2003), especially as relates to overbank flows. Because of the potential for legal challenge, property damage, and most importantly the threat to human life, the Sabine-Neches BBEST agrees that implementation of overbank flows should remain within the domain of nature.

2.2.2 Recognition 2: Toledo Bend Reservoir FERC Relicensing

The relicensing of the Toledo Bend Project is ongoing at this time. The relicensing will recognize the Project's primary use as a water supply project with the capability of generating hydroelectric power. Since no major changes in operations are planned, a maintenance flow will continue to be maintained from the spillway.

Rationale There are no major revisions proposed for the operations of the Toledo Bend Project during the relicensing that is currently underway and will be completed in September 2013. Under the existing license, the Project maintains a continuous discharge from the spillway of the dam with a minimum flow established by the license. While the Pre-Application Document (PAD), submitted in September 2008, outlines a small hydroelectric unit for the spillway, it is simply to extract the energy from the currently required spillway discharge.

A series of aquatic studies are underway downstream of the dam and will be used to determine if current operation of the Project has an adverse impact upon the Sabine River. These studies will be completed prior to submitting the Application of the new license in September 2011.

2.2.3 Recognition 3: Sabine River Compact

The major purposes of the Sabine River Compact are to provide for the equitable apportionment between the States of Louisiana and Texas of the waters of the Sabine River and its tributaries. Texas retains free and unrestricted use of the water of the Sabine River and its tributaries above the Stateline, subject only to the provisions that the minimum flow of 36 cfs must be maintained at the Stateline. All free water (free water means all waters other than stored water) and stored water in the Stateline reach, without reference to origin, will be divided equally between the two states.

Rationale Under the Sabine River Compact, there is a minimum flow requirement of 36 cfs at the Stateline. According to the USGS, this equilibrates to 22 cfs at the Beckville Gage (USGS 08022040). The SRA-TX releases 6 cfs from Lake Tawakoni and 4 cfs from Lake Fork as its prorated share of the Compact Stateline requirement. "Stateline" means the point on the Sabine River where its waters in downstream flow first touch the states of both Louisiana and Texas.

2.2.4 Recognition 4: Cutoff Bayou

Environmental flows as well as the diversions for the water supply canal system in Texas are adversely affected by migration of channel flow to the Old River Channel in Louisiana during low and average flow conditions.

Rationale The historic flow distribution between the Texas and Louisiana channels occurring near Cutoff Bayou (river mile 29.3) is changing. Since Hurricane Rita, the flow split, historically measured as close to 50/50, has been determined to be closer to 70 to 80 percent flow to the Old River channel in Louisiana and 20 to 30 percent flow to the Texas Stateline reach. The hydrologic flow conditions in the lower Sabine River Basin are complexly interrelated. That is evidenced by the historic and present flow distribution between the Texas and Louisiana channels occurring near Cutoff Bayou. Recent observations indicate that during low flow conditions, distribution appears to favor Louisiana with greater quantities of water. If recently observed trends were to continue, there is potential for flow during normal flow, and especially during low flow, conditions to be essentially eliminated in the Sabine River within Texas below Cutoff Bayou. These conditions may establish the Old River in Louisiana as the sole conveyance channel to the Gulf of Mexico through that reach. (AECOM 2009)

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3 BASINS AND BAY DESCRIPTIONS AND CURRENT CONDITIONS

The Study Area defined for the Sabine-Neches BBEST, the Sabine and Neches Rivers, and Sabine-Neches Estuary (Sabine Lake), are shown on Figure 5 (page 25).

3.1 SABINE RIVER BASIN

The Sabine River originates in Texas northeast of Dallas and flows southeast towards Logansport, Louisiana, then south to Sabine Lake. The crescent-shaped basin is 48 miles across at its widest point and over 300 miles in length from its headwaters to its mouth at the northeast end of Sabine Lake (580 river miles). All or part of twenty-one Texas counties and seven Louisiana parishes are in the Sabine Basin. The total drainage area of the Basin is 9,756 square miles, with 7,396 square miles (76 percent) in Texas and 2,360 square miles (24 percent) in Louisiana. The Sabine River Authority of Texas (SRA-TX), the Sabine River Authority, State of Louisiana (SRA-LA), and the Sabine River Compact Administration (SRCA) (Sabine River Compact Administration 2008) all have responsibilities relating to the waters of the Sabine Basin. (Sabine River Authority of Texas 1999)

SRA-TX is authorized to store water in the upper Sabine Basin in Lake Tawakoni and Lake Fork, and in the lower Sabine Basin in Toledo Bend Reservoir. SRA-TX and SRA-LA jointly own and operate Toledo Bend Reservoir through the Toledo Bend Project Joint Operation (TBPJO) with the minimum firm yield of Toledo Bend Reservoir being shared 50-50. Toledo Bend Reservoir was constructed for the purposes of water supply, hydroelectric power generation, and recreation and is licensed by the FERC. The FERC license currently requires a minimum flow release from the spillway at Toledo Bend Reservoir.

The Sabine River Basin has 14 major reservoirs (storage > 5,000 ac-ft), 11 in Texas, two in Louisiana, and one jointly in Texas and Louisiana. All of these projects are non-Federal reservoirs constructed for the purposes of water supply, hydropower, and recreation. There are no flood control reservoirs in the Sabine River Basin.

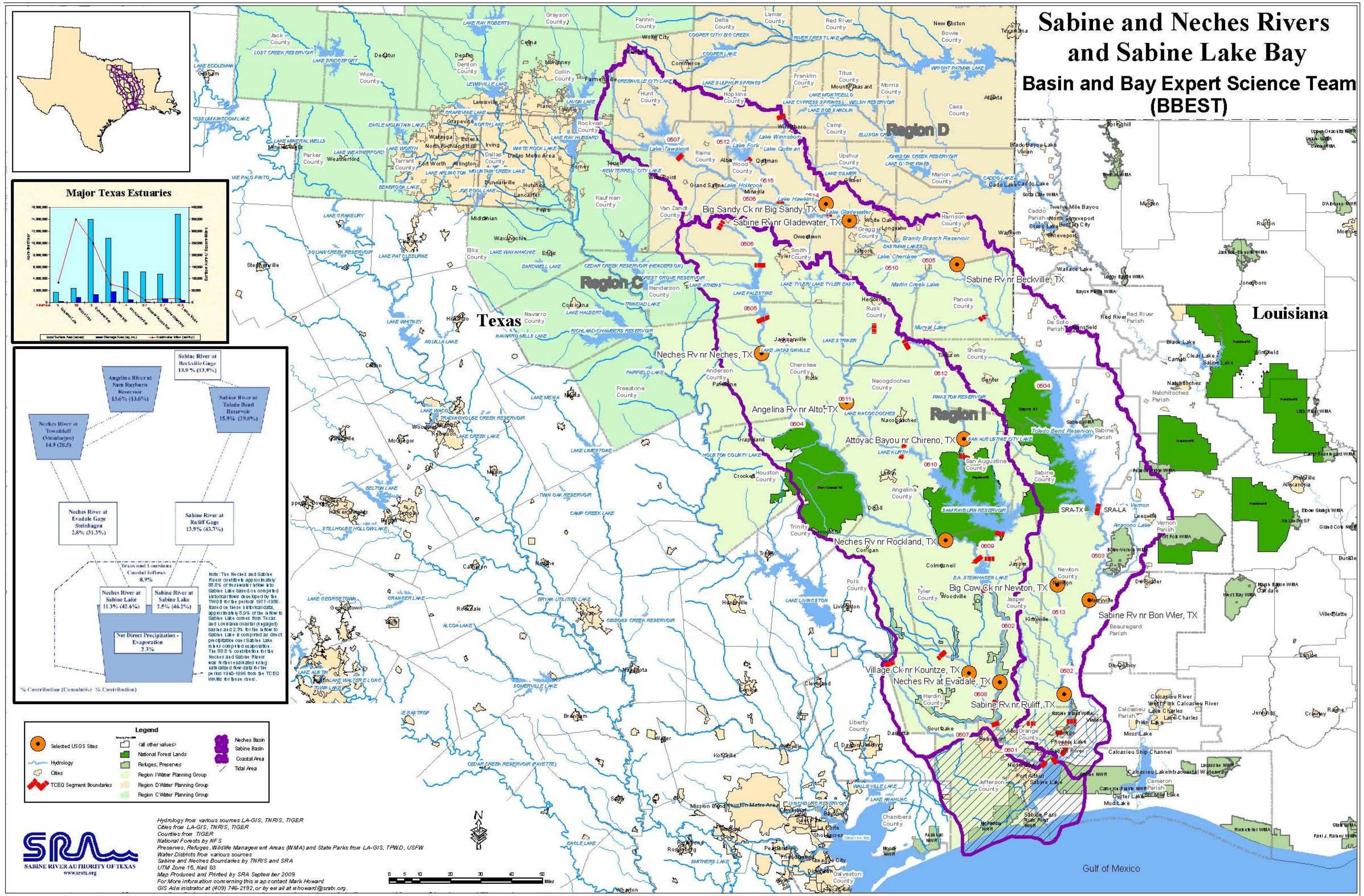
3.2 NECHES RIVER BASIN

The Neches River Basin is situated in east Texas between the Trinity River Basin to the west, the Sabine River Basin to the north and east, and the Neches-Trinity Coastal Basin to the south. It consists of the main stem Neches River, with headwaters in Van Zandt County, and the Angelina River which joins the Neches River in Jasper County just upstream of B.A. Steinhagen Reservoir. The basin covers approximately 10,000 square miles, is approximately 210 miles long, and ranges in width from just a few miles wide near its mouth to roughly 70 miles wide at its broadest point. Within the basin are 12 water supply lakes (10 of which are major reservoirs), the largest being Sam Rayburn Reservoir which serves as a hydropower reservoir, water supply, and flood control project. Sam Rayburn has nearly 4 million acre feet of total combined storage capacity and is the largest lake completely within the State of Texas. The Neches River empties into the northwest end of Sabine Lake near Port Arthur, Texas. The Angelina-Neches River Authority (ANRA), the Lower Neches Valley Authority (LNVA), and the Upper Neches River Municipal Water

Authority (UNRMWA) have responsibilities relating to the waters of the Neches River Basin in the Sabine-Neches Study Area.

The LNVA manages and operates the Neches River Saltwater Barrier under an agreement with the USACE. In accordance with its permit as issued by TCEQ, there is a minimum pass-through flow requirement of 400 cfs for the saltwater barrier.

FIGURE 5. SABINE AND NECHES RIVERS AND SABINE-NECHES ESTUARY (SABINE LAKE)



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3.3 SABINE-NECHES ESTUARY (SABINE LAKE)

3.3.1 ESTUARY DESCRIPTION

Sabine Lake is a 55,000 to 60,000 acre (volume approximately 300,000 acre-feet), shallow, brackish water lake located on the Texas-Louisiana stateline. Sabine Lake is the smallest major estuary in Texas, but receives the largest volume of freshwater inflow; the combined discharge of the Sabine and Neches Rivers is greater than the freshwater discharge into any other Texas bay system (Sabine River Authority of Texas and Lower Neches Valley Authority 2006). Figure 6 (page 28) shows the relative size and freshwater inflows of Sabine Lake with respect to the other major estuaries in Texas (and the adjacent Calcasieu Lake in Louisiana). Figure 7 (page 29) shows the Coastal Plains of the Calcasieu and Sabine-Neches Drainages. The Sabine-Neches Estuary is further discussed in Section 6.2.3 (page 141).

FIGURE 6. MAJOR TEXAS ESTUARIES

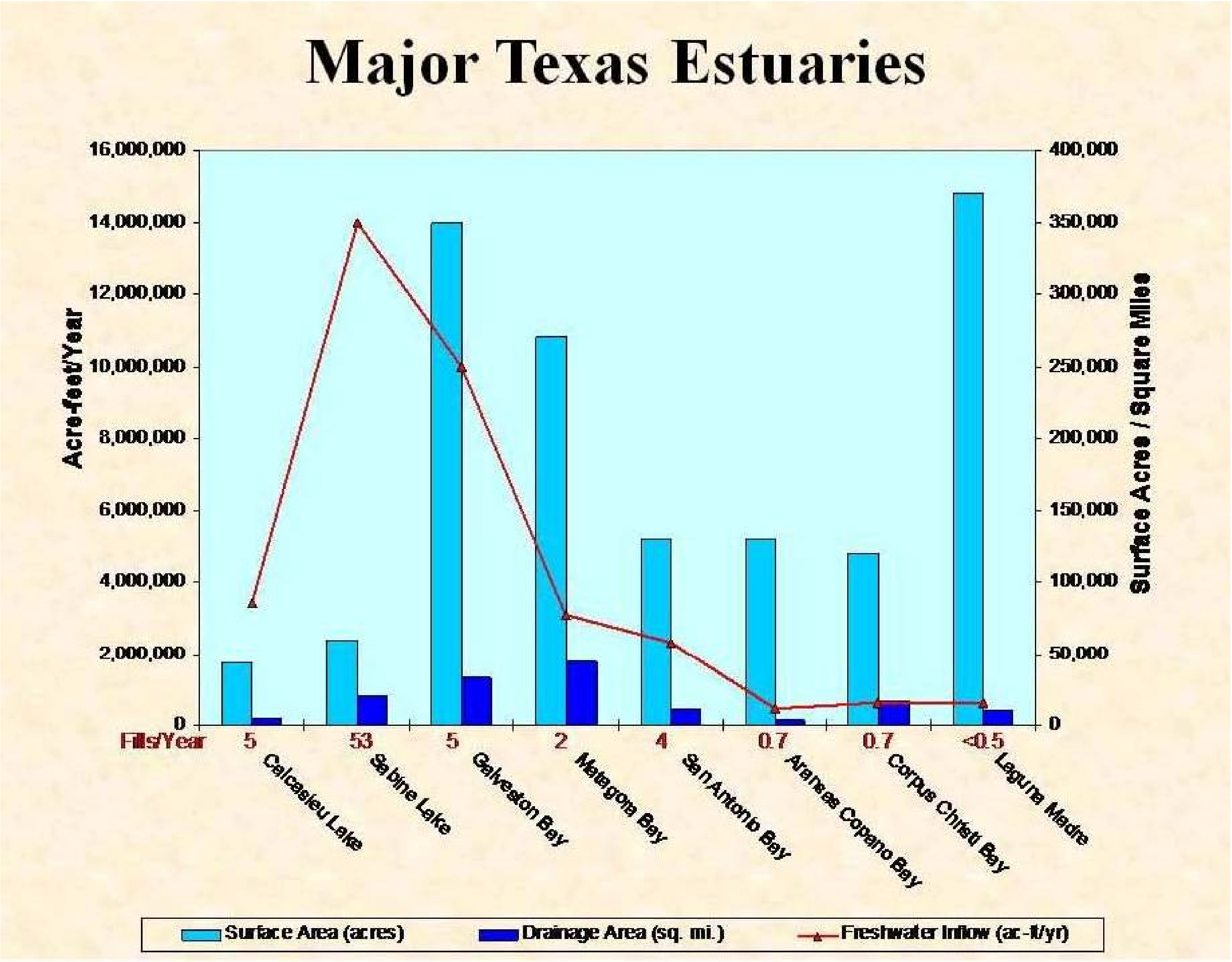
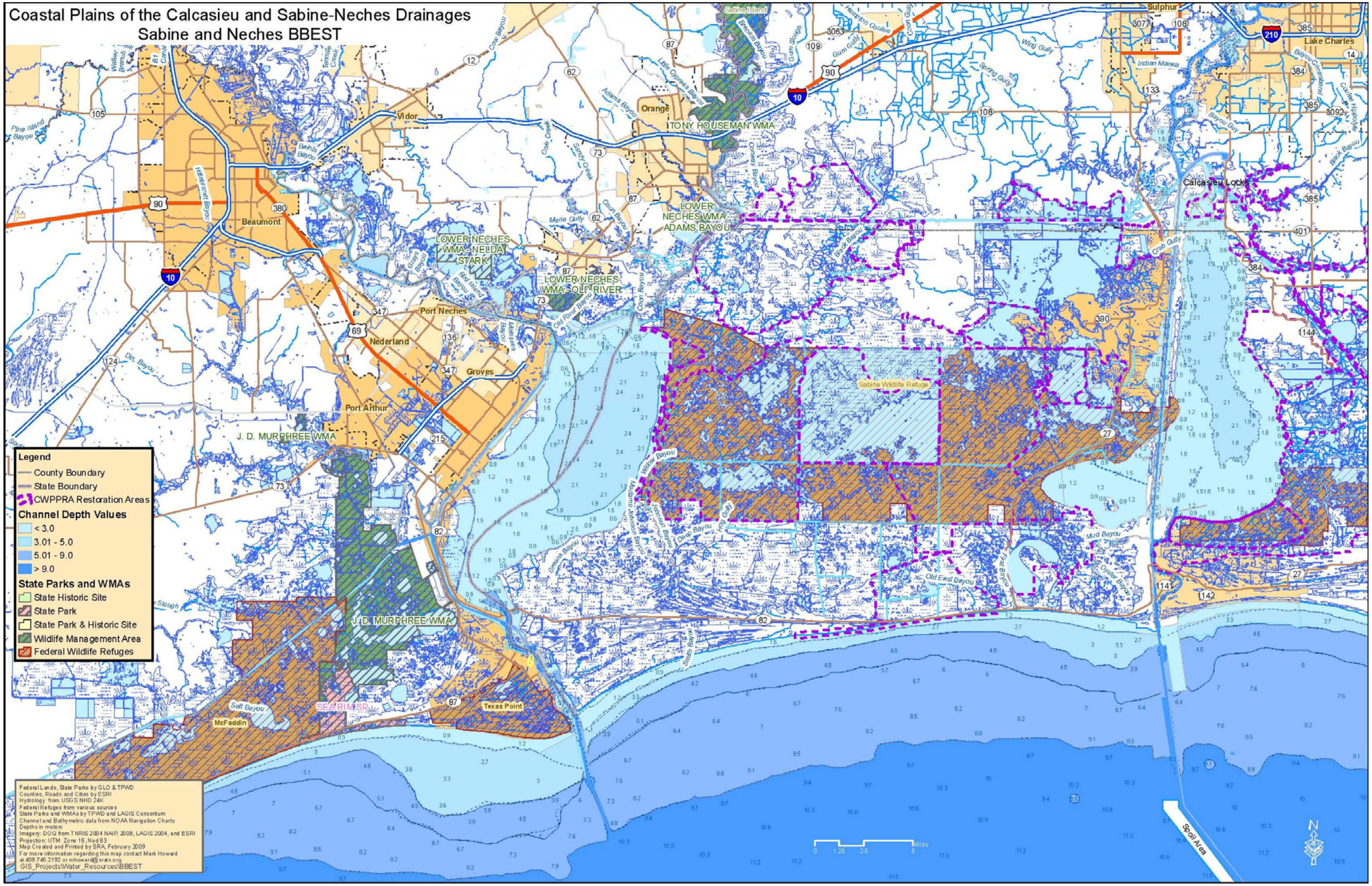


FIGURE 7. COASTAL PLAINS OF THE CALCASIEU AND SABINE-NECHES DRAINAGES



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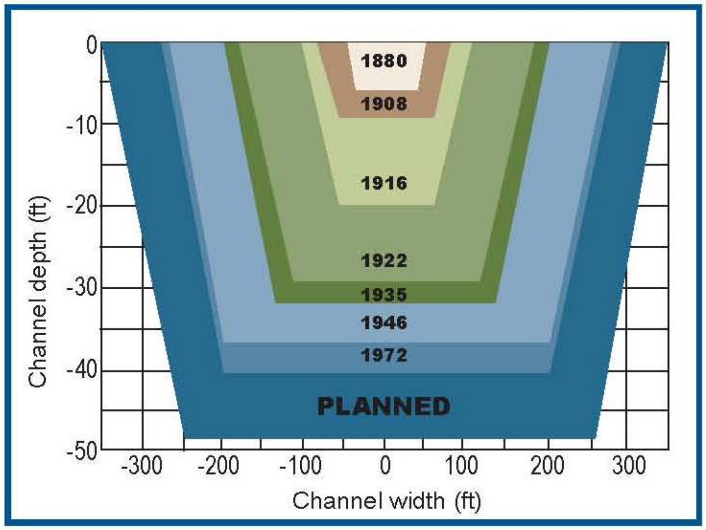
3.3.2 Estuary History

Earliest available records indicate that Sabine Lake was primarily a freshwater lake with extensive sand bar deltas at the mouths of the Sabine and Neches Rivers and the narrow opening to the Gulf of Mexico. In the 1870'S navigation channels began to be maintained in both the Calcasieu Pass (U.S. Army Corps of Engineers 2004) and the Sabine Pass, and navigation channels have been maintained and enlarged ever since. The estuary and its surrounding marshes have been heavily modified. In the past 120 years, a wide range of man-made activities have altered Sabine Lake and its surrounding wetlands and marshes. The current ship channel, the SNWW, completed in 1972 consists of a 40-ft channel to the Port of Beaumont and a 30-ft channel to the Port of Orange (Sutherlin 1996). See Figure 8 (page 32), taken from *Preliminary Investigation Saltwater Barrier* (Sabine River Authority of Texas 2009a). The Calcasieu Ship Channel is maintained at 40-ft depth and 400-ft width. The GIWW completed in 1933 (Sutherlin 1996) and other canals through the marsh have linked Sabine Lake to Calcasieu Lake in multiple locations (Paille 1996).

These navigation channels affect the Sabine-Neches Estuary in at least two ways. First, during times of high tide, they allow saltwater to intrude into the estuary and further upstream into the rivers, lakes, bayous, the GIWW, and marshes. Secondly, during times of flooding, they move fresh water out of the estuary more quickly reducing the amount of marsh land flooding; thereby, giving less retention time for freshwater flows and the accumulation of sediments in the marsh (Boesch, Josselyn et al. 1994, and references therein). Moreover, the USACE is planning additional navigational access improvements in Sabine Lake (Tatum 2009). The USACE plans to complete a draft study of the feasibility and environmental impact of deepening the SNWW from 40-ft to 48-ft and submit the draft for public comments on December 17, 2009. A final report is expected in August 2010. These modifications will undoubtedly exacerbate the impact of the channels.

The dredging of secondary channels for oil and gas drilling in the marshes have allowed saltwater intrusion into the marshes; these canals are a "source of erosive energy on the surrounding marsh" (Boesch, Josselyn et al. 1994, and references therein) with subsequent land subsidence in some areas, resulting in loss of vegetation and erosion of organic soil. Open water lakes have formed in the marshes that have become increasingly unstable and continue to degrade into larger open-water areas under existing conditions (Boesch, Josselyn et al. 1994, and references therein). Today the amount of wetlands lost from coastal Louisiana and Texas is staggering. These canals have been estimated to be responsible for the majority of this loss (Scaife, Turner et al. 1983).

FIGURE 8. HISTORIC WIDENING AND DEEPENING OF THE SABINE-NECHES SHIP CHANNEL[5]



3.4 REGIONAL WATER PLANNING

SB 3 instructs each BBEST to consider all reasonably available science and to base its environmental flow regime recommendations solely on the best science available, without regard to the need for the water for other uses. The Sabine-Neches BBEST has complied with this charge, yet recognizes in a practical sense, that the Sabine-Neches BBASC will consider the science team's recommendations as it works to balance environmental flows with the needs of the people of Texas.

In response to the historic drought of the 1950s (drought-of-record) and in recognition of the need to plan for the future, the Texas Legislature created the TWDB to develop water supplies and prepare plans to meet the state's future water needs. In 1997, with SB 1, the legislature established a new water planning process, based on a "bottom-up," consensus driven approach. Coordinating this water planning process are 16 regional water planning groups (RWPGs), one for each regional water planning area. (Texas Water Development Board. 2007). The Sabine and Neches Basins include Regions I, D, C, and a small portion of Region H.

3.4.1 2007 STATE WATER PLAN

The current Texas State Water Plan, "Water for Texas 2007" (Texas Water Development Board. 2007) provides for

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[5] The latest USACE draft study report indicates just deepening with selected widening areas; they do not plan to widen the entire channel length.

the orderly development, management, and conservation of water resources and preparation for and response to drought conditions, in order that sufficient water will be available at a reasonable cost to ensure public health, safety, and welfare; further economic development; and protect the agricultural and natural resources of the entire state. Texas Water Code, §16.051.

"Water for Texas 2007" projects water supply needs (demands in excess of existing supplies that would be physically and legally available during a repeat of the drought-of-record) of 3.7 million acre-feet in 2010; 5.9 million acre-feet by 2030; and 8.8 million acre-feet by 2060. The various water management strategies identified to meet these needs include the water supply reservoirs in the Sabine and Neches Basins (mainly Region I, East Texas) which have combined over 2 million acre-feet of annual permitted yield. The regional water plans that will contribute to the 2012 State Water Plan are currently being developed in Regions I, D, C, and H.[6]

3.4.2 Unique Stream Segments

Each RWPG may include in its adopted regional water plan all or parts of stream segments considered as having "unique ecological value." According to TWC Subchapter C. §16.051(e), designation of a unique stream segment "solely means that a state agency or political subdivision of the state may not finance the actual construction of a reservoir in a specific river or stream segment designated by the legislature under this subsection."

To recommend a site, RWPGs prepare a recommendation package to be submitted to the legislature. According to 31 TAC §357.8, recommendation packages should include a description of the site location along with maps, photographs, and documentation with supporting literature and data that characterize a site's unique ecological value. This data must be based upon the following criteria:

- Biological Function: streams displaying significant habitat value including both quantity and quality considering degrees of biodiversity, age, and uniqueness including terrestrial, wetland, aquatic, or estuarine habitats.
- Hydrologic function: stream segments fringed by habitats that perform valuable hydrologic functions relating to water quality, flood attenuation, flow stabilization, or groundwater recharge and discharge
- High water quality/exceptional aquatic life/ high aesthetic value: stream segments and spring resources that are significant due to unique or critical habitats and exceptional aquatic life uses dependent on or associated with high water quality.
- Riparian conservation areas: stream segments fringed by significant areas in public ownership including state and federal refuges, wildlife management areas, preserves, parks, mitigation areas, or other areas held by governmental

[6] http://www.twdb.state.tx.us/wrpi/rwp/rwp.htm, retrieved October 12, 2009

organizations for conservation purposes or stream segments fringed by other areas managed for conservation purposes under a governmentally approved conservation plan.

- Threatened or endangered species/unique communities: sites along streams where water development projects would have significant detrimental effects on state or federally listed threatened and endangered species, and sites along streams significant due to the presence of unique, exemplary, or unusually extensive natural communities.

Recommendations included in regional water plans are incorporated into the State Water Plan and considered by the legislature for designation. If the Texas Legislature designates a stream or river segment as unique, the RWPG must quantitatively assess how recommended water management strategies in a regional plan would affect flows deemed important to the stream or river segment in question.

RWPGs have been concerned with the implications of designation of unique stream segments and the intended effects of designation have been discussed at length among state agencies and RWPGs. The 77th Texas Legislature sought to clarify the regulations in 2002 by adding language indicating that the only intended effect was to prevent development of a reservoir on the designated segment by a political subdivision of the state. However, concerns still remain regarding the implications of designation.

In the 2007 State Water Plan, no unique stream segments were considered by the two predominant water planning regions in the Sabine and Neches Basins.

3.4.2.1 Region I

Region I, which covers a 20-county area including the metropolitan areas of Beaumont-Port Arthur, Lufkin, Nacogdoches, and Tyler, declined to recommend unique stream segments in its 2006 Regional Water Plan due to lack of clarity in regulations. In consideration of its 2011 Regional Water Plan, Region I's RWPG, the East Texas Regional Water Planning Group (ETRWPG), met and considered recommendations of unique stream segments in April and July 2009. The TPWD produced a 121-page document listing ecologically significant river and stream segments in Region I to aid in the identification of potentially unique stream segments (Texas Parks and Wildlife Department 2005). However, the ETRWPG voted in July 2009 to not recommend unique stream segments for its 2011 Regional Water Plan.

3.4.2.2 Region D

TPWD provided a document entitled, "Ecologically Significant River and Stream Segments of Region D, Regional Water Planning Area" (May 2000), which presents information on 14 stream segments within the region meeting one or more of the criteria for designation as ecologically unique. Region D's RWPG, the North East Texas Regional Water Planning Group (NETRWPG), elected to not recommend stream segments for ecologically unique designation. The NETRWPG's 2006 Regional Water Plan (NETRWPG 2006) cites the following reasons for this decision:

1. The RWPG feels that there exists a lack of clarity as to the effects of designation with respect to private property takings issues;
2. The RWPG does not wish to infringe upon the options of individual property owners to utilize stream segments adjacent to their property as they deem appropriate. For example, if reservoirs cannot be built in unique segments, will these become prime candidates for mitigation sites acquired by eminent domain?
3. Despite previous legislative clarification, there remains uncertainty as to the myriad ways in which the designation may ultimately be construed.
4. Where overlap occurs between unique stream candidates and water management strategies, sufficient information to express preference for one use to the exclusion of another is not available at this time.

3.4.3 Unique Reservoir Sites

RWPGs may recommend sites for reservoir construction that have “unique value.” The planning groups may prepare a recommendation package including a description of the site, reasons for the unique designation and expected beneficiaries of water supplies developed at a given site. According to 31 TAC §357.7, criteria used to designate unique reservoir sites are as follows:

1. Site specific reservoir development is recommended as a specific water management strategy or alternative long-term scenario in an adopted regional water plan;
2. The location, hydrologic, geologic, topographic, water availability ,water quality, environmental, cultural, and current development characteristics, or other pertinent factors make the site uniquely suited for:
    a. reservoir development to provide water supply for the current planning period; or
    b. where it might reasonably be needed to meet needs beyond the 50-year planning period.

According to TWC Subchapter C §16.051, designation of unique sites for reservoir construction means that “a state agency or political subdivision of the state may not obtain a fee title or an easement that would significantly prevent the construction of a reservoir on a site designated by the legislature under this subsection.”

To date, only two sites have been designated as unique reservoir sites in the Neches Basin (and both in Region I) and no sites in the Sabine Basin have been so designated. Following is a brief description of the approach to unique reservoir sites taken by RWPGs in Regions I and D.

3.4.3.1 Region I

Region I has two potential reservoir sites designated as unique sites for reservoir construction. Lake Columbia was designated separately through the legislature[7] and Fastrill Reservoir was recommended by Region C. The two reservoirs are also currently identified as strategies to meet water shortages in the planning period for Regions I (Lake Columbia) and C (Fastrill Reservoir) during the 50-year planning period. The Region I RWPG will review the status of future unique reservoir sites for the 2011 update of its regional water plan in December 2009.

3.4.3.2 Region D

The Region D RWPG recognizes 15 locations where the topography is such that the area could be classified as uniquely suitable as a reservoir site. Six of the 15 potential reservoir sites are located in the Sabine River Basin: Prairie Creek, Big Sandy, Carl Estes (Mineola), Carthage, Kilgore II, and Waters Bluff Reservoirs. However, the NETRWPG recommends that any new reservoir in Region D be pursued only after all other viable alternatives have been exhausted.

3.5 Sabine-Neches Study Area Unique Issues

Issues unique to the Sabine-Neches Study Area include the following.

3.5.1 Texas Louisiana

The Sabine River Basin from the stateline to the mouth of the river as well as the Sabine Neches Estuary is shared with Louisiana—approximately 25 percent of the Sabine River Basin watershed above the river's mouth is in Louisiana. Louisiana does not have a program similar to SB 3.

3.5.2 Texas State Water Quality Flows (7Q2)

Because the Sabine River portion of the study area involves two states, it must be recognized that each state uses a different flow for implementation of water quality standards when calculating effluent limits for water quality permits. In Texas, a 7Q2 (a 7-day low flow with a 2 year recurrence interval) is used as the flow below which water quality standards do not apply. Louisiana uses a 7Q10 (a 7-day low flow with a 10-year recurrence interval) for similar purposes. The applicability of water quality flows to be used in this process is discussed further in Section 5.4. (page 93)

3.5.3 Senate Bill 2: Lower Sabine River Priority Instream Flow Study

The lower Sabine River downstream from Toledo Bend Reservoir to the tidal waters of the Sabine River is included as a priority sub-basin, first tier, for TIFP study under SB 2. The

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[7] Texas Senate Bill 1362 designated the site for Lake Columbia as a site of unique value for the construction of a dam and reservoir in 2003.

upper Sabine River and the upper and lower Neches River areas have not been included in the first tier studies. Although Louisiana agencies (Louisiana Department of Environmental Quality, Louisiana Department of Wildlife and Fisheries, Coastal Protection and Restoration Authority) have participated in SB 2 meetings, Louisiana does not have a similar program and Louisiana stakeholders have expressed the desire to make their own decisions related to how Louisiana's half of the water would be used.

3.5.4 Toledo Bend Project Joint Operations

SRA-TX and SRA-LA collaborated to develop the Toledo Bend Project located on the Sabine River. Construction was completed in October 1966. The Project is jointly operated by SRA-TX and SRA-LA through TBPJO. The Project, which was originally licensed by the FERC's predecessor agency the Federal Power Commission, in 1963, was initially conceived, licensed, and developed primarily as a water supply reservoir, with secondary uses including hydroelectric power generation and recreation. The original license was a 50-year license that is scheduled to expire in September 2013.

Relicensing of the Project is currently underway using the FERC Integrated Licensing Process (ILP)[8] with the anticipated completion of the process in September 2013. The ILP is intended to assess the impact of the Project upon the environment and resources based upon the current conditions and any impacts that may occur in the future as a result of the project operations. The PAD, submitted in September 2008, outlines that there are no major revisions proposed for the operations of the Toledo Bend Project during the next licensing period. The PAD does describe a small hydroelectric generation unit for the spillway to recover energy from the required release from the spillway.

Currently the TBPJO is in the study phase of the ILP. Of relevance to the Sabine-Neches BBEST is a significant amount of aquatic studies that are underway on the lower Sabine River below the Toledo Bend dam. The aquatic studies include fish community sampling and assessment, freshwater mussel distributions, macroinvertebrate sampling, and physical parameters such as water temperature and flows. While the data from this effort is not available at this time, it will provide information that will be used by the TBPJO and FERC to refine future flow conditions and will be available to the Sabine-Neches BBEST for adjustments in the flows that may be needed by the environment.

3.5.5 Sabine River Compact

The Sabine River Compact was signed by representatives of the State of Texas and Louisiana, and the United States on January 26, 1953, and subsequently was ratified by the

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[8] FERC: Hydropower - Integrated Licensing Process (ILP), http://www.ferc.gov/industries/hydropower/gen-info/licensing/ilp.asp, retrieved November 8, 2009

legislatures of the States and approved by the Congress of the United States. The major purposes of the Compact are to:

- provide for the equitable apportionment between the States of Louisiana and Texas of the waters of the Sabine River and its tributaries;
- establish a basis for cooperative planning and action by the States for the construction, operation, and maintenance of projects for water conservation and utilization on the reach of the Sabine River common to both States; and
- provide for the apportionment of the benefits.

As used in the Compact, the word "Stateline" means the point on the Sabine River where its waters in downstream flow first touch the States of both Louisiana and Texas. The essentials of water apportionment provisions of the Compact are as follows:

- Texas retains free and unrestricted use of the water of the Sabine River and its tributaries above the Stateline, subject only to the provisions that the minimum flow of 36 cfs must be maintained at the Stateline.
- Any reservoir constructed in the watershed above the Stateline subsequent to January 1, 1953, will be liable for its prorata share of the guaranteed minimum flow.
- Texas may either use the yield of the reservoirs above the Stateline or allow it to flow downstream in the Stateline reach to a desired point of removal without loss of ownership.
- All free water (free water means all waters other than stored water) in the Stateline reach, without reference to origin will be divided equally between the two States.
- Neither State may construct a dam on the Stateline reach without the consent of the other State.
- Water stored in reservoirs constructed by the States in the Stateline reach shall be shared by each State in proportion to its contribution to the cost of storage.
- Should either State construct a reservoir on a stream tributary to the Stateline reach of the Sabine River, that State is entitled to the yield of the reservoir, but its share of the flow of the Sabine River is reduced by the reduction in flow resulting from the operation of the reservoir.
- Water consumed for domestic and stock water purposed is excluded from the apportionment under the Compact.

3.5.6 Lower Neches River Saltwater Barrier

The LNVA manages and operates the lower Neches River Saltwater Barrier under an agreement with the USACE. There is a minimum flow requirement of 400 cfs for the saltwater barrier.

3.5.7 Cutoff Bayou: Lower Sabine River

The Cutoff Bayou area is an environmental as well as a water supply concern in the lower Sabine River. The stateline river reach in this area has historically flowed with approximately equal amounts to both the stateline river and to the Old River channel during lower flows. Since Hurricane Rita, the flow split has been determined to be closer to 70 to 80 percent flow to the Old River channel in Louisiana and 20 to 30 percent flow to the Texas stateline reach. Studies are needed to determine measures to stabilize this area before the river reroutes the lower flows entirely to the Old River channel in Louisiana. (AECOM 2009)

3.5.8 USACE Sabine-Neches Waterway Feasibility Study

The USACE is currently completing the Sabine-Neches Waterway Feasibility Study. The recommended plan is to deepen the existing ship channel from 40 to 48 feet. This nine year/15+ million dollar study includes a Hydrodynamic-Salinity Model with a revised period of analysis to include baseline Texas Water Availability Model (WAM) current conditions, completion of the deepening project by 2019 and Texas Water Plan 2007 year 2060 projections for year 2069 conditions. The study also includes analysis of Hydrologic Units in existing marshes/cypress-tupelo swamps in Texas and Louisiana for mitigation and habitat restoration related to the incremental changes of deepening the ship channel. For details of this USACE study, see Section 6.2.3 Sabine-Neches Estuary (Sabine Lake), page 141.

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4 SCIENCE ADVISORY COMMITTEE

4.1 BACKGROUND

The Texas Environmental Flows Science Advisory Committee (SAC) serves as an objective scientific body to advise and make recommendations to the Environmental Flows Advisory Group on issues relating to the science of environmental flow protection and develop recommendations to help provide overall direction, coordination, and consistency. The SAC consists of five to nine members appointed by the advisory group.

The SAC appoints one of its members to serve as a liaison to each basin and BBEST to facilitate coordination and consistency in environmental flow activities throughout the State.

4.2 GUIDANCE

The SAC provides an objective perspective and diverse technical expertise, including expertise in hydrology, hydraulics, water resources, aquatic and terrestrial biology, geomorphology, geology, water quality, computer modeling, and other technical areas pertinent to the evaluation of environmental flows. To date, the SAC has six technical documents available as guidance resources to state BBESTs. Unfortunately, the Sabine-Neches BBEST was unable to take full advantage of the SAC guidance because its timeline predated the availability of the final documents in some cases. However, the SAC liaison assisted the Sabine-Neches BBEST by providing initial drafts of available works in progress, and the group utilized information provided to the extent practical.

The SAC guidance documents to date are as follows.

4.2.1 GEOGRAPHIC SCOPE

Geographic Scope of Instream Flow Recommendations This document presents various factors that could be considered by the BBEST in determining geographic scope for instream flows development. The importance of existing streamflow-gaging stations, primarily operated by the U.S. Geological Survey (USGS), is identified. The report suggests using the USGS Core Network gages as a starting point. It encourages the BBESTs to fully evaluate the adequacy of this network and modify the number of recommended streamflow-gaging stations as deemed appropriate to adequately define the environmental flow regime. (SAC 2009c, Appendix III)

4.2.2 USE OF HYDROLOGIC DATA

Use of Hydrologic Data in the Development of Instream Flow Recommendations for the Environmental Flows Allocation Process and The Hydrology-Based Environmental Flow Regime (HEFR) This document provides an overview of how hydrologic data may be used in the identification of instream flow recommendations pursuant to the requirements of SB 3. As such, it describes one piece of the collaborative process envisioned by SB 3 for the identification of flows to maintain a sound ecological environment in rivers and streams. (SAC 2009f, Appendix VI)

4.2.3 Fluvial Sediment Transport (Geomorphology)

Fluvial Sediment Transport as an Overlay to Instream Flow Recommendations for the Environmental Flows Allocation Process This document reviews various methods for assessing suspended-load and bedload transport, and recommends that the BBESTs consider application of the Sediment Transport Models (SAM) Hydraulic Design Package for estimating effective discharge. (SAC 2009b, Appendix II)

4.2.4 Freshwater Inflow Regime

Methodologies for Establishing a Freshwater Inflow Regime for Texas Estuaries Within the Context of the Senate Bill 3 Environmental Flows Process This document provides background information and discussion of various methods that can be used to develop freshwater inflow recommendations for Texas bays and estuaries. While a few germane references to the literature are made, this document is not intended to be a tutorial on the physics and ecology of estuaries, nor on the range of modeling techniques of potential application. Rather, it attempts to present a succinct summary of methods that are presently sufficiently developed and suitable for application to Texas estuaries, for consideration by the BBESTs. (SAC 2009d, Appendix IV)

4.2.5 Water Quality

Nutrient and Water Quality Overlay on Hydrology-Based Instream Flow Recommendations Water quality is the focus of this overlay document. Numeric and narrative criteria developed by the state address matter carried in suspension and solution, such as dissolved and suspended solids, as well as nutrients, toxics, indicator bacteria, temperature, pH, dissolved oxygen, and other parameters. Under some circumstances all might play a role in the determination of an environmental flow regime. Changes in a flow regime can be expected to produce changes in water quality conditions. The challenge is to ensure that the recommended flow regime protects water quality, particularly during low or subsistence flow conditions, and also considers water quality needs during higher flow conditions. (SAC 2009e, Appendix V)

4.2.6 Biology

Essential Steps for Biological Overlays in Developing Senate Bill 3 Instream Flow Recommendations The Biological Overlay document provides guidance on:

1. Assimilating biological information needed to develop a biological overlay within the context of SB 3;
2. Applying biological information to inform the geographic scope of instream flow recommendations;
3. Addressing decision points required before and during hydrology-based modeling;
4. Applying a biological overlay for the purpose of refining and/or confirming preliminary hydrology-based instream flow recommendations; and
5. Using the biological overlay document in a hydrology-based environmental flow determination. (SAC 2009a, Appendix I)

5 DISCIPLINE REPORTS

The TIFP "Texas Instream Flow Studies: Technical Overview" (Texas Commission on Environmental Quality 2008b) identified four riverine components – biology, hydrology and hydraulics, water quality, and geomorphology – as key disciplines that must be included in any successful instream flow program. SAC guidance reinforced the significance of these disciplines by including them in its guidance (SAC 2009a, Section 5.2). The Sabine-Neches BBEST, under its SB 3 charge to use the "best available science" to develop environmental flow regime recommendations for the Sabine-Neches Study Area (Figure 5 page 25), named subcommittees for each discipline to gather and analyze information related to that riverine component. An overview of the findings of each subcommittee is presented in Section 6 with more extensive information and data found in the appendices of this report.

5.1 HYDROLOGY

The Sabine-Neches BBEST established six subcommittees with two of these, gaging and hydrology, primarily developing recommendations to the Sabine-Neches BBEST on the geographic scope of Instream flow recommendations (using SAC guidance, SAC 2009c, in evaluation of use of USGS gages) and the use of hydrologic data in the development of instream flow recommendations for environmental flows using SAC guidance for utilizing the Hydrology-based Environmental Flow Regime (HEFR) (SAC 2009f).

The Sabine-Neches BBEST selected FNI (Jon Albright) as an outside consultant to prepare three memoranda:

1. "Analysis of BBEST Stream Gages" (Gage Memo) (FNI 2009a)
2. "Hydrology-Based Environmental Flow Regime (HEFR) Analyses for Sabine-Neches Bay and Basin Expert Science Team (BBEST)" (HEFR Memo) (FNI 2009b)
3. "Water Availability Analyses for Sabine-Neches Bay and Basin Expert Science Team" (BBEST) (WAM Memo) (FNI 2009c)

The two subcommittees worked with FNI in the preparation of these memos and have used this baseline work to develop flow regime matrices for work performed by the Biology, Water Quality, and Geomorphology Subcommittees. The Recommendations Report Subcommittee is responsible for bringing the report documentation from each of these disciplines into the final report.

5.1.1 GAGE SELECTION AND GEOGRAPHIC COVERAGE

5.1.1.1 GAGE SELECTION

The Sabine-Neches BBEST selected six USGS stream gages in the Sabine River Basin and six USGS stream gages in the Neches River Basin for hydrologic analyses. These gages serve as the hydrologic basis for flow regime recommendations developed to satisfy the SB 3 environmental flows process. Gage locations are shown in the study area map (Figure 5.

Sabine and Neches Rivers and Sabine-Neches Estuary (Sabine Lake), page 25). Data used in the analysis were obtained from the USGS website.

Two gages in each basin have minimally controlled or altered watersheds. In the Sabine Basin, Big Sandy Creek near Big Sandy has one small recreation reservoir, Lake Winnsboro, in its watershed. Big Cow Creek near Newton has very little modification in its watershed and represents nearly natural conditions. In the Neches Basin, Attoyac Bayou near Chireno is downstream from one small water supply reservoir, Lake Pinkston. Village Creek near Kountze has only a few appropriated water rights upstream.

In addition to the twelve stream gages, the Sabine-Neches BBEST also requested hydrologic analyses of the total inflows into Sabine–Neches Estuary, for a total of thirteen analysis locations.

5.1.1.2 Geographic Coverage of Selected Gages

The SAC has developed guidance for the selection of stream gages for analyses as part of the SB3 process in the report "Geographic Scope of Instream Flow Recommendations" (SAC 2009c, Appendix III). Although this document was not available to the Sabine-Neches BBEST at the time of gage selection, FNI (FNI 2009a, Appendix IX) analyzed several of the criteria in the geographic scope document, including coverage of:

- USGS Core Network of gages;
- TCEQ Water Quality Segments;
- USGS Hydrologic Units;
- TCEQ Ecoregions and TPWD Significant Stream Segments; and
- identified geomorphic process zones.

Based on these criteria, the twelve gages selected by the Sabine-Neches BBEST have sufficient geographic coverage to adequately represent the hydrologic conditions found in the two basins. Three gages, the Sabine River near Ruliff, the Neches River at Evadale and Village Creek near Kountze, measure a significant portion of inflow into Sabine Lake (see Figure 35, page 146). (FNI 2009a)

5.1.2 HEFR Analysis for Sabine-Neches BBEST

FNI conducted hydrologic analyses of the twelve gages in the Sabine-Neches River Basins and inflows into Sabine Lake, including HEFR analyses. This work is discussed in detail in the SAC guidance (SAC 2009f, Appendix VI) and FNI HEFR Memo (FNI 2009b, Appendix X). The Hydrology Subcommittee has used this baseline of hydrology analyses to develop the flow regime matrices presented in this document.

5.1.3 WAM Analysis for Sabine-Neches BBEST

The FNI WAM Memo (FNI 2009c, Appendix XI) describes an analysis of water available for the environmental flows preformed by FNI. These analyses employed the TCEQ WAM) for the Sabine and Neches River Basins, as modified for use by the Region I (East Texas) RWPG. The analyses include assessments of:

- unappropriated and regulated flows;
- frequency of compliance with preliminary hydrology-based environmental flow regime matrices by both naturalized and regulated flows.

The WAM analyses include use of both the current conditions (Run 8) and full authorization (Run 3) scenarios.

5.1.4 Instream Flow Regime Components

Subsistence flows are low flows that occur during times of drought or under very dry conditions (Texas Commission on Environmental Quality 2008b). The primary objective of subsistence flows is to maintain water quality to prevent loss of aquatic organisms due to, for example, lethal high temperatures or low dissolved oxygen levels. Secondary objectives may include providing life cycle cues based on naturally occurring periods of low flow or providing refuge habitat to ensure a population is able to re-colonize the river system once more normal, base flow conditions return.

Base flows represent the range of “average” or “normal” flow conditions in the absence of significant precipitation or runoff events (Texas Commission on Environmental Quality 2008b). Base flows provide instream habitat conditions needed to maintain the diversity of biological communities in streams and rivers. Habitat quality and quantity are important for survival, growth, and reproduction of fish and other aquatic organisms (e.g., mussels and benthic macro invertebrates, other vertebrates, and flora). Base flows can also support the maintenance of water quality conditions and can contribute to the alluvial groundwater that supports riparian habitats, which are important components of river ecosystems.

High flow pulses are short duration, high magnitude (but still within channel) flow events that occur during or immediately following rainfall events (Texas Commission on Environmental Quality 2008b). High flow pulses serve to maintain important physical habitat features and connectivity along a stream channel. Many physical features of a river or stream which provide important habitat during base flow conditions cannot be maintained without appropriate high flow pulses. High flow pulses also provide longitudinal connectivity along the river corridor for many species (e.g., migratory fish), lateral connectivity to near-channel features (e.g., connections to some oxbow lakes), and can support the maintenance of water quality.

Overbank flows are infrequent, high magnitude flow events that produce water levels that exceed channel banks and result in water entering the floodplain (Texas Commission on Environmental Quality 2008b). A primary result of overbank flows is to maintain riparian areas associated with riverine systems. For example, overbank flows transport sediments and nutrients to riparian areas, recharge floodplain aquifers, and provide suitable conditions for seedlings. Overbank flows also provide lateral connectivity between the river channel and the active floodplain, supporting populations of fish or other biota utilizing floodplain habitat during and after flood events. Other objectives for overbank flows include the movement of organic debris to the main channel, providing life cycle cues for various species, and maintaining the balance of species in aquatic and riparian communities.

5.1.5 Hydrologic Data

Hydrologic data have several advantages for characterizing riverine systems over many other forms of environmental data in that they are relatively consistently and continuously measured at numerous locations and are also easily obtainable from the USGS.[9] These characteristics, along with the comparatively simple nature of the data themselves, mean that hydrologic datasets can be evaluated using fairly generic statistical approaches and tools. Thus, hydrologic data typically provide the most convenient, initial understanding of riverine systems.

5.1.6 Advantages and Disadvantages Common to All Hydrologic Methods

Hydrologic methods share certain advantages and disadvantages (relative to biological, geomorphologic, and water quality methods).

Common advantages include:

1. relatively robust and consistent datasets at multiple locations,
2. the understanding that hydrology has been considered the "master variable" with regard to environmental instream flows (Poff, Allan et al. 1997), and
3. ease of use.

Common disadvantages include:

1. a lack of validation against biological, geomorphologic, and water quality data (e.g., the methods are largely designed to mirror some fraction of historical hydrology and are not based on defined flow alteration-ecological response relationships), and
2. unsuitability where hydrologic data are lacking and cannot be synthesized.[10]

Because of these disadvantages, the hydrologic methods are only recommended when sufficient data to define flow alteration – ecological response relationships are unavailable. In Texas, such data are probably currently unavailable on all river segments with the exception of the lower Colorado River (SAC 2009f). As per Dr. Kirk Winemiller, the San Marcos River, lower Sabine River, lower Neches River, and Big Cypress Bayou should be included (Winemiller 2009).

Even though comprehensive datasets to define flow alteration–ecological responses are generally unavailable, some biological, geomorphologic, and water quality data is available

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[9] Real-Time Data for Texas Streamflow, http://waterdata.usgs.gov/tx/nwis/current/?type=flow, retrieved November 3, 2009

[10] Synthesizing hydrologic data involves a wealth of complexities that are beyond the scope of SAC guidance.

in each major river basin. Thus, following the application of any of these hydrologic methods, the SAC recommended that the available data be used to corroborate or refine selected hydrology-based flow recommendations, as appropriate.

5.1.7 Available Methods

The Instream Flow Council has described and summarized a number of methods for assessing instream flow requirements (Annear, Chisholm et al. 2004). Over 30 techniques are grouped into three broad categories: Standard Setting, Incremental, and Monitoring/Diagnostic. Standard Setting methods (e.g., the Lyons Method) set limits to define threshold flow regimes and can be done relatively quickly using hydrologic data but are not considered as rigorous as methods that also use biologic data. Incremental methods (e.g., the SB 2 TIFP method) analyze one or more variables to enable assessment of different flow management alternatives. Incremental methods are often considered more scientifically accepted but also require more resources to execute since site-specific data must be collected. Monitoring/Diagnostic methods are those methods that can be used to assess conditions and how they change over time. An example of this type of method is the Nature Conservancy's Indicators of Hydrologic Alteration method (IHA).

Based on recommendations from the SAC created by the Study Commission on Water for Environmental Flows (Senate Bill 1639 from 2003), TCEQ created a Technical Review Group (TRG) to review available instream flow assessment tools and to develop one or more desktop methodologies specifically applicable to Texas river and stream conditions. The term "desktop" refers to methods that can be applied using readily available information and do not require site-specific field studies.

The TRG focused its initial review on desktop methodologies that have been applied to Texas streams (Technical Review Group 2008). These included the Lyons Method, the Consensus Criteria for Environmental Flow Needs, the Texas Method, and IHA. After further deliberation the TRG chose to focus its final review on the Lyons Method and IHA.

In addition to the above methods, the HEFR method is a new, relatively flexible computational approach for developing a flow regime matrix that is consistent with the TIFP. HEFR was initiated by TPWD with input from other agencies and organizations as an alternative to the Lyons Method for use in water rights permitting. Although the method as a whole has not been peer reviewed, the Environmental Flow Components (EFC) algorithm and IHA software used by HEFR for hydrographic separation have been used extensively. In addition, HEFR forms the framework for the environmental flow recommendations in the Brazos River Authority's Systems Operation draft water right permit pending at the TCEQ.

Following a HEFR technical workshop (February 24, 2009), a number of enhancements and modifications were suggested and implemented. This work has been completed at the direction of the SAC. Alternative methods of hydrographic separation and methods of identifying and characterizing high flow pulses and overbank events have been evaluated and implemented. The current version of HEFR includes both the original TPWD methods and the new alternative methods.

The method is based on simple summary statistics of individual flow regime components. Either the EFC algorithm (in the IHA software) or the Modified BFI with Threshold (MBFIT) method (implemented in a Microsoft Excel™ spreadsheet) is used as a convenient tool to parse a hydrograph into individual flow regime components. Excel is then used to efficiently develop summary statistics of these flow regime components. Other software tools could be used for either or both of these steps.

In the context of SB 3, the HEFR methodology has several advantages, including:

1. it is computationally efficient, allowing for repeated tests and exploratory analyses;
2. there is significant flexibility in setting parameters to parse the hydrograph as well as summary statistics of the flow regime components,
3. the results have the same format as expected results from the TIFP studies, and
4. it provides an initial set of recommendations that reflect key aspects of the natural flow regime including multiple flow components and hydrologic conditions (Poff, Allan et al. 1997).

Disadvantages of this method are:

1. there is no track record of application;
2. there are few precedents for some of the decisions that must be made by the analyst;
3. there is a lack of theoretical basis (linkage of particular statistical element to environmental health);
4. HEFR is specific while most matrix methods give a range for each criteria;
5. HEFR is sensitive to flow separation and period of record which can give different answers for gages with little or no upstream impacts;
6. reference to other environmental factors (biology, water quality, and geomorphology for example) is needed to increase confidence that the tables produced by the HEFR method have any meaning.

5.1.8 HEFR Basics

HEFR was developed to efficiently use hydrologic data to populate a flow regime matrix. As a hydrologic method, it suffers from many of the same weaknesses as other hydrologic methods described above. However, unlike other hydrologic methods, HEFR can generate values for an entire flow regime in which the different flow regime components, hydrologic conditions, and component characteristics are internally consistent. The results are internally consistent in the sense that:

1. hydrologic conditions (e.g., dry, average, and wet) are tied to percentiles of a distribution, and thus the recommendation under average conditions is guaranteed to equal or exceed the recommendation under dry conditions (and similar for wet versus average);

2. the hydrographic separation that generates the flow regime component values is performed using a single software tool (different tools are provided, but any given simulation will use only one); and
3. high flow pulse and overbank flow characteristics of duration, magnitude, and volume are generated using a consistent set of quantified flow regime components, as opposed to different statistical measures of the entire hydrograph (e.g., as in the Texas Hydrologic Assessment Tool ,TX-HAT).

HEFR begins with the selection of a flow gage and a period of record. A hydrographic separation algorithm is then used to parse the daily hydrograph into the four or more flow regime components, based on user-specified parameters. This parsing classifies each day of the hydrograph as one of the four flow regime components (subsistence, base, high-flow pulse, or overbank; see Table 2. Instream Flow Regime Components Definitions, page 11). Excel is used to post-process the hydrographic separation and to generate summary statistics. These summary statistics are also specified by the user.

Thus, the core foundation of HEFR is flow separation and statistical summaries of each flow regime component. The specific decisions and tools used in the current version of HEFR were identified through discussions and negotiations; however, they are not incontrovertible. Decisions and tools may change because of location, professional judgment, context, objectives, and/or convenience.

5.1.9 Approach

The Sabine-Neches BBEST used hydrologic data to develop initial values for a flow regime and then modified the selected values in cases where additional information (e.g., water quality, biology, and geomorphology) was available, a reasonable and scientifically defensible approach in the context of SB 3.

5.1.10 Sabine-Neches BBEST Hydrology

The Sabine-Neches BBEST selected HEFR as the desktop method to use for developing the required flow matrices for the Sabine and Neches River Basins and the Sabine-Neches Estuary.

Following selection of HEFR as the desktop hydrologic method for use, the Sabine-Neches BBEST Gages Subcommittee evaluated information on the USGS gages in the Neches and Sabine basins. Of the gages in these basins, the Gages Subcommittee recommended 6 for use in each basin. Table 3 (page 51) presents the gages recommended for use (denoted by checkmark) and the information considered in selecting each.

Table 4 (page 52) lists the selected gages and Figure 5 (page 25) shows the locations of each within the Sabine-Neches Study Area. In addition to the twelve stream gages, the BBEST also requested hydrologic analyses of the total inflows into the Sabine-Neches Estuary, for a total of thirteen analysis locations.

Figure 10 and Figure 11 (page 54) show the period of record for each gage and the year major reservoirs were built upstream from the gage for the Sabine Basin and Neches Basin, respectively. Data used in the analysis were obtained from the USGS website.[11]

The Sabine-Neches BBEST considered a number of issues for which decisions must be made to run HEFR. The first considerations were the period of record for use in the HEFR runs, how the seasons would be defined, and whether to use IHA or MBFIT as the hydrographic separation algorithm.

[11] United States Geological Survey, Surface Water Daily Data for Texas, available on-line at http://waterdata.usgs.gov/tx/nwis/dv/?referred_module=sw, retrieved October 8, 2009

TABLE 3. PRELIMINARY SELECTION OF STREAM FLOW GAGES FOR EVALUATION

Select	River Basin	USGS Stream Gage Name	Map#	USGS#	First Full Year	Full Years of Record	USGS Rating	Gage Status	Drainage Area (sqmi)	WAM Primary Control Area	Region I & State Water Plan	Reservoir Site	Unique Reservoir Site	TWDB Ecologically Significant Segment	USFWS Bottomland Hardwood Preservation Site
✓	Sabine	Big Sandy Creek n. Big Sandy	109	8019500	1940	69	Good	Active	231	Yes	No	Yes	No	No	Priority 2
✓	Sabine	Sabine River n. Gladewater	110	8020000	1933	76	Good	Active	2791	Yes	No	Yes	No	No	No
	Sabine	Sabine River n. Tatum	116	8022000	1939	39	Fair	Replaced by Beckville in 1978	3493		No				
✓	Sabine	Sabine River n. Beckville	116	8022040	1979	30	Good	Active	3589	Yes	Yes	Yes	No	Yes	Priority 1
	Sabine	Tenaha Creek n. Shelbyville	123	8023200	1952	29	Good	Out in 1981	97.8	Yes	No	Yes	No	No	Priority 2
	Sabine	Sabine River n. Burkeville	129	8026000	1956	53	Fair	Active	7482	Yes	Yes	Yes	No	Yes	No
✓	Sabine	Sabine River n. Bon Wier	130	8028500	1924	85	Fair	Active	8229	Yes	Yes	Yes	No	Yes	No
✓	Sabine	Big Cow Creek n. Newton	131	8029500	1953	56	Fair	Active	128	No	Yes	Yes	No	No	No
	Sabine	Cypress Creek n. Buna	132	8030000	1953	30	Good	Out in 1983	69.2	?	No	No	No	Yes	No
✓	Sabine	Sabine River n. Ruliff	133	8030500	1925	84	Fair	Active	9329	Yes	Yes	No	No	Yes	Priority 2
	Sabine	Cow Bayou n. Mauriceville	134	8031000	1953	39	Fair	Out in 1986. Active since 2002	83.3	Yes	No	No	No	No	No
✓	Neches	Neches River n. Neches	139	8032000	1940	69	Good	Active	1145	Yes	Yes	Yes	Yes	Yes	Priority 1
	Neches	Neches River n. Alto	140	8032500	1944	34	Good	Out in 1978	1945	Yes	No	Yes	Yes	Yes	Priority 1
	Neches	Neches River n. Diboll	141	8033000	1940	46	Good	Out in 1985	2724	Yes	No	Yes	No	Yes	Priority 1
✓	Neches	Neches River n. Rockland	143	8033500	1904	105	Fair	Active	3636	Yes	Yes	Yes	No	Yes	No
	Neches	Mud Creek n. Jacksonville	147	8034500	1940	46	Good	Out in 1979. Active since 2001	376	Yes	No	Yes	Yes	Yes	No
✓	Neches	Angelina River n. Alto	149	8036500	1960	49	Good	Active	1276	Yes	Yes	Yes	No	No	No
	Neches	Angelina River n. Lufkin	150	8037000	1940	39	Good	Out in 1979. Active since 2001	1600	Yes	No	No	No	Yes	Priority 1
✓	Neches	Attoyac Bayou n. Chireno	153	8038000	1940	45	Good	Out in 1985	503	Yes	No	No	No	Yes	Priority 4
✓	Neches	Neches River @ Evadale	161	8041000	1922	87	Fair	Active	7951	Yes	Yes	Yes	No	Yes	No
✓	Neches	Village Creek n. Kountze	162	8041500	1940	69	Good	Active	860	Yes	Yes	No	No	Yes	No
	Neches	Pine Island Bayou n. Sour Lake	163	8041700	1968	41	Fair	Active	336	Yes	No	No	No	Yes	Priority 2

TABLE 4. SELECTED STREAMFLOW GAGES FOR EVALUATION

USGS Gage Name	USGS Gage Number	HUC	County	Datum NGVD 29 (Feet)	Start Date	End Date	# of Full Years of Record	Drainage Area (Sq Mi)	Un-controlled Drainage Area [b] (Sq Mi)	Percent Un-controlled [b]
SABINE BASIN										
Big Sandy Creek nr Big Sandy[a]	8019500	12010002	Upshur	278.38	10/1/1939	9/30/2008	68	231	204	88%
Sabine River nr Gladewater	8020000	12010002	Gregg	243.85	10/1/1932	current	76	2,791	1,404	50%
Sabine River nr Beckville	8022040	12010002	Panola	190.00	10/1/1938	current	70	3,589	2,044	57%
Sabine River nr Bon Wier	8028500	12010005	Newton	33.42	10/1/1923	current	85	8,229	842	10%
Big Cow Creek nr Newton	8029500	12010005	Newton	134.69	5/1/1952	current	56	128	128	100%
Sabine River nr Ruliff	8030500	12010005	Newton	-5.92	10/1/1924	current	84	9,329	1,942	21%
NECHES BASIN										
Village Creek nr Kountze	8041500	12020006	Hardin	25.12	5/1/1939	current	69	860	860	100%
Neches River at Evadale	8041000	12020003	Jasper	8.25	4/1/1921	current	87	7,951	378	5%
Attoyac Bayou nr Chireno	8038000	12020005	San Augustine	169.58	8/1/1939	10/31/1954	14	503	489	97%
					10/1/1955	9/30/1985	29			
Angelina River nr Alto	8036500	12020004	Cherokee	204.30	3/1/1959	current	49	1,276	987	77%
Neches River nr Rockland	8033500	12020003	Tyler	88.41	12/1/1912 [c]	current	96	3,636	2,763	76%
Neches River nr Neches	8032000	12020001	Cherokee	264.06	3/1/1939	current	69	1,145	306	27%

a Gage is currently out of service because of bridge construction at the gaging site.

b Uncontrolled drainage area is the portion of the gage's watershed located downstream from reservoirs.

c Start of continuous record. Rockland has incomplete data back to 7/1/1903.

FIGURE 9. SELECTED GAGES LOCATION MAP

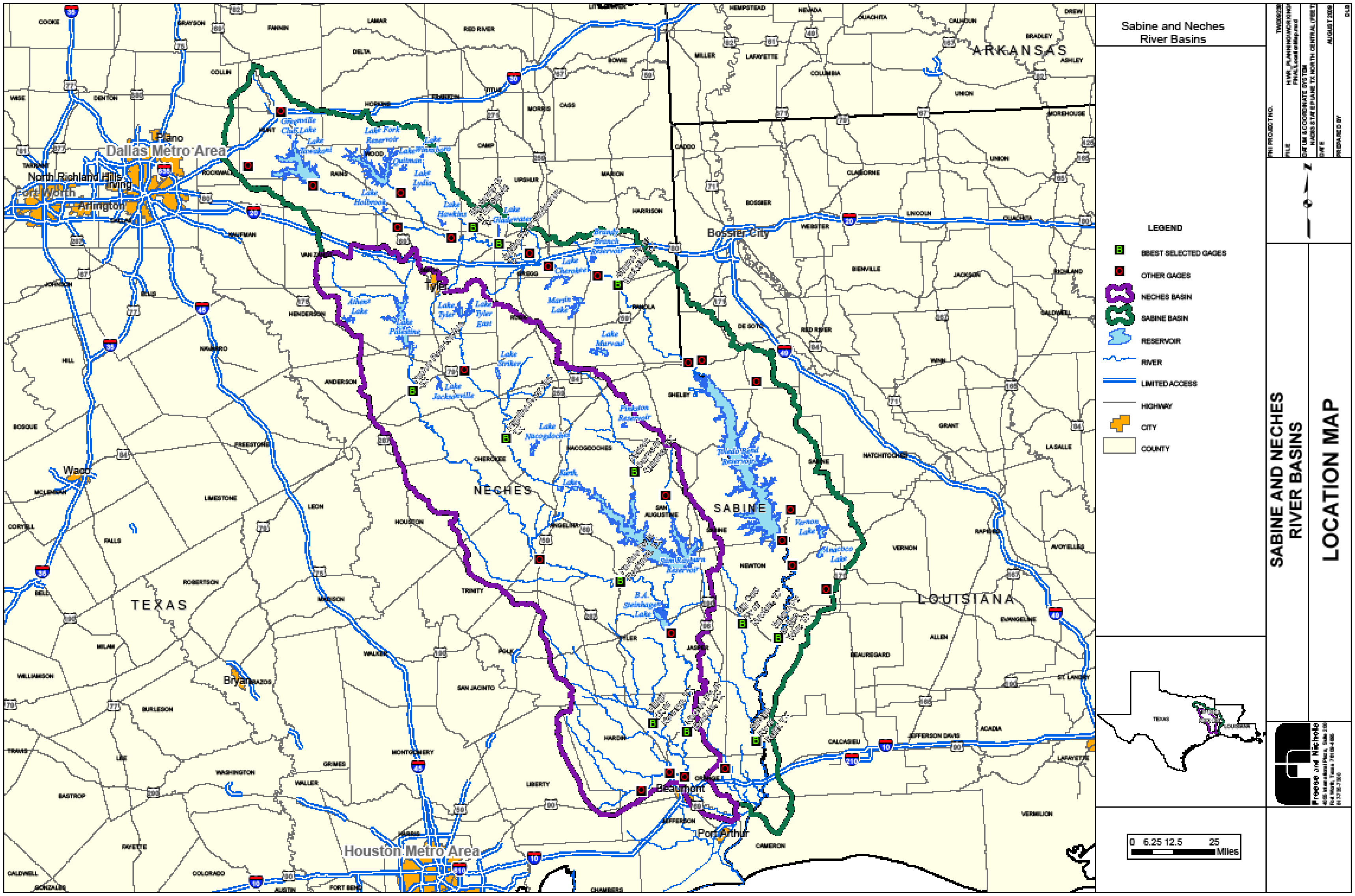
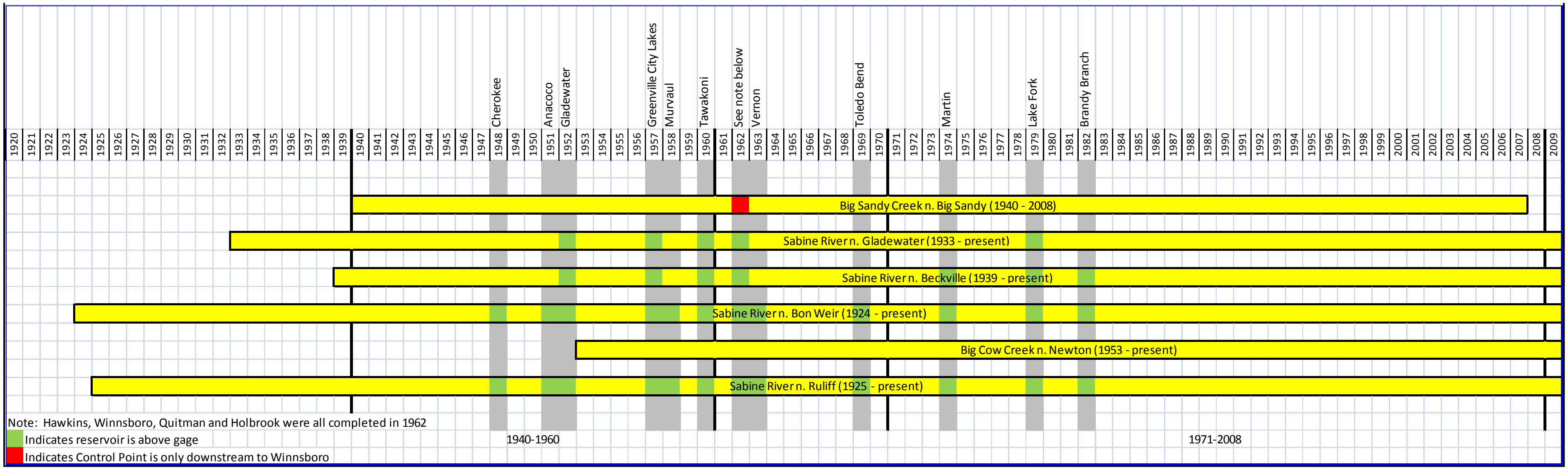
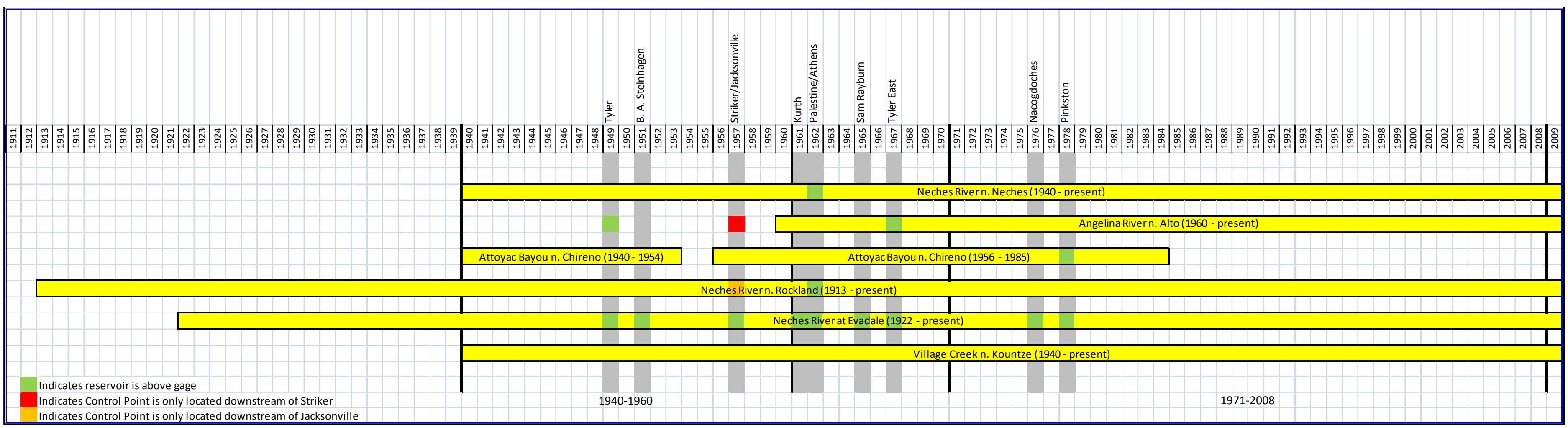


FIGURE 10. SABINE BASIN PERIOD-OF-RECORD FOR BBEST SELECTED GAGES



Note: Hawkins, Winnsboro, Quitman, and Holbrook are known collectively as the "Wood County Lakes."

FIGURE 11. NECHES BASIN PERIOD-OF-RECORD FOR SELECTED GAGES



In examining the periods of record available for the selected gages, it was obvious the overall period of record was split into a period prior to construction of the two large reservoirs, Sam Rayburn and Toledo Bend, and one after. There are a total of 24 major reservoirs (14-Sabine [2 in Louisiana]; 10-Neches) with eight constructed in the 1940-1960 "pre-dam" period. The Sabine-Neches BBEST decided to run HEFR for three periods:

1. the full period of record available at each gage;
2. the period from 1940 to 1960; and
3. the period from 1970 to present.

As expected, the only gages showing differences between the pre and post reservoir runs were those downstream of the hydropower reservoirs: Bon Wier and Ruliff on the Sabine and Evadale on the Neches. Ultimately, the Sabine-Neches BBEST decided to use the runs for the full period of record for all 12 gages.

As can be seen on the graphs of median flow per square mile of drainage area for each gage in Appendix 1, Figures 16 thru 19 on pages 24 - 27 of the Gage Memo (FNI 2009a), there is a very consistent seasonal pattern for flow in each basin. There is a wet winter, transitional periods in spring and fall, and a dry summer. The periods do not match the traditional calendar seasons exactly, but are not offset a full month either. The Sabine-Neches BBEST elected to use winter as January through March, spring as April through June, summer as July through September, and fall as October through December.

Comparison of the two hydrographic separation methods may be found in Appendix 2 of the Gage Memo on pages 8 - 16. Based on the results of this comparison, the Sabine-Neches BBEST selected the MBFIT method as best for the Sabine-Neches Study Area.

The Sabine-Neches BBEST next decision point was subsistence flows. Using the definition adopted for subsistence flow (Table 2) and the work done on water quality for the gage locations, the Sabine-Neches BBEST decided to not specify 7Q2 as the default subsistence flow at each gage location. The Sabine-Neches BBEST had HEFR determine the median value of the 10^{th} percentile of base flows at each gage as subsistence flow at that location.

A maximum of six HEFR runs were made for each gage location. Those runs were for the three periods discussed earlier with output for each period in the original percentile based format and in the frequency distribution output. A discussion of the differences between the two outputs can be found in Appendix 2 pages 27, 28, and 45. Printed copies of the matrices for each run are also in Appendix 2.

5.1.11 Use of 7Q2 and Other Alternate Low Flow Statistics

During early trial runs using the HEFR flow analysis tool, the problem of minimum flow criteria arose. FNI provided the following excerpted from the full document (FNI 2009b), Appendix X:

> *HEFR provides the option to specify a minimum "water quality protection flow". If this parameter is specified, base or subsistence flow statistics produced by HEFR may never fall below this value. HEFR guidance suggest using a 7Q2 (a historical*

7-day average low flow with a 2-year recurrence interval) as this limit. In Texas, a 7Q2 is used as the flow below which water quality standards do not apply. It is also considered when determining stream loading for wastewater discharges. Other states, including Louisiana, use a 7Q10 (a 7-day low flow with a 10-year recurrence interval) for similar purposes. The 7Q2 is also used as a minimum flow limit in other desktop environmental flow methods such as the Lyons or Consensus methods described in the SAC hydrologic methods (SAC 2009f). Table 11 lists the 7Q2 values for the BBEST gages published in the Texas Surface Water Quality Standards (this table is reproduced in this report as Table 5, below).

One of the issues with using a 7Q2 for a minimum discharge is the influence of hydropower at the Ruliff, Bon Wier and Evadale gages. Table 5 (reproduced in this report as Table 6, below) compares 7Q2 and 7Q10 values at these three gages calculated using the Environmental Protection Agency's DFLOW model. (7Q10 values are used in the State of Louisiana and are included for comparison purposes.) The periods in this table include the period prior to the construction of Sam Rayburn Reservoir for the Evadale gage and Toledo Bend Reservoir for the Ruliff and Bon Wier gages. Note that the pre-dam 7Q2 values are significantly lower than the published 7Q2 values. The reason for the discrepancy between the published 7Q2 and the DFLOW output for the Ruliff gage is unknown.

TABLE 5. PUBLISHED 7Q2 VALUES

USGS Stream Gage Name	USGS#	7Q2 (cfs)
Big Sandy Creek n. Big Sandy	8019500	12.4
Sabine River n. Gladewater	8020000	46.4
Sabine River n. Beckville	8022040	75.9
Sabine River n. Bon Wier	8028500	703.1
Big Cow Creek n. Newton	8029500	30
Sabine River n. Ruliff	8030500	1,121.3
Neches River n. Neches	8032000	70.7
Neches River n. Rockland	8033500	111.7
Angelina River n. Alto	8036500	37.7
Attoyac Bayou n. Chireno	8038000	25.6
Neches River @ Evadale	8041000	1,838.6
Village Creek n. Kountze	8041500	78.9

TABLE 6. COMPARISON OF PUBLISHED 7Q2 TO DFLOW 7Q2 AND 7Q10 FOR HYDROPOWER INFLUENCED GAGES

Gage	Period	DFLOW Output[a]									
		Pre-Dam			TCEQ Published Period			Full Period			
		7Q2	7Q10	Period	7Q2	7Q10	Period	7Q2	7Q10	HEFR	Period
Evadale	'66-'96	308	138	'22-'64	1,839	361	'66-'96	497	167	228	'22-'08
Ruliff	'68-'96	683	349	'25-'65	1,109	584	'68-'96	895	417	396	'25-'08
Bon Wier	'68-'96	399	218	'24-'65	703	371	'68-'96	545	250	241	'24-'08

a. Values in cfs

Using a 7Q2 as a minimum flow recommendation primarily affects subsistence criteria. Subsistence flows are infrequently occurring low flows during extremely dry periods. However, with a 2-year recurrence interval, a 7Q2 is not a particularly rare occurrence. When considering recommendations for subsistence criteria, the BBEST [needed to] balance the function of subsistence flows (the minimum flow to sustain life) and the presence of waste loading in the stream with the natural occurrence of extremely low flows. In the case of hydropower influenced gages, the BBEST [had to] consider how hydropower operations affect biology, as well as the potential for hydropower operations to cease or be reduced in the future. [For example-future use of Toledo Bend for direct diversion water supply use with hydropower generation occurring only during spills, releases would return downstream flow to naturalized summer patterns.]

The BBEST elected not to use a 7Q2 as a limit in the HEFR runs because it can easily be added as a limit later in the process if needed.

After review of biology and water quality overlays the Sabine-Neches BBEST determined there was not sufficient evidence to modify HEFR-derived subsistence flows with other flow statistics. After review of EPA's DFLOW biologically-derived low flow statistics (xBy) documentation and sources on hydrologically derived low flow statistics (xQy), the Sabine-Neches BBEST concluded that none of these methods determine what the ecological subsistence flow should be for a specific stream.

Both xQy and xBy are strictly focused on determining the flow below which stream standards do not apply (this is sometimes called the "low-flow exclusion" in water quality standards). The hydrologic method uses historical flows and the biological method uses response of organisms to a toxicant in an effluent. But both are aimed at establishing water quality limitations in NPDES[12] permits. Therefore, one method is not better than the other when it comes to determining subsistence flow because neither is actually looking at the ecological health of the stream. As a result, the Sabine-Neches BBEST does not recommend the use of either method as a check-point for its subsistence flow recommendations.

Other flow selection methods were considered, and the BBEST concluded that each has certain strengths and weaknesses. The biology subcommittee had earlier recommended the 95th percentile of flows as the subsistence threshold, for which the account and rationale are given in the biological overlay document (Appendix XIII), but this was later rejected in favor of the HEFR subsistence estimates, by consensus. There is no evidence that the subsistence flows the BBEST selected are inappropriate, and there is evidence that dissolved oxygen in the stream is sufficient at the selected subsistence flows. Flows at and, in many cases, below the HEFR subsistence flow have occurred before; and the Sabine-Neches BBEST agrees the ecological health of the Sabine and Neches basins is currently good. Based on these demonstrations of the health of the streams, the preponderance of current knowledge is that subsistence flow recommendations for the gages are based on the soundest of science that is currently available. Future consideration is dependent on studies to fill data gaps and subsequent confirmation of specifically identified subsistence flow alterations through the adaptive management process.

5.1.12 Sabine-Neches Estuary Flow Matrix

In addition to the HEFR analyses for the 12 stream gages, a HEFR analysis was performed on inflows into Sabine Lake. A discussion of how the Sabine-Neches Estuary inflow was developed is in Appendix 2 pages 49-51.

Table 7 (page 60) compares the annual volume from the HEFR runs using the percentile-based approach for Sabine Lake to the annual volume for MinQ[13], MaxC[14] and MaxQ[15] (Kuhn and Chen 2005) from the State Methodology for bay and estuary inflows. HEFR matrix volumes for each flow condition (25th percentile, median or 75th percentile) are shown for base flows only, base plus pulse flows and with the entire HEFR overbank event added to each condition. (Overbank flows may not occur in any given year.) Subsistence

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[12] EPA National Pollutant Discharge Elimination System, http://cfpub.epa.gov/npdes/, retrieved November 4, 2009

[13] MinQ: the minimum inflow that meets the salinity and biological constraints of the State Methodology model

[14] MaxC: the State Methodology model solution with the maximum total (annual) catch and satisfies applicable constraints; this inflow lies between MinQ and MaxQ

[15] MaxQ: the maximum inflow which satisfies all the salinity and biological constraints of the State Methodology model

flows have not historically occurred during the winter and spring months. In these months the fall HEFR result was used to calculate volumes.

Comparing HEFR to the State Methodology shows that the HEFR 25th percentile (dry) conditions are less than the MinQ unless an overbank event occurs during the year. Base plus pulse flows for median (average) conditions are less than MinQ for the Full Period and Pre-Dam time periods, but are more than MinQ for the Post-Dam period. MaxC values are exceeded for the median (average) condition if an overbank event occurs during the year. The 75th percentile (wet) condition is relatively close to the MaxQ even without the occurrence of an overbank flow.

Also note that for the HEFR results in Table 7, most of the volume entering the estuary is included in the base flow component. The base flow by itself is about 70% of the Base + Pulse volume in the 25th percentile (dry) conditions and over 90% for 75th percentile (wet) condition. Also, note that the Post-Dam HEFR results have higher volumes than the Full Period or Pre-Dam results.

Figure 12 (page 61) compares the seasonal distribution of the HEFR volumes to the seasonal distribution using the State Methodology. (The monthly State Methodology values were summed by the same seasons used in the HEFR analysis.) Note that the distribution for the HEFR volumes without overbank flows is similar to the State Methodology, with the highest flows occurring during the winter months and the lowest during the summer months. The occurrence of an overbank flow can alter the distribution. The HEFR volumes are for the Full Period of record. The Pre-Dam and Post-Dam periods have similar results. The Sabine-Neches BBEST chose not to use results from the State Methodology, referencing *Methodologies for Establishing a Freshwater Inflow Regime for Texas Estuaries Within the Context of the Senate Bill 3 Environmental Flows Process* (SAC 2009d, Appendix IV):

> *… for this as well as technical issues in the development of these flow patterns, these flow recommendations are not endorsed as satisfactory for the objective of Senate Bill 3 of maintaining a sound ecological environment.*

TABLE 7. COMPARISON OF HEFR ANNUAL VOLUMES TO STATE METHODOLOGY FOR THE SABINE-NECHES ESTUARY

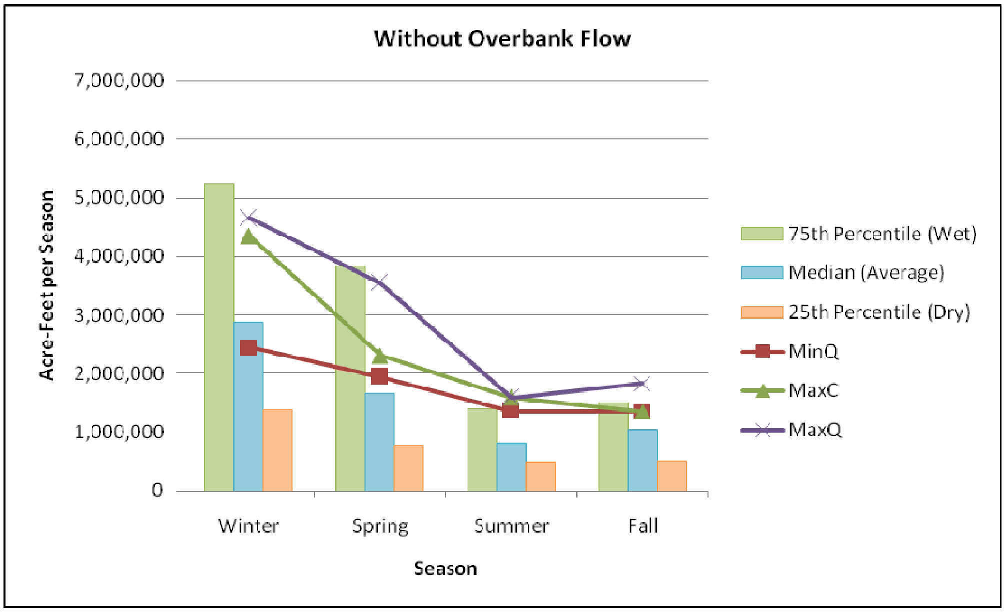
HEFR Annual Volumes (Values in Acre-Feet per Year)

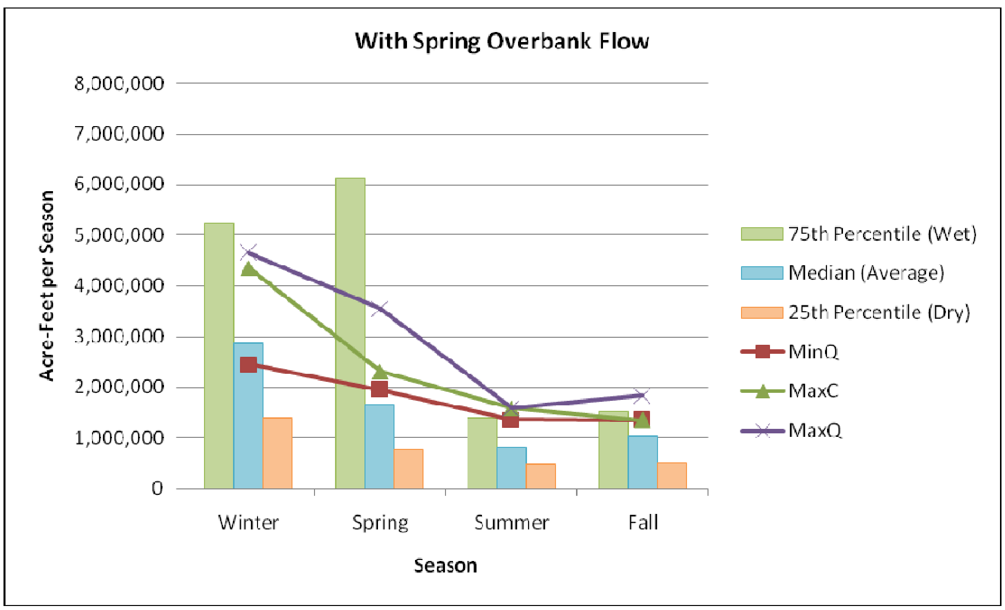
		Full Period (41-05)	Pre-Dam (41-60)	Post-Dam (71-05)
Subsistence		549,757	535,467	680,223
25th Percentile (Dry) Condition				
	Base Only	2,243,997	2,316,804	3,306,215
	Base + Pulse	3,150,508	3,643,588	4,114,963
	Base + Pulse + Overbank	6,451,892	8,646,629	7,316,168
Median (Average) Condition				
	Base Only	5,018,915	5,013,258	7,240,502
	Base + Pulse	6,380,477	6,325,716	8,234,125
	Base + Pulse + Overbank	9,467,182	10,719,867	11,271,050
75th Percentile (Wet) Condition				
	Base Only	11,076,875	10,520,563	13,694,250
	Base + Pulse	11,986,199	11,300,553	14,298,506
	Base + Pulse + Overbank	14,266,063	14,416,682	16,359,393

State Methodology

MinQ	7,114,000
MaxC	9,596,600
MaxQ	11,619,300

FIGURE 12. COMPARISON OF SEASONAL FLOW VOLUMES FOR FULL PERIOD HEFR AND STATE METHODOLOGY FOR SABINE LAKE, WITH AND WITHOUT OVERBANK FLOW





5.2 Biology (Ecological Review)

The Sabine-Neches BBEST established a subcommittee of its members with expertise in stream and riparian ecology to lead the evaluation of the statistically-derived HEFR matrix in terms of biological response mechanisms. This Biology Overlay Subcommittee assisted in selection of focal species thought to best represent the flora and fauna most responsive to flow characteristics of the two river basins and the Sabine-Neches Estuary. A large body of knowledge is represented in the cumulative educational and applied experience of the biological subcommittee members, BIO-WEST's research team who performed the biological literature review, the body of knowledge amassed in available literature, TPWD, and the NWF. The Biological Overlay Subcommittee's report appears in its entirety in Appendix XIII and is summarized here in terms of decisions and processes that were directly related to the recommendations and recognitions the Sabine-Neches BBEST is providing.

5.2.1 Fluvial Ecosystem Realm

The Sabine-Neches BBEST's Biological Overlay Subcommittee adopted the basic approach for determining environmental flow recommendations for the fluvial realm of the Sabine and Neches river basins recommended by the SAC (SAC 2009a, Appendix I) which involves defining and estimating subsistence flow, base flow, high flow pulses, and overbanking flow pulses. Hydrological output was then compared with biological data and modified as needed to comply with the needs of floral and faunal focal species selected by the Sabine-Neches BBEST.

5.2.2 SAC Recommended Procedure for Biological Overlays

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 Sabine-Neches BBEST adopted the definition proposed by the SAC (Section 1.2.4, page 9).

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

The Sabine-Neches BBEST extensively reviewed available information for ecosystems and important species in the basins of interest. Early in this process, a list of focal species was identified, and these species were the main focus of the biological overlays. It also relied on ecological studies from other major Texas river systems (i.e., Brazos, Colorado), as well as inferences based on life history information compiled from the literature, and reliance on general habitat suitability criteria developed for species from multiple regions. BIO-WEST was contracted to provide synopses of our focal species for both fluvial and estuarine systems (BIO-WEST 2009b; BIO-WEST 2009a)[16]; these are available in Appendix VIII and VII, respectively.

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[16] Citations refer to bibliography items in the Recommendations Report, not the Biology Overlay Discipline Report; they may vary (e.g. "a" vs. "b" and citation style).

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

Following initial reviews and deliberations and in consultation with our hydrological analysis contractor (FNI 2009a) 12 gages were selected with sufficient historical flow records to provide broad geographic coverage within the two basins. Reports were obtained for studies of historical records of fishes in the Sabine Basin (Bonner and Runyan 2007; Bart 2008) and historical records of freshwater mussel collections in the Sabine and Neches basins were reported by (Howells, Neck et al. 1996). An analysis of wetland and riparian vegetation communities was performed by the NWF and Greater Edwards Aquifer Alliance (GEAA) (Appendix XVII), and the Sabine-Neches BBEST's analysis of this information appears below in the section addressing flow pulses.

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

Due to severe time constraints and the limited nature of the biological information available, little biological information was used to set or modify default parameters for both the hydrographic separation method (MBFIT) and the HEFR analysis.

STEP 5. Evaluate and refine the initial flow matrix.

The flow regime matrix produced by the HEFR hydrological analysis was evaluated to ensure that the ecological needs of the major components of the biological system, their water quality requirements, and geomorphic processes that create and maintain their habitats are maintained. According to the SAC Biological Overlay Guidance document, this final step is perhaps the most critical one in the environmental flow evaluation process. Three multidisciplinary integration workshops were convened to evaluate and refine the flow regime matrix.

5.2.2.1 Subsistence Flows

Current Conditions and Responses of Focal Species to Subsistence Flows

Subsistence flows represent the minimum flow requirement to maintain populations during periods of severe and prolonged drought. Subsistence flows thus should be viewed as the emergency ration of water required to prevent local extirpation of aquatic and riparian species (Richter 2003; Acreman and Dunbar 2004; Richter, A.T. Warner et al. 2006), and references therein. Subsistence flows provide minimal yet sufficient habitat of sufficient quality such that populations can rebound upon reestablishment of base flow conditions. Thus, subsistence flow conditions are infrequent.

Few site-specific studies have been performed in the Sabine and Neches River Basins to inform the Sabine-Neches BBEST's recommendations for subsistence flows. Werner (1982a; Werner 1982b) performed an analysis of hydraulic habitat in the lower Sabine River and lower Neches River reaches. Werner's maintenance flows are defined in a manner that blends elements of what are now defined as subsistence flows and base flows. Thus, it is difficult to make a direct comparison of his flow recommendations with those derived by the Sabine-Neches BBEST from HEFR analysis of hydrological data. In addition, Werner provided recommended flows during periods of drought, and these would be equivalent to what we now refer to as subsistence flows. In general, Werner's recommendations for drought/maintenance flows are significantly higher than the values obtained by the HEFR hydrological analysis.

Although no other specific instream flow studies have been completed in the Sabine-Neches Study Area, the Biological Overlay Subcommittee's evaluation of biological/ecological responses to flow variation was greatly aided by data collected over broader spatial and temporal scales (Evans and Noble 1979; Moriarty and Winemiller 1997; Bonner and Runyan 2007; Bart 2008) and other studies summarized in BIO-WEST (2009b). No species of fishes, mussels, or wetland/floodplain plants appear to have been extirpated from the basins as a result of subsistence flow conditions. A trend in the lower reaches of the mainstems of both the Sabine and Neches Rivers is toward higher flow during exceptionally dry summers, as compared to historical flows under the same conditions. This is due to summertime hydropower releases (summer is the period when energy demand is high). Major changes in minnow communities in the lower Sabine River documented by both Bart (2009) and Bonner and Runyan (2007) appear to be due to altered hydrology and a reduction in delivery of fine sediments and reduced turbidity that favored species associated with clear-water conditions (e.g. *Cyprinella venusta*) and simultaneously resulted in reductions of minnows preferring turbid waters and fine bottom sediments (e.g. *Cyprinella lutrensis*, *Notropis buchanani*). Long-term trends in subsistence flows in the unregulated upper reaches of tributaries are not apparent, and available evidence suggests that no native faunal or floral elements have been extirpated from the basins. In streams such as Village Creek, the fish fauna and riparian vegetation community seem to be in good condition. Ecologically Significant River & Stream Segments of Region I (East Texas) Regional Water Planning Area (Texas Parks and Wildlife Department 2005) provides a good overview of the current state of many of these tributaries.

Subsistence Flow Recommendations

For lack of specific studies to address the subsistence flow component, the Subcommittee's ecological analysis began with the HEFR subsistence estimates from each gage. As explained in Section 5.1 of this report, HEFR outputs were used to estimate subsistence flows based on historical streamflow data and manipulation of the MBFIT option. For the ecological analysis, the HEFR subsistence estimates for each season from each gage were compared with: 1) the recorded minimum flows, 2) percentiles of seasonal flows, 3) the 5th percentile of all flows, 4) 7Q2 and 7Q10 values which are a standard used by the state and federal agencies for water quality risk assessment under severe low-flow conditions (Table 4 and 5, FNI , HEFR Memo, Sept. 17, 2009), and Werner's (1982a; Werner 1982b) drought flow recommendations based on PHABSIM[17]/IFIM[18] analysis (the latter only available for the lower Neches and Sabine River segments).

Initially, the Sabine-Neches BBEST considered use of the lowest seasonal subsistence flow from MBFIT/HEFR analysis for the subsistence flow recommendation. The reasoning here was that if no fish populations are known to have been lost from the rivers and streams over the past 50 years of hydrological records and biological surveys, then this is evidence that the local biodiversity (populations of plants and animals) are able to recover and persist when faced with these severe reductions in flow. Next, the Sabine-Neches BBEST discussed problems with this reasoning. First, it is important to consider the frequency of occurrence and

[17] Physical Habitat Simulation (Software), http://www.fort.usgs.gov/Products/Software/PHABSIM/, retrieved November 19, 2009

[18] Instream Flow Incremental Methodology, http://www.fort.usgs.gov/Products/Software/IFIM/, retrieved November 19, 2009

duration of these low flow events. By definition, subsistence flows are intended to be severe but infrequent events of low flow. The risk of setting subsistence flows too low is that aquatic and riparian populations of plants and animals might experience stressful environmental conditions, including crowding that leads to increased predation mortality, for unusually long periods with excessive frequency. Initial adoption of the summer seasonal subsistence flow from HEFR for the entire year resulted in seasonal flows well below levels ever recorded for the segment in the winter. Winter is the season when flows tend to be higher naturally. Second, adoption of the summer seasonal subsistence flow level for all seasons resulted in many seasonal values that were significantly below 7Q2, and values recommended by Werner for the two lower river segments, though such subsistence flow levels are comparable to available 7Q10 values (Table 6) for the full period of record. Third, it seemed possible that although responses of water quality factors during Winter may not appear to be as potentially impactful as during Summer and early Fall, unforeseen ecological factors (e.g., those related to metabolism of ectothermic organisms at low winter temperatures) may result in negative influences on aquatic and riparian systems if Winter flows were permitted to fall to levels never before observed in the ecosystems.

Some members of the Biological Overlay Subcommittee supported use of the 5th percentile of all recorded flows as the subsistence flow criterion, because there appears to be growing support for its adoption within the environmental flows literature, especially in the absence of site-specific findings from research on habitat availability, habitat connectivity, and water quality. Through a consensus workshop approach, Acerman, Dunbar et al. (2006) established the Q95 (5th percentile) as the hands-off (emergency low flow) criterion for regulatory standards to ensure ecological protection for rivers and lakes in the United Kingdom. Acerman, Dunbar et al. (2006) concluded that the "Q95 marks a significant point where below which conditions in the river change rapidly and hence the river is more sensitive to flow change." Citing this and other work, Hardy, Addley et al. (2006) used the monthly Q95 in the Klamath River in California as the ecological base flow (= subsistence flow) recommendation. In Texas, BIO-WEST (2008a) used the 5th percentile flow as a starting point for evaluating subsistence flow recommendations in the lower Colorado River. BIO-WEST evaluated this flow level and found only a few instances where individual habitat categories went to 0 or below 5% of the available habitat in a given reach (BIO-WEST 2008a). Although extreme, these conditions when considered with monthly variation were deemed appropriate for an initial subsistence flow recommendation. Subsistence levels for the lower Colorado River were then modified (in some cases up and in some down) based on specific results from water quality modeling and reach-specific species requirements (BIO-WEST 2008a). Preliminary subsistence flow guidelines for the lower San Antonio River identified by BIO-WEST (2008b) were also compared to 5th percentile flows. Although field investigations were performed, the preliminary subsistence flow values proposed were conservatively higher than the historical 5th percentile (through 1971). It is noted, however, that treated effluent comprises a significant component of the subsistence and base flows of the San Antonio River.

Next, the Sabine-Neches BBEST re-examined the issue of setting a single subsistence threshold versus separate seasonal thresholds. There is extensive support within the instream flow literature for adoption of monthly or seasonal subsistence flow recommendations. As a result, Sabine-Neches BBEST ultimately decided to make subsistence flow recommendations on a seasonal basis.

As a result of deliberations by the BBEST Biological Overlay Subcommittee and the full membership of the Sabine-Neches BBEST, a series of adjustments were made to the subsistence flow estimates from the MBFIT/HEFR hydrological analysis.

The Sabine-Neches BBEST recommends adoption of the seasonal subsistence flows from MBFIT/HEFR, unless 1) the seasonal value is less than the summer value in which case the summer value is adopted by default, and 2) MBFIT/HEFR failed to calculate a value (this occurred usually for winter) in which case the lowest recorded flow value for that season at that gage was adopted by default. The Sabine River near Beckville subsistence flow was modified to be consistent with the Sabine River Compact minimum flow requirement.

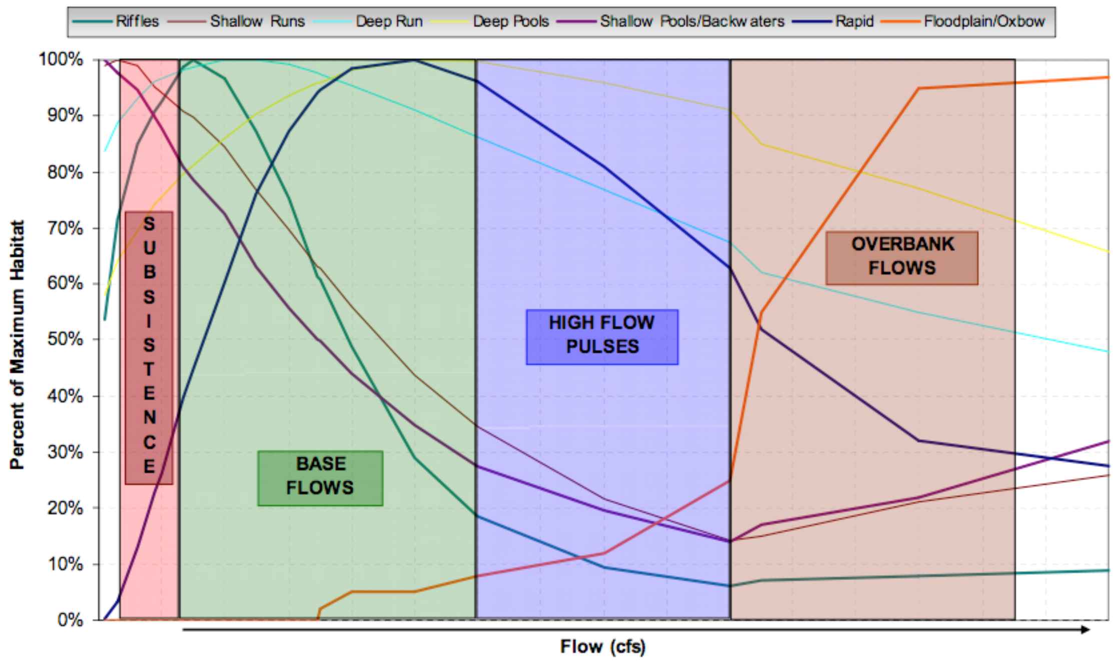
5.2.2.2 Base Flows

Current Conditions and Responses of Focal Species to Base Flows –

Ecological roles of base flows include providing suitable habitat, maintaining habitat diversity, and supporting the survival, growth, and reproduction of aquatic organisms. Base flows are also important for riparian areas (see Table 1. Some ecological functions performed by Instream flow regime components in the SAC guidance *Essential Steps for Biological Overlays in Developing Senate Bill 3 Instream Flow Recommendations* (SAC 2009a, Appendix I)). Information on focal species (i.e., species that indicate the needs for a group of species with similar ecological requirements) can be used to confirm and refine base flow estimates. Flow-ecology relationships discovered in literature reviews were used to guide our interpretations of likely species responses to flow variation in the east Texas basins. Qualitative life history information and conceptual models of focal species' life cycles, such as data on fish spawning seasons, were used to evaluate hydrologically derived base-flow estimates during different seasons and across dry, average, and wet years.

To guide inferences about required base flows during dry, average, and wet years, the Subcommittee examined the findings from the extensive research conducted by BIO-WEST (2008a; BIO-WEST 2008b). The Subcommittee acknowledges that some degree of inter-annual variation in base flows is natural, and very necessary to maintain a balance of aquatic species belonging to different habitat guilds. This is because some fish guilds will have more habitat available to them during dry-year conditions and others will have less (Figure 13). The relative availability of habitat types generally undergoes a shift with a transition to average and wet year conditions (BIO-WEST 2008a; BIO-WEST 2008b). This shifting in the amount of instream habitat during years with different amounts of rainfall is important for maintaining secure populations of all the species characteristic of the region's rivers and streams.

FIGURE 13. HABITAT AVAILABILITY CURVES FOR SEVEN FISH HABITAT GUILDS IN THE LOWER COLORADO RIVER, TEXAS



This figure was derived from recent instream flows research by BIO-WEST (BIO-WEST 2008a)

Periods of prolonged and stable base flow, especially during the summer-fall, can be beneficial for many species in terms of feeding interactions. Predatory fishes can exploit prey populations that are at higher per-unit-area densities during periods of low flow. For sight-oriented predators, water generally is more transparent during these periods when prey populations are more concentrated. Mussels can filter feed on higher densities of water-column food resources (phytoplankton and derived fine particulate organic detritus) during periods of extended base flow (Rypel, Haag et al. 2009). Also, sediments become more stable, which is beneficial for many mussel species (Vaughn and Taylor 1999; Strayer 2008). Certain minnow species spawn and may have better recruitment during prolonged periods of stable base flow during summer (e.g., ironcolor shiner). Base flow conditions also are important for survival of riparian plants that obtain groundwater from the hyporheic zone during periods of low rainfall (Rypel, Haag et al. 2009).

Base Flow Recommendations

For the ecological analysis, the HEFR base flows for dry-year, average-year, and wet-year estimates from each gage were compared with information on the ecology of focal species (BIO-WEST 2009a, Appendix VIII) and, when appropriate, findings from the BIO-WEST instream flow study of fishes in the lower Colorado River (BIO-WEST 2008a). Adoption of base flow benchmarks for dry years (low precipitation years when reservoir pools are low), average years, and wet years (high precipitation years when reservoir pools are high) was deemed critical for protecting populations of aquatic organisms within the various diverse habitat guilds.

Base flow estimates from the HEFR analysis were deemed ecologically suitable.

5.2.2.3 High Flow Pulses and Overbank Flows

High flow pulses shape physical habitat of the river channel, contribute to sediment transport and flushing of silt and fine particulate matter and provide other geomorphic and water quality functions. Biological roles include providing spawning cues and habitat for some species of fish and facilitating connectivity to oxbows and other wetlands. The timing of high flow pulses may be critical for triggering spawning migrations or actual spawning events. The role of high flow pulses for supporting aquatic and riparian/floodplain plants and animals was summarized in the SAC Biological Overlays Guidance Document (SAC 2009a, Appendix I).

The evaluation of the benefits to the biota of high pulses must focus on two components: time (or more accurately—the timing and duration of the pulse in relation to the requirements for spawning cues, feeding opportunities of juveniles, etc.) and space (or more accurately—how the rise in water level interacts with local landscape topography/geomorphology to produce connections with and enhancement of marginal and off-channel aquatic habitats). In evaluating the spatial aspects of high flow pulses, various kinds of maps are extremely useful (topographic, digital elevation, wetlands, vegetation categories, etc.). The Subcommittee relied on NWS estimates of overbank flooding[19] and a specific analysis by the NWF and the GEAA (Appendix XVII).

Responses of Aquatic Focal Species to High Flow Pulses

Tributaries: Although lateral connectivity to off-channel floodplain habitats is relatively less important in smaller headwaters and tributaries (e.g. Angelina River, Village Creek) than larger mainstem reaches located downstream, it is still critical, from an ecological standpoint, to have periodic high flow pulses to permit organisms to occupy marginal habitats for feeding and/or reproduction (connected backwaters, sloughs, etc.).

Mainstem river/floodplains: A great deal of ecological literature demonstrates that paddlefish, alligator gar, flathead catfish, blue sucker, and other species characteristic of large mainstem rivers have major requirements for high flow pulses. High flows transport eggs/larvae of broadcast spawners and the availability of submerged bank feeding habitats increases during high flows. Some degree of stability in flow pulses is beneficial for substrate nesting/guarding centrarchids. High flow pulses during spring are most beneficial for spotted bass and other sunfishes when they have 3 weeks time to construct a nest, spawn, and guard the eggs and larvae until they are large enough to swim effectively. White crappie prosper greatly within the lentic and highly productive environment of oxbows which are maintained by pulse flows (Zeug, Winemiller et al. 2005).

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[19] National Weather Service River Forecast Center, West Gulf RFC, http://www.srh.noaa.gov/wgrfc/, retrieved November 6, 2009

TABLE 8. SABINE/NECHES FISH SPECIES WITH SPAWNING SYNCHRONIZED TO FLOW PULSES DURING LATE WINTER-SPRING (FEBRUARY-JUNE) WITHIN-CHANNEL, WATER-COLUMN SPAWNERS (N= 26)

Sabine-Neches BBEST FOCAL SPECIES: Paddlefish, blue sucker, white bass, shoal chub, emerald shiner, sabine shiner

OTHER Sabine/Neches SPECIES: gizzard shad, threadfin shad, cypress minnow, Mississippi silvery minnow, pallid shiner, ribbon shiner, redfin shiner, silver chub, golden shiner, blackspot shiner, ghost shiner, silverband shiner, weed shiner, mimic shiner, river carpsucker, smallmouth buffalo, spotted sucker, blacktail redhorse, yellow bass, freshwater drum

Spawning in submerged river margins* (eggs scattered on vegetation, rocks or other submerged structure, or nest constructed) (N=18)

Sabine-Neches BBEST FOCAL SPECIES: Alligator gar, black crappie, white crappie, spotted bass, harlequin darter

OTHER Sabine/Neches SPECIES: Longnose gar, spotted gar, red shiner, blacktail shiner, fathead minnow, bullhead minnow, creek chub, creek chubsucker, lake chubsucker, yellow bullhead, blue catfish, channel catfish, redfin pickerel

* This list only includes fish species that are strongly responsive to high flow pulses, usually moving into newly submerged littoral habitats or littoral habitats that become deeper with more suitable hydraulics (e.g., slow back eddies) to spawn or nest. This list does not include other species that spawn or nest in littoral habitats even without springtime cues provided by high flow pulses (e.g., the various sunfish species, darters, and topminnows). (Winemiller 2009)

Responses of Focal Species to Overbanking Flows

As discussed in the SAC Biological Overlays Guidance Document, overbanking flows are important for moving coarse woody debris and sediments, scouring deep pools and depositing sediments to form sandbanks, and allowing aquatic organisms to colonize ephemeral aquatic floodplain habitats. The inundation of floodplains allows seeds of bottomland hardwood tree species to disperse or germinate following flood subsidence. The overbanking flow components of a flow matrix (as derived from the HEFR analysis) thus have important functions for the ecological system. It is essential to recognize that overbanking flows are a part of the natural flow regime that maintains the native biodiversity of the two basins. Two terrestrial focal species, overcup oak and water tupelo, have aspects of their lifecycle dependent on periodic high flood pulses. These bottomland hardwood tree species require periodic flooding (including occasional growing season overbank flows) for successful germination, seedling recruitment, and elimination of upland plant species that are competitively superior on well-drained soils (Sharitz and Mitsch 1993).

Among alligator gars and other gar species, adults and juveniles (particularly juveniles) commonly move into flooded plains to feed opportunistically on insects, amphibians, and other fish species that also exploit temporarily abundant food resources (Robertson 2008). Many small fishes also use temporarily flooded riparian habitats to feed on terrestrial and soil invertebrates (Kwak 1988).

Pulse Flow and Overbanking Flow Recommendations

HEFR pulse flows were evaluated in the context of ecological information compiled for the Sabine-Neches BBEST's focal species (BIO-WEST 2009b, and sources cited therein). For the issue of lateral connectivity of aquatic habitats, we also relied on ecological inferences derived from research findings on the ecological dynamics of the lower Brazos River by Winemiller and colleagues (Winemiller, Tarim et al. 2000; Zeug, Winemiller et al. 2005; Zeug and Winemiller 2007; Robertson 2008; Zeug and Winemiller 2008; Zeug, Peretti et al. 2009). Protection of high flow pulses during late winter and early spring is essential for providing spawning cues and environmental conditions required for successful spawning and early life stage survival for a great many fish species in the streams and rivers of the region. High flow pulses during other times of the year are important for inducing varying degrees of lateral aquatic habitat connectivity which provides for movement between the main channel and backwater/off-channel habitats.

To quantify the extent of lateral connectivity of aquatic habitats during high flow pulses and overbanking events, we also examined the percent flooding of wetland and bottomland hardwood vegetation zones in several of our reaches (this information was provided by the NWF and the GEAA; Appendix XVII). High flow pulse and overbank flow values generated from the HEFR outputs were evaluated for the total area of Pineywoods Riparian Ecotones identified in the NWF/GEAA inundation flows analysis. Determining the amount of riparian area inundated by the recommended high flow pulses and overbank flows is not only important in evaluating if riparian needs are being met, but will also help evaluate other important aspects of high flow pulses such as channel maintenance, lateral floodplain connectivity, and migratory and spawning cues. Data from the NWF/GEAA analysis was used to develop a relationship between flow and the percent total area of Pineywoods Riparian Ecotones inundated. The analysis was set up as such:

- Data were obtained from the NWF Overbank Analysis Excel spreadsheet.
- Only gauges with more than two observations were used (valid observations were those that were indicated as being used in the "BH Inflows Analysis").
- A best fit trend line was applied to the data (linear or logarithmic).
- The percentage of the total wetland/riparian vegetation community zone inundated was determined for each high flow pulse category.

Results of the regression models developed between flow and percent area of inundation are shown in Figure 2[20] of the Sabine-Neches BBEST Biological Overlay Approach Discipline Report (Appendix XIII). Only four gages had sufficient data to develop models (Big Sandy, Ruliff, Neches, Evadale) and correlation (i.e., R^2) for all four models was high. The model equations developed for each of the four gages were then applied to the HEFR high flow pulses, including the 1-per-year overbanking flow, to predict the percent total area of the

[20] Relationship between observed flow and percent total area of Pineywoods Riparian Ecotones (wetlands and bottomland hardwood vegetation communities) inundated using NWF/GEAA overbanking flows analysis for the maintenance of bottomland hardwoods

pineywoods wetland/riparian zones inundated (Table 1[21], Appendix XIII). Results of this analysis are shown in each of the gages HEFR version 2 outputs (Figures 3 – 6, Appendix XIII). HEFR-derived high flow pulses of 2-per-season and 1-per-season plus overbanking pulses of 1-per-2 years in the upper basin gages (Neches and Big Sandy) provide good levels of riparian zone inundation. For the lower basin gages (Evadale and Ruliff), overbanking (1-per-2 year) flow outputs provide sufficient riparian inundation (100% inundation for both gages), but the smaller 2-per-season and 1-per-season high flow pulses do not appear to be sufficient for providing a degree of lateral connectivity and flooding of the pineywoods wetland/riparian zones on an annual basis (0% inundation for all high flow pulses at the Evadale gage, and only up to 25% inundation for the 1-per-season flows and 0% inundation for all 2-per-season flows).

Flow versus percent-area-of-inundation relationships were only possible for 4 gages, nonetheless a trend is observed geographically. It appears that the HEFR high flow pulse and the 1-per-2 year overbanking flows may be sufficient to maintain riparian habitats and lateral connectivity for both of the upper basin gauges in the Neches and Sabine Rivers. The two seasonal categories of HEFR high flow pulses (2-per-season, 1-per-season) for the three lower-reach gauges are not sufficient to inundate riparian areas on an annual basis in both the lower Sabine River and lower Neches River. Given this trend, the Biology Overlay Subcommittee recommends a 1-per-year high flow pulse for all three of lower basin gages (all located below reservoirs) to ensure that sufficient riparian inundation, lateral connectivity, and channel maintenance flows are attained. These flows also would facilitate migration and spawning of river fishes if provided during the months of February-May.

Based on the analysis of these multiple sources of information, it was concluded that the following categories of flood pulses in the HEFR output matrix require protection: 2-per-season, 1-per-season, and 1-per-year (the latter for the three lower river segments only: Neches River at Evadale, Sabine River at Bon Wier, Sabine River at Ruliff) or 1-per-2 years (for the other 9 segments). Clearly, other high pulse categories would be beneficial for the ecosystems, both aquatic and riparian/wetland, but in the Subcommittee's judgment and based on currently available information, these three are most essential for a sound ecological environment. It also is important to emphasize that the larger pulses (1-per-year; 1-per-2 years) are essential for the long-term maintenance of the biota and ecosystems, because these are, in addition to providing critical ecological functions, the flow levels that cause significant movement of bed materials, a process that creates both instream and floodplain aquatic habitat structure. This latter category also causes more extensive flooding in the lower reaches of the two rivers, which is critical for maintaining plant communities of wetlands and bottomland forests. The magnitudes of these 1-per-year and 1-per-2 years flows would inundate the lowest areas within floodplains – the areas associated with wetland and riparian vegetation communities. Nonetheless there also could be variable degrees of risk to certain economic activities in the floodplains, property, and public safety.

Seasonal high flow pulses have recognized ecological benefits and are recommended for protection with certain reservations associated with environmental and operational liability

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[21] Predicted percent area of inundation for overbanking flows and high flow pulses derived from our HEFR frequency-based analysis using the full period of record

risks. The Sabine-Neches BBEST also recognizes the ecological functions and benefits of overbank flows, but does not recommend actions be taken to produce such flows. Climatic conditions and flood events are expected to produce these levels of flow even with full use of existing water rights and realistic projections of water supply development.

5.2.3 Estuarine Ecosystem Realm

According to the SAC Guidance Document for Estuarine Ecosystems (SAC 2009d, Appendix IV), "the estuarine ecosystem is complex, comprised of many variables and their interactions." "Much of the complexity of estuaries derives from their nature as a transitional watercourse between freshwater and marine water. This is reflected in the multiple external forces controlling the estuary." "The exchange between estuary and sea is mainly affected by tides, gravity currents and meteorology (especially wind stress). Exchange between estuary and sea also manifests itself in the organisms, …. Many of the important estuarine animals, notably major fish and shellfish species, migrate between the sea and the estuary at various life-history stages. Most immigrate into the estuary from the sea as young, and mature in the estuary, taking advantage of sheltered, food-rich environments, then return to the sea as adults." "A direct measure of the physical exchange with the sea is the salinity distribution within the estuary. Salinity is the quintessential estuary parameter." "Most freshwater organisms cannot survive if salinity is too high, and most seawater organisms cannot survive if salinity is too low. An estuary is therefore an inhospitable environment for these "stenohaline" organisms. There are, however, "euryhaline" organisms that have a physiological capability to function—even thrive—in the intermediate and variable salinities of an estuary. The range and distribution of salinities can therefore be important demarcators of suitable habitat for estuarine species. The spatial estuarine gradient is fundamental for regulating differences in the functions, habitats, and integrity along the salinity gradient. Much is known about salinity gradients in estuaries and the average salinity over long time periods is an indicator of organisms' habitat." (SAC 2009d, Appendix IV)

Estuarine ecosystems are spatially heterogeneous, physically and biologically dynamic, and highly complex owing to interactions among numerous environmental variables and diverse species spanning a range of salinity tolerances and ecological niches. Given these realities and complexities, the initial position examined by the Sabine-Neches BBEST was that the Sabine Lake estuary would receive the freshwater inflows that result from the HEFR-hydrological analysis and recommendations of flow components for the Sabine-Ruliff, Neches Evadale, and Village Creek gages. Once these volumes were calculated, we addressed the question: what are the likely responses of estuarine components? This was examined following two approaches. First, the Sabine-Neches BBEST contracted BIO-WEST to provide a literature review and summary of focal species for the Sabine Lake ecosystem (BIO-WEST 2009a, Appendix VII). Several plant, invertebrate, and fish species were selected to cover a range of population responses to salinity levels in Upper Gulf Coast estuaries. Second, the Sabine-Neches BBEST enlisted the help of the NWF to analyze the potential responses of estuarine focal species to the salinity regimes resulting from the HEFR-derived freshwater inflows to the ecosystem. The NWF approach estimated habitat suitability within three zones of the estuary as a function of salinity regimes. Third, the Sabine-Neches BBEST examined (analysis performed under contract by Freese and Nichols) the relationship between the HEFR-derived freshwater inflows to Sabine Lake with inflow requirements estimated from Freshwater Inflow Recommendation for the Sabine Lake Estuary of Texas and Louisiana (Kuhn and Chen 2005). The Subcommittee considered these two different approaches to be the best available science available for evaluating the suitability of freshwater inflows derived from the fluvial analysis for meeting the ecological needs of the estuarine ecosystem. Clearly, more research is needed and refinements to these analyses are warranted to reduce uncertainty. Nonetheless, these approaches, at present, provided the most feasible and robust means for independent assessment of environmental flows for the estuary. Both analyses supported the view that the fluvial-derived environmental flow recommendations fall within the range of values that should provide freshwater inflows sufficient to maintain a sound ecological environment within Sabine Lake under its current geomorphological configuration.

5.2.3.1 National Wildlife Federation (NWF) Analysis of Habitat Suitability for Key Estuarine Species under Alternative Flow Regimes

The recent SB 3 SAC report on methods for establishing an estuarine inflow regime (SAC 2009d, Appendix IV) recognizes a variety of potential approaches. The goal of these approaches is to link freshwater inflows, and its various attributes such as timing and volume, to the biologic response of the estuary. One of the principal methods for characterizing the biota of the estuary is the "Key Species" method. For the purposes of establishing an estuarine inflow regime, key species should exhibit sensitivity to inflow-controlled parameters, such as salinity or nutrient concentrations.

An analysis performed by NWF to assist the Sabine-Neches BBEST (Appendix XVI) focused on key species with specified salinity tolerance ranges (salinity suitability relationships) and used a variety of methods for coupling species' biologic responses to the inflow-salinity patterns. The NWF analysis focused on a suite of four species and two marshland communities, all with well-established and published salinity tolerance (a.k.a. salinity suitability) information. These key species and communities are: *Rangia cuneata* larvae, blue crab juveniles, oysters, Olney bulrush (adults and seedlings), Intermediate Marsh, and Brackish Marsh. The bivalve mollusk *R. cuneata*, blue crabs, oysters, and the Olney bulrush were recommended "focal species" in a previous report to the BBEST (BIO-WEST 2009a). As per Dr. Richard Harrel, the larval stage of *R. cuneata* is not suitable as a focus or key species: it is present for only a short time period after spawning; it is very steno-tolerant to everything; after a few days it is benthic; and after a few months it is eury-tolerant (Harrel 2009). The spatial extent and abundance of oyster and blue crabs are well known in Sabine Lake based on the TPWD's long-term sampling program. The Olney bulrush was recommended by BIO-WEST (2009a, Appendix VII) due to its likely occurrence in the marsh types surrounding Sabine Lake.

The spatial extent and abundance of *R. cuneata* was not well established for Sabine Lake and thus an important preliminary undertaking was a field investigation with sonar imaging and field sampling. In summary, *R. cuneata* are widespread in the majority of Sabine Lake, approximately the upper three-fourths of the estuary. Thus *R. cuneata* is a very good key species for this estuary evaluation not only because of the well-defined salinity tolerance limits of the larvae (more below), but also due to the fact that they comprise a substantial benthic biomass in much of the estuary. The two marshland communities are widespread around the margins of Sabine Lake as indicated by Kuhn and Chen (2005).

The NWF analysis focused on two of the four flow components because of their likely importance in the overall flow regimes and potential role in influencing the ecology of Sabine Lake. Time limitations prevented a more complete evaluation of the full spectrum of flow components. First, they focused on the "base average" condition flows because they may be in effect for a substantial portion of the time as these environmental flow regimes are implemented. However, because no attainment frequency for this component has been explicitly specified as of the time of their analysis, the precise percentage of time those conditions might be expected to pertain is unclear. Their second primary area of focus was "subsistence" flows. Flows of this low magnitude should be rare events, occurring only during very dry, near drought-of-record, periods (Texas Commission on Environmental Quality 2008b). They focused on subsistence flows in order to assess their implications for Sabine Lake.

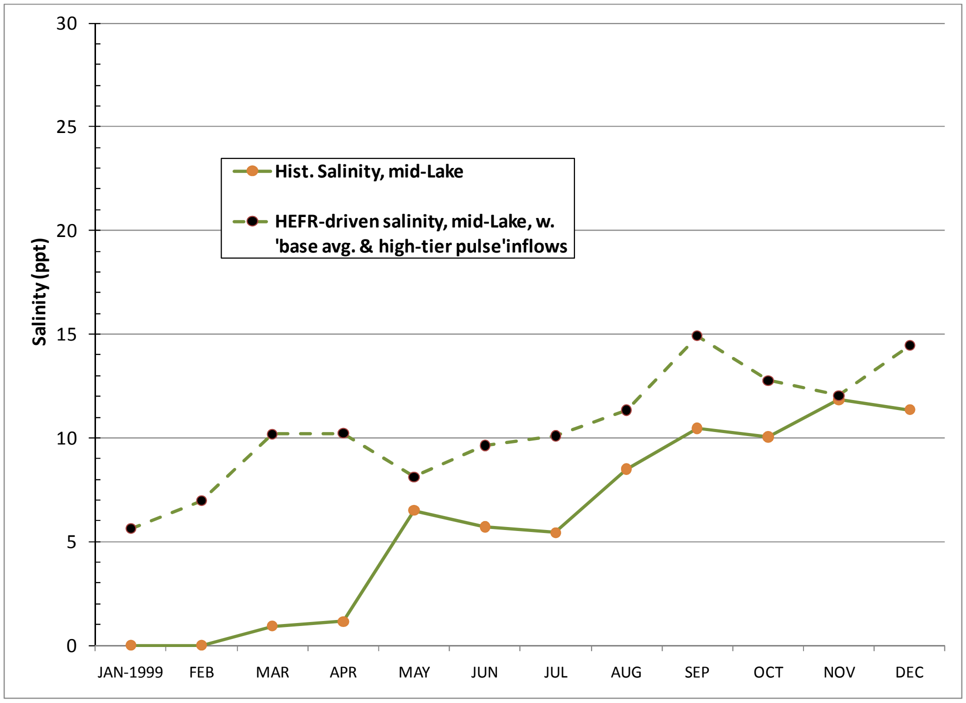
To assess the implications of adopting and implementing the proposed HEFR-derived flows, they used a procedure similar to that employed by the TWDB and TPWD in earlier salinity modeling of Sabine Lake (Kuhn and Chen 2005). The HEFR-derived flow values were substituted for the actual historic values at the three BBEST sites Sabine River at Ruliff, Neches River at Evadale, and Village Creek near Kountze. Other historic inflow contributions as reflected in TWDB records, including from other gaged watersheds (Pine Island Bayou and Cow Bayou) as well as ungaged areas below these gauges and other wholly ungaged drainages, remained unchanged.

Figures 7[22] and 8[23] of Appendix XIII illustrate the salinity response at the mid-estuary site for representative "average" and "very dry" years 1999 and 1996, respectively (Figure 7 of Appendix XIII is reproduced below as Figure 14). For 1999 the salinities shown are those predicted with the salinity-inflow regression for both the historic inflows and the synthetic inflow record constructed with the HEFR-derived values at the "base average and high-tier seasonal pulse" levels at the Ruliff, Evadale, and Village Creek sites. Similarly, for the 1996 depictions, the regression-predicted salinity responses are shown for both the historic values and the synthetic inflow record, but here HEFR subsistence flows at the three sites are substituted in for the March-June period.

[22] Predicted salinity in Sabine Lake under the original historic inflows for 1999 and with the synthetic inflow record of HEFR-derived values corresponding to "base average and high-tier seasonal pulse" for the sites at Ruliff, Evadale, and Village Creek

[23] Illustration of the predicted salinity in Sabine Lake under the original historic inflows for 1996 and with the synthetic inflow record of HEFR-derived values corresponding to "subsistence" levels for the March – June period at the sites at Ruliff, Evadale, and Village Creek

FIGURE 14. PREDICTED SALINITY IN SABINE LAKE UNDER THE HISTORIC INFLOWS FOR 1999



This graphic is for the synthetic inflow record of HEFR-derived values corresponding to "base average and high-tier seasonal pulse" for the sites at Ruliff, Evadale, and Village Creek.

Salinity Suitability of Key Species and Communities

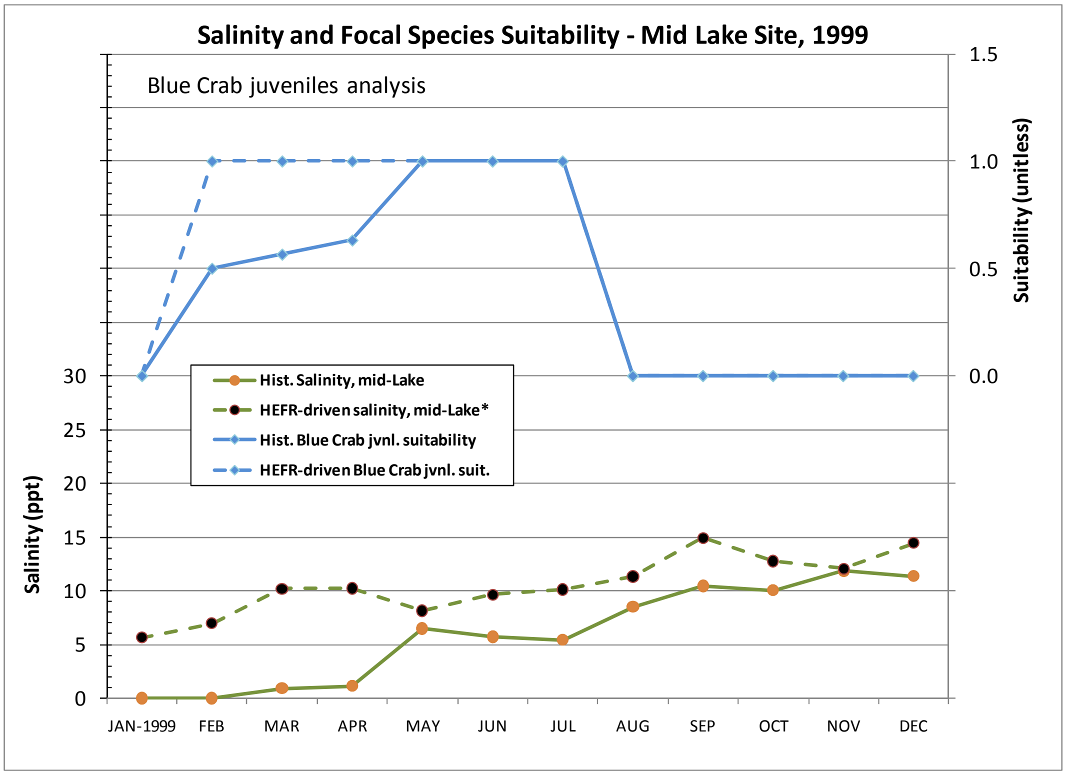
Another essential element of the NWF analysis is the published salinity suitability information for the four key species (*R. cuneata*, oysters, blue crab, and Olney bulrush) and two key marshland community types (intermediate and brackish). This information provides the critical link between freshwater inflows, the associated salinity patterns, and the ecological health of the biota in the estuary. With a salinity suitability relationship, as shown in Figure 9[24] of Appendix XIII for blue crabs, they were able to ascribe a relative level of significance for any given salinity for that species or community. With a suite of such relationships, a broad perspective was sought regarding the potential effects of salinity changes tied to freshwater inflow alterations.

They also examined important seasonal considerations for each focal species. These are essentially the portions of the year in which the relationship of salinity to biologic health is thought to be most important. Figure 15, below, illustrates how the predicted salinities, salinity suitability curve, and the seasonal constraints (blue crabs as an example) were used in the analysis. On the bottom half of the figures are the

[24] The salinity suitability relationship for blue crabs (based on the synthesis of literature from LCRA-SAWS (2007))

salinity responses for historic inflows and the HEFR-derived "base average and high-tier seasonal pulse" inflows at the Ruliff, Evadale, and Village Creek sites. Appearing in the top half of the graph are the computed salinity suitability for both of the salinity traces. In the upper panel, only salinities for the period Feb.-July are used; for the remainder of the months, a default value of 0.0 is shown.

FIGURE 15. ILLUSTRATION OF SALINITY SUITABILITY RELATIONSHIP FOR BLUE CRABS



Findings: Salinity Suitability Analysis of HEFR-derived Inflows

Inflows at the "base average and high-tier seasonal pulse" level – the Sabine River at Ruliff, Neches River at Evadale, and Village Creek near Kountze segments were assigned flows at the "base average and high-tier seasonal pulse" level for the whole year. 1980 was used as an example year since historic total inflows were at the 50th percentile of the historic record for 1941-2005. All other inflow contributions to Sabine Lake were maintained at their historic level during the year. Findings of habitat suitability analysis for several focal species are shown in Figure 11 a-f of Appendix XIII (Figure 11a, 11b, and 11f are reproduced below as Figure 16, Figure 17, and Figure 18, respectively).

FIGURE 16. SALINITY AND FOCAL SPECIES SUITABILITY FOR RANGIA LARVAE - MID SABINE LAKE SITE, 1980

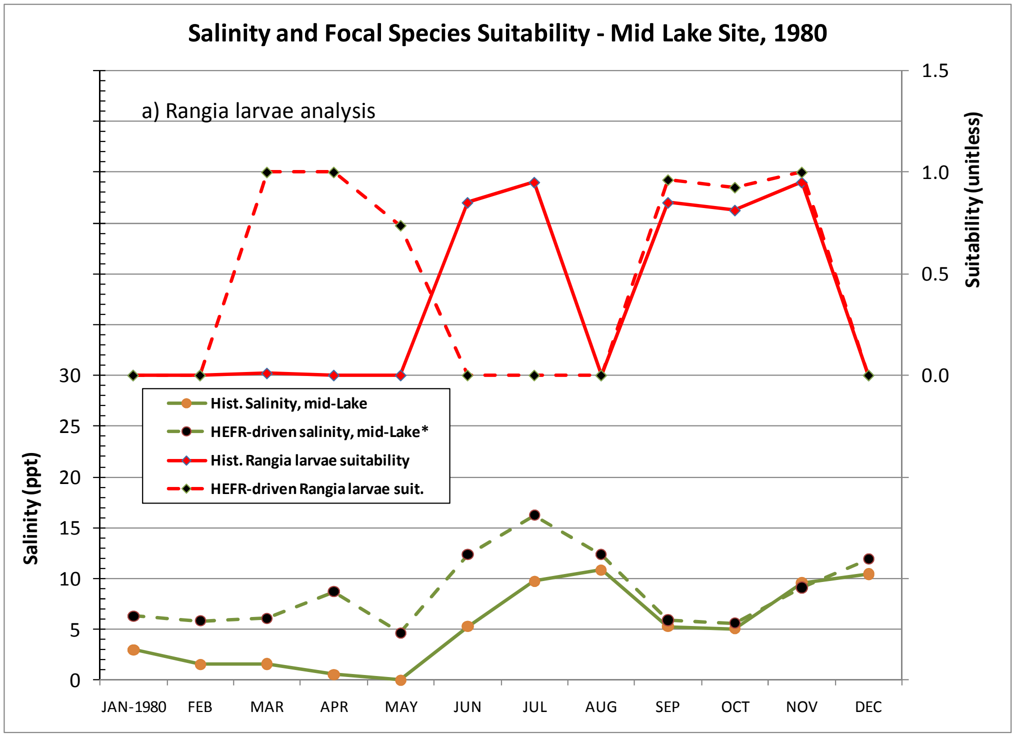


FIGURE 17. SALINITY AND FOCAL SPECIES SUITABILITY FOR BLUE CRAB JUVENILES- MID SABINE LAKE SITE, 1980

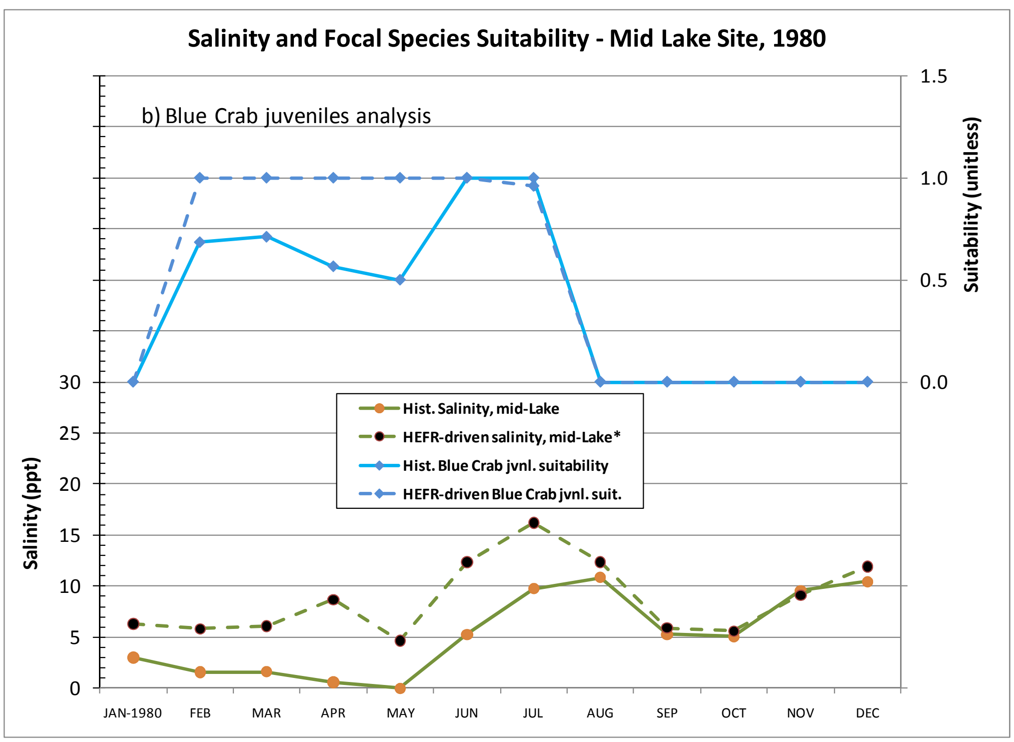
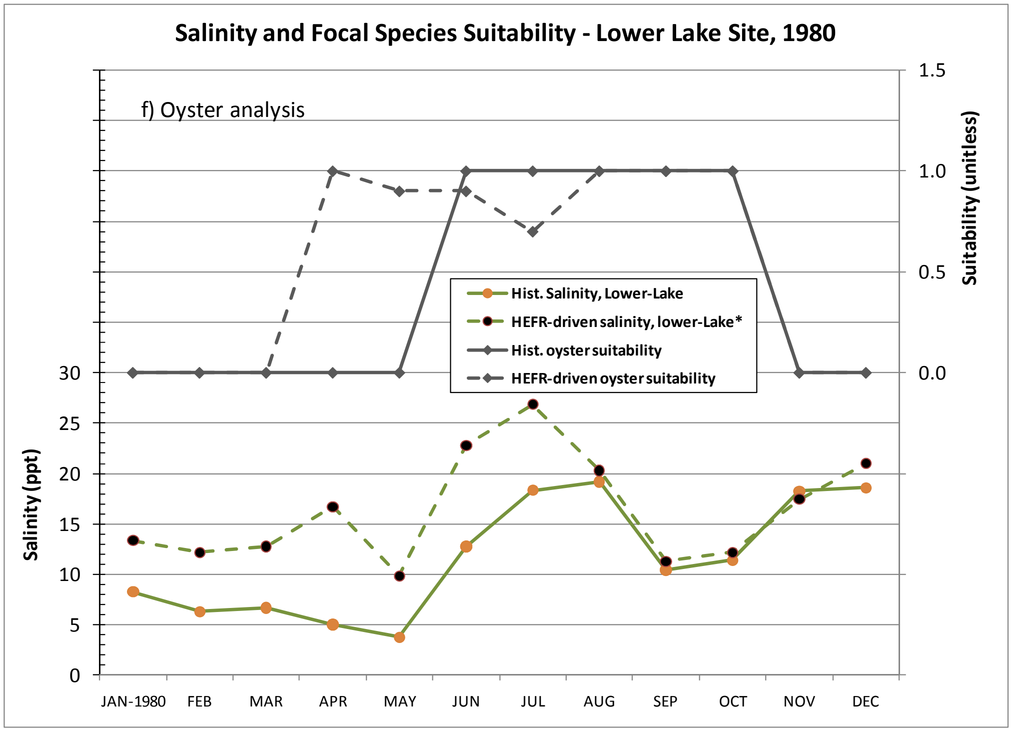


FIGURE 18. SALINITY AND FOCAL SPECIES SUITABILITY FOR OYSTERS - LOWER SABINE LAKE SITE, 1980



Discussion of Estuarine Inflow - Focal Species Findings

Generally, the base average conditions, represented here by the "base average and high-tier seasonal pulse" analyses, appear to be reasonable in terms of the average salinity suitability for *R. cuneata*, blue crabs, oysters, and brackish marsh. The average salinity suitability for these four key species and communities vary among years, but the overall average for the thirteen years are not greatly different when comparing the historical conditions to the HEFR-based conditions. In fact, conditions for blue crabs and oysters, both tolerant euryhaline species, might improve based on these analyses.

The most significant area of concern for the base average conditions was with the marshland species and community that are less salinity tolerant: the Olney bulrush and intermediate marsh. Both the upper- and mid-Sabine Lake areas showed significant reductions in salinity suitability on average for this species and the intermediate marsh community.

With subsistence flows for a four-month period, they concluded that there would be more potential for widespread deleterious impacts, although presumably on a less frequent basis. Assumed subsistence flows did not include periodic dry base flows. Since one assumes these very low inflows would occur in what is already a very dry year (e.g. one similar to 1967), essentially the HEFR-derived inflows amplify an already bad situation for most of the key species and communities. For instance *R. cuneata* suitability moved from an already poor value of about 0.2 to just 0.06 on average at the upper lake site for the 4 very dry years. Even for these four driest years of the historic record, there was some portion of the year in which *R. cuneata* reproduction (larval survival) was possible at the upper lake site. However, under the "subsistence" inflow scenario, three of the four years would lose even this limited suitability. A somewhat lesser, but still substantial, decline in *R. cuneata* suitability was evident at the mid-Sabine Lake site.

Unlike the analysis at "base average" conditions, "subsistence" inflows would be expected to result in a significant deleterious impact on the brackish marsh communities according to their analysis. Conditions for the less salinity tolerant Olney bulrush and intermediate marsh are already so poor, even under historic conditions in these very dry years, that the incremental effects of the "subsistence" inflows are small. Finally, under the "subsistence" inflow conditions, there were significant declines in salinity suitability conditions even for blue crabs and oysters.

5.2.3.2 The State Methodology for Estimating Freshwater Inflow Needs of Bays and Estuaries

General Procedure

The TWDB and the TPWD are responsible for determining the total inflow to each bay necessary "...for the maintenance of productivity of economically important and ecologically characteristic sport or commercial fish and shellfish species and estuarine life upon which such fish and shellfish are dependent," referred to as "beneficial inflows" [TWC §11.147]. The State Methodology is documented in an extensive report (Longley 1994), consisting of many components of study, data compilations and analyses, and modeling. The methodology arrives at a solution for a given estuary that is a sequence of monthly flows that will achieve a specified "goal". Central to the inflow determination are two sets of relationships:

1. salinity at selected locations in the estuary as a function of inflow, and
2. abundances of several key species as a function of inflow. Both of these are determined by a statistical fit to data.

For the salinity-inflow relationship, a multivariate linear regression is used on two independent inflow variables, the monthly mean flows corresponding to, and preceding, the date of salinity measurement. More important is the relation between inflow and the abundance of key species. For further discussion of the State Methodology, see the Sabine-Neches BBEST Biological Overlay Discipline Report (Appendix XIII).

5.2.3.3 Comparison of HEFR-Generated Freshwater Inflows to Sabine Lake with Freshwater Inflow Requirements Based on the State Methodology

A HEFR hydrological analysis was performed on inflows into Sabine Lake was performed under contract with the Sabine-Neches BBEST by FNI (FNI 2009b). The flow data consisted of historical daily flows from the selected study gages Village Creek near Kountze, Neches River at Evadale and Sabine River near Ruliff, plus the USGS gages Pine Island Bayou near Sour Lake (08041700) and Cow Bayou near Mauriceville (08031000). The historical daily gage flows were added to estimated ungaged inflows obtained from the TWDB. The ungaged flows consist of monthly data for the period from 1941 to 2005. These flows were distributed to daily using historical flow patterns from the Kountze gage. TWDB also has monthly estimates of diversions and return flows for the ungaged data. These data were distributed evenly throughout each month and the diversions were subtracted and the return flows added to the daily flows. TWDB also has historical monthly precipitation and evaporation estimates for Sabine Lake. These data were not included in the inflows. The median net precipitation on Sabine Lake (precipitation – evaporation) for the 1941 to 2005 period averages about 49,000 acre-feet per year, which is less than 1 percent of the average annual flow into the Sabine Lake.

Table 7 (page 60) compares the annual volume from the HEFR runs using the percentile-based approach for Sabine Lake to the annual volume for MinQ, MaxC and MaxQ from the State Methodology for bay and estuary inflows. HEFR matrix volumes for each flow condition (25^{th} percentile, median or 75^{th} percentile) are shown for base flows only, base plus pulse flows and with the entire HEFR overbank event added to each condition. Subsistence flows have not historically occurred during the winter and spring months. In these months the fall HEFR result was used to calculated volumes.

Comparing HEFR-generated flow components to the State Methodology shows that the HEFR 25th percentile (dry) conditions are less than the MinQ unless an overbank event occurs during the year. Base + pulse flows for median (average) conditions are less than MinQ for the Full Period and Pre-dam time periods, but are more than MinQ for the Post-dam period. MaxC values are only exceeded for the median (average) condition if an overbank event occurs during the year. The 75th percentile (wet) condition is relatively close to the MaxQ even without the occurrence of an overbank flow.

Most of the volume entering Sabine Lake is included in the base flow component. The base flow by itself is about 70% of the Base + Pulse volume in the 25th percentile (dry) conditions and over 90% for 75th percentile (wet) condition. Post-dam HEFR results have higher volumes than the Full Period or Pre-dam results.

Figure 12 (page 61) compares the seasonal distribution of the HEFR volumes to the seasonal distribution using the State Methodology. The monthly State Methodology values were summed by the same seasons used in the HEFR analysis. The distribution for the HEFR volumes without overbank flows is similar to the State Methodology, with the highest flows occurring during the winter months and the lowest during the summer months. The occurrence of an overbank flow can significantly alter the distribution, however. The HEFR volumes are for the Full Period of record. The Pre-Dam and Post-Dam periods have similar results.

5.2.3.4 Impacts of Oil and Gas Exploration and Ship Channel Dredging on Salinity and Ecological Dynamics in Sabine Lake and Fringing Wetlands

Changes to the Sabine-Neches Estuary (Sabine Lake) began in the 1870's with navigation channels being cut through the offshore bar at the mouth of both Sabine Pass and Calcasieu Pass (Morton 1996; U.S. Army Corps of Engineers 2004). These navigation channels have been maintained and enlarged ever since. The current SNWW completed in 1972 consists of a 40-ft channel to the Port of Beaumont and a 30-ft channel to the Port of Orange. The Calcasieu Ship Channel is maintained at 40-ft depth and 400-ft width. The GIWW completed in 1933 (Sutherlin 1996) and other canals through the marsh have linked Sabine Lake to Calcasieu Lake in multiple locations (Paille 1996). Some of these connections have been plugged (rock weir control structures) by restoration efforts but the two systems are still linked.

Today the Sabine-Neches Estuary and the Calcasieu Estuary cannot be viewed separately. The system is a marsh at its center cut by an impressive network of canals and secondary channels with many open water areas therein, bracketed by deep water channels to the east and west, with a shallower channel cut through the north end (GIWW) and a chenier ridge to the south protecting it from the Gulf of Mexico. The Sabine National Wildlife Refuge occupies some 125,000 acres in the middle stretching from the east shore of Sabine Lake to the west shore of Calcasieu Lake, with three man-made impoundments totaling 33,000 acres (largest being 30,000 acres). The proximity of the channel to the east (Calcasieu Ship Channel) seems to have a greater effect on the marsh than the channel to the west (SNWW) which is protected somewhat by a spoil bank and Sabine Lake. This is evidenced by salinity data showing higher numbers on the east side of the marsh than the west (Paille 1996). These navigation channels affect the Sabine-Neches Estuary in at least two ways. First during times of high tide they allow saltwater to intrude into the estuary and further upstream into the rivers, lakes, bayous, the GIWW and marshes. Secondly, during times of flooding they move fresh water out of the estuary more quickly reducing the amount of marsh land flooding; thereby, giving less retention time for fresh water flows and the accumulation of sediments in the marsh (Boesch, Josselyn et al. 1994, and references therein). The GIWW allows water to infiltrate the marsh through unprotected locations. At times of low flow and high tide, which in this area means a strong southerly wind, saline waters move up the deep channels of the SNWW and the Calcasieu Ship Channel and into the GIWW. Saline waters also flow into Sabine Lake through connections with the SNWW at the north and south end of the Lake as well as the lower Sabine and Neches Rivers. This sometimes leaves the center of the lake fresher than either end. These saline waters then move into the marshes though canals and secondary channels from the GIWW, the Calcasieu Ship Channel and Sabine Lake. These canals, dredged for the petroleum operations, have had a devastating effect on the marsh by allowing saltwater intrusion into the marshes; and are a "source of erosive energy on the surrounding marsh" (Boesch, Josselyn et al. 1994, and references therein) with subsequent land subsidence in some areas resulting in loss of vegetation and erosion of organic soil. Open water lakes have formed in the marshes that have become increasingly unstable and continue to degrade into larger open-water areas under existing conditions (Boesch, Josselyn et al. 1994, and references therein; Tatum 2009). Today the amount of wetlands lost from coastal Louisiana and Texas is staggering. These canals have been estimated to be responsible for the majority of this loss (Scaife, Turner et al. 1983).

During periods of normal and high flows, fresh water as expected freshens the rivers and lakes but is expedited to the Gulf through the enlarged openings of both navigation channels. It is uncertain how much freshwater inflows affect the marshes other than freshening the canals. However, precipitation seems to contribute most of the fresh water to the marsh as shown by salinity data (Paille 1996).

5.2.4 Adaptive Management

SB 3 envisions an adaptive management process for revisiting the environmental flow standards and environmental flow set-asides derived through the TCEQ rulemaking procedure. The SB 3 adaptive management process envisions that additional data, information, and studies will be necessary in order to make informed decisions regarding future changes to environmental flow recommendations. The on-going TIFP studies will provide useful information, but more research will likely be needed. In particular, dependence upon hydrology-based environmental flow recommendations, which may be largely required to meet the aggressive time frames specified in SB 3, highlights the need for future adaptation of the adopted flow standards. While application of the pre- and post-biological overlay process can substantively improve the hydrology-based recommendations, future refinements and validation will accrue only from the use of new and better science developed through the adaptive management process.

The Biology Overlay Subcommittee has identified several priority areas for research that would greatly assist in filling critical information gaps.

1. More data and improved knowledge of the ecological conditions and responses to flow variation are needed for the zone between the subsistence flow and dry base flow thresholds for each season. Field studies are needed in multiple stream and river segments of the basins to reveal relationships between key environmental parameters and biotic components during periods of low flow.
2. Additionally, more thought and deliberation are needed regarding alternative implementation guidelines (policies) for water diversions as flows change within the zone lying between the thresholds for subsistence and dry base flows. The concern here is that diversions under dry-year base flow conditions could drive flows to the subsistence flow threshold for long periods of time.

The subsistence flow defines a very rare occurrence, on the order of the lowest 1-2 percentile of all recorded flows.

3. More research is needed to establish, with greater precision and accuracy, the relationships between discharge and inundation of riparian bottomland hardwood and wetland zones of the floodplain. The Subcommittee was only able to obtain data for a limited number of stream and river segments, but more aerial images may be available for analysis, and additional high quality images should be obtained in the future.
4. Research is needed to quantify relationships between flow pulses (timing, duration, frequency) and reproduction and recruitment of important fish populations, within mainstem and tributary segments of the basins. Research is needed for species that complete their life cycle within the main channel as well as those that use both channels and backwaters (aquatic floodplain habitats).
5. More research is needed to establish relationships between the freshwater inflows established under the fluvial environmental flow recommendations and biological components of Sabine Lake. Given the heterogeneity and diversity of the estuarine ecosystem, focal species should receive greatest attention.
6. Relationships between freshwater inflows and salinity in fringing marshes, especially in the northern regions of Sabine Lake are needed. The influence of wind, tides, and depth of human-constructed channels on salinity dynamics in these regions should be examined.

5.2.5 BIO-WEST Ecological Review

BIO-WEST, Inc., was awarded contracts to assist in identification of focal species for fluvial and estuarine habitats that have characteristics representative of the majority of the flow-sensitive biota in the Sabine and Neches Basins and the Sabine-Neches Estuary. Focal species were selected by BIO-WEST, in collaboration and coordination with the Biological Subcommittee of the Sabine-Neches BBEST and state agency personnel involved in the TIFP. An attempt was made to select species which are known to be flow-dependent, use a variety of habitats, and exhibit multiple feeding and reproductive strategies. Special consideration was given to species of conservation concern, and economically important sport fish.

5.2.5.1 Fluvial

The purpose of the Bio-West Fluvial Focal Species Summary Report (BIO-WEST 2009b, Appendix VII) was to summarize information for select focal species regarding:

- Basic life history and ecological information including environmental requirements for reproduction and recruitment into adult populations and habitats used by various life stages;
- Spatial and temporal trends in population abundance or biodiversity within the basins (where available); and
- Key relationships between flow variation and the ecology of the species at the individual or population level.

Focal Species Selection

Eighteen riverine focal species were chosen to support environmental flow recommendations of the Sabine-Neches BBEST. The list of focal species was collectively identified by BIO-WEST in collaboration and coordination with the Biological Subcommittee of the Sabine-Neches BBEST, and state agency personnel involved in the Texas Instream Flow Program (TIFP). Expert opinion on freshwater mussels was also gathered from researchers at local universities (Dr. Neil Ford, UT-Tyler; and Charles Randklev, University of North Texas). Focal species included 14 fish taxa, two mussel species, and two floodplain vegetation species (Table 9).

TABLE 9. FOCAL RIVERINE/FLOODPLAIN SPECIES IDENTIFIED TO SUPPORT INSTREAM FLOW RECOMMENDATIONS OF THE SABINE-NECHES BBEST

Common Name	Scientific Name	River/Trib/Floodplain	Unique Distribution in Texas	Species of concern	Sportfish
paddlefish	*Polyodon spathula*	River	Limited	Yes	--
white bass	*Morone chrysops*	River	--	--	Yes
flathead catfish	*Pylodictis olivaris*	River	--	--	Yes
shoal chub	*Macrhybopsis hyostoma*	River	--	--	--
emerald shiner	*Notropis atherinoides*	River	--	--	--
blue sucker	*Cycleptus elongatus*	River	Limited	Yes	--
spotted bass	*Micropterus punctulatus*	River/Tributary	--	--	Yes
dusky darter	*Percina sciera*	River/Tributary	--	--	--
sabine shiner	*Notropis sabinae*	River/Tributary	East TX	--	--
harlequin darter	*Etheostoma histrio*	Tributary	East TX	--	--
freckled madtom	*Noturus nocturnus*	Tributary	East TX	--	--
ironcolor shiner	*Notropis chalybaeus*	Tributary	East TX	Yes	--
alligator gar	*Atractosteus spatula*	River/Floodplain	--	Yes	--
black/ white crappie	*Pomoxis spp.*	River/Floodplain	--	--	Yes
Texas pigtoe	*Fusconaia askewi*	River/Tributary	East TX	Yes	--
pistolgrip	*Tritogonia verrucosa*	River/Tributary	--	--	--
overcup oak	*Quercus lyrata*	Floodplain	East TX	--	--
water tupelo	*Nyssa aquatica*	Floodplain	East TX	--	--

5.2.5.2 ESTUARINE

The Estuarine Focal Species Summary Report's (BIO-WEST 2009a, Appendix VII) goal was to:

- Summarize the dependencies of focal species with regard to habitat conditions, especially as affected by freshwater inflow variation, salinity patterns and seasonality;
- Provide graphical or tabular summaries of population abundance or biodiversity trends within the estuary; and
- Describe key relationships between inflow and salinity variation and the ecology of focal species at the individual or population level

Sabine-Neches Estuary Focal Species

Ten estuarine focal species were chosen to support environmental flow recommendations to the Sabine-Neches BBEST. The list of focal species was collectively identified by BIO-WEST in collaboration and coordination with the Biological Subcommittee of the Sabine-Neches BBEST, state agencies involved in the Texas Bays and Estuary Study Program, Louisiana Department of Wildlife and Fisheries (LDWF), and local universities.

Table 10, below, lists the selected species and a summary of the inflow-related traits for each species this table is from the BIO-WEST, Inc., Estuarine Focal Species Report (Appendix VII).

TABLE 10. ESTUARINE-DEPENDENT FOCAL SPECIES INTENDIFIED TO SUPPORT ENVIRONMENTAL FLOW RECOMMENDATIONS OF THE SABINE-NECHES BBEST

Wetland Plants	Bivalve Mollusks
Olney bulrush (*Schoenoplectus americanus*)	Atlantic rangia (*Rangia cuneata*)
Saltmeadow cordgrass (*Spartina patens*)	American oyster (*Crassostrea virginica*)
Crustaceans	**Fish**
White shrimp (*Litopenaeus setiferus*)	Atlantic croaker (*Micropogonias undulatus*)
Brown shrimp (*Farfantepenaeus aztecus*)	Spot (*Leiostomus xanthurus*)
Blue crab (*Callinectes sapidus*)	Gulf menhaden (*Brevoortia patronus*)

5.2.6 NATIONAL WILDLIFE FEDERATION

Voluntary work performed by the National Wildlife Federation and their consulting firms was provided to the Biology Subcommittee of the Sabine-Neches BBEST.

5.2.6.1 NATIONAL WILDLIFE FEDERATION *RANGIA* STUDY

Salinity Suitability Analyses of *Rangia cuneata* and Other Characteristic Species and Communities of the Sabine-Neches Estuary in Order to Develop a Freshwater Inflow Regime. The NWF provided this report in support of the efforts of the Sabine-Neches BBEST to develop an estuarine inflow regime for the Sabine-Neches Estuary. Much of the information is summarized in the Biology Subcommittee's report (Appendix XIII) and the full NWF report is provided in Appendix XVI.

5.2.6.2 National Wildlife Federation Bottomland Hardwood Forests Study

"Analyses of Satellite Imagery in the Sabine and Neches River Basins in Support of Developing Overbank Instream Flow Recommendations for the Maintenance of Bottomland Hardwood Forests."

Bottomland plant species often have characteristics allowing them to tolerate conditions such as flooding that are not as well tolerated by upland or invasive species. Periodic flooding thus benefits certain species adapted to these habitats. A second NWF report done for the Sabine-Neches BBEST provided satellite imagery analyses on overbank events for their beneficial bottomland forest inundation characteristics at several sites. This report is also referenced by the Biological Subcommittee report in Appendix XIII and the full NWF report is provided in Appendix XVII.

5.3 Geomorphology (Sediment Transport)

Fluvial sediment transport has been widely recognized as an important process to maintaining a sound ecological environment within both alluvial and estuarine environments. The TWDB has conducted studies of sediment transport and geomorphological characterization within Texas river systems starting in the late 1990's and has continued those studies into this decade, especially as it relates to the SB 2 program. As a part of this SB 3 process, the Sabine Neches BBEST has reviewed these historical studies by the TWDB and the conclusions of those studies have been summarized in this section of the report. The Sabine Neches BBEST has also reviewed the guidance documents developed by the SAC that address fluvial sediment transport. These guidance documents recommend certain analyses that are considered useful to the environmental flows allocation process as it relates to sediment transport. Appendix XIV contains the complete Geomorphic Overlay discipline report for the Sabine-Neches BBEST.

5.3.1 Recent Senate Bill 2 Studies

5.3.1.1 Geomorphic Processes, Controls, and Transition Zones in the Lower Sabine River, Final Report, June 2007

The TWDB retained Jonathan D. Phillips PhD and Michael C. Slattery, PhD to conduct a study of geomorphic processes, controls, and transition zones in the lower Sabine River as a part of the SB2 work program (Phillips and Slattery 2007). The specific objectives of the study were to:

- Develop a baseline characterization of the condition and behavior of the lower Sabine River (downstream of Toledo Bend reservoir);
- Examine longitudinal (downstream) changes in flow processes and energetics, channel and valley morphology, and patterns of recent geomorphic change;
- Classify the lower Sabine (based on items 1, 2) into geomorphic process zones;
- Identify the primary controls—both contemporary and historic—of the geomorphic process zones; and
- Identify the current location, primary controls over, and potential future changes in critical transition zones.

The primary findings of this study are outlined here.

Sediment Discharge

Measurements of sediment concentration and transport are rare for the lower Sabine River. The USGS collected depth-integrated suspended sediment samples at the Sabine River nr Ruliff (Ruliff) station for the 1974-1995 period. A summary of these measurements is given in Table 3 in (Phillips and Slattery 2007). Using reservoir survey data from the upper Sabine basin to estimate delivery of eroded sediment to streams, Phillips (2003) found that if all sediment delivered to channels were transported by the river it would imply sediment yields of more than 400 t km^{-2} yr^{-1}. This is at least an order of magnitude higher than is typical of the region, and is larger than the 159 t km^{-21} recorded in the Trinity River over the 1936-1946 period, which represents the highest suspended sediment yield for the lower reaches of a major river in Texas over a period of years (Solis, Longley et al. 1994). The low sediment yield at Ruliff (8.9 t km^{-2} yr^{-1}) is not unusual for streams in the southeast Texas coastal plain (see Table 4. Measurements and estimates of fluvial sediment yields in southeast Texas in (Phillips and Slattery 2007)).

Estuary Sediment Delivery

Ravichandran, Baskaran et al. (1995) determined sedimentation rates in Sabine Lake using 239,240Pu profiles, which were 4 to 5 mm yr^{-1} in both the upper and lower estuary. If this is extrapolated over the entire 53,349 ha (131,828 acres) surface area of the estuary, assuming a density of 0.7 t m^{-2}, it implies a sediment yield of nearly 37 t km^{-2} yr^{-1} for the entire upstream drainage area of Sabine Lake, which includes the Neches as well as the Sabine River—if all the sediment comes from those two rivers. A significant portion of the sedimentation, however, likely comes from autochthonous organic matter, shoreline erosion, marine and coastal sources, reworking of bed sediments, and local fluvial inputs from coastal watersheds (Phillips and Slattery 2006).

According to TCB|AECOM (2006, p. 6-6), the Sabine and Neches Rivers discharge “large quantities of fine muddy sediment” into Sabine Lake, with “very little bedload sand … transported along the lower Neches and Sabine Rivers.” Mud-rich freshwater, especially during floods, spreads extensively across the upper lake area and reduces salinity. During floods, suspended sediment may reach the Gulf, but most is deposited within Sabine Lake. Within the lake, sandy bedload sediment is generally restricted to small areas near river mouths (TCB|AECOM 2006, p. 6-6). However, the extent to which suspended sediment in the lake is derived from river inputs is unknown.

Stream Power

The relative sediment transport capacity of streams is directly related to stream power, which for a cross-section is given by

EQUATION 1. RELATIVE SEDIMENT TRANSPORT CAPACITY OF STREAMS

$$\Omega = \gamma Q S$$

where γ is specific gravity of water, Q is discharge, and S is energy grade slope.

For the gaging stations at Burkeville, Bon Wier, and Ruliff, stream power for the bankfull, flood stage discharges were calculated, using channel bed slopes calculated from the Digital Elevation Model (DEM) in the immediate vicinity of the gaging stations (from three to four meander wavelengths upstream to a similar distance downstream of the site). As discussed earlier, bankfull or flood stage flows occur at different frequencies at each site. However, beyond being a convenient reference, bankfull flow may represent the maximum net downstream sediment transport.

Results (Table 11, below) (Phillips and Slattery 2007, Table 5) show a significant decrease in stream power between Burkeville and Bon Wier, with an increase at Ruliff, due to channel slopes about double those at the upstream sites. At the Ruliff station, however, channel slope from the DEM likely overestimates the energy grade slope due to the thalweg being cut to below sea level, and the tidal backwater effects. Similar calculations for 50, 10, and 1 percent probability flows show comparable stream power at Burkeville and Bon Wier, with apparently higher power at Ruliff.

To overcome the limitations of using channel slopes calculated from digital elevation data, stream power was calculated for several specific times during the October 2006 flood event. For any specific time, gage heights at the Bon Wier and Ruliff stations, the gage datums, and the distance between stations allows calculation of the mean water surface slope. These calculations were made for the point at which flow at Ruliff went overbank (Q = 516 m^3 sec^{-1}), the peak flow at the site (Q = 1640), and the beginning of the falling limb (Q = 492). Results, below, show stream powers at near bankfull flow (Qbf = 510 m^3 sec^{-1}) considerably lower than bankfull stream power at the upstream stations. Such a reduction in sediment transport capacity downstream is common in the lower coastal plain reaches of other rivers in Texas and elsewhere (Phillips and Slattery 2007; Phillips and Slattery 2006).

TABLE 11. CROSS-SECTIONAL STREAM POWER (Ω) FOR BANKFULL FLOWS, BASED ON CHANNEL SLOPES

	Burkeville	Bon Wier	Ruliff
Slope	0.0004	0.00034	0.00079
Q (m^3 sec^{-1})	1880	793	510
Ω (W m^{-1})	7.3696	2.6423	3.9484

TABLE 12. CROSS-SECTIONAL STREAM POWER AT SABINE RIVER NR RULIFF DURING OCTOBER 2006 FLOOD EVENT, BASED ON WATER SURFACE SLOPES

	Slope	Q (m3 sec-1)	Ω (W m-1)
Beginning of overbank flow	0.00015	516	0.7452
Peak flow	0.00013	1640	2.0374
Receding limb	0.00010	492	0.5068

Summary and Conclusions

Flows in the lower Sabine River are affected by the climate and hydrologic response of the drainage basin, releases from Toledo Bend Reservoir, water withdrawals, and tidal and coastal backwater effects. Releases from Toledo Bend create a highly pulsed discharge regime, but the effects exhibit both spatial and temporal decay. The influence of dam releases on flow is reduced downstream—dam releases dominate flow at the Burkeville gaging station, but are superimposed on patterns determined by watershed runoff at Ruliff. Dam releases are most influential during dry, low-flow periods, and hydrographs reflect runoff responses during wet, high-flow periods. The effects of the dam are most evident on an hour and daily time scale, and do not substantially influence monthly or annual mean flows, or peak flows.

Water diversions have significant impacts on flows, but such effects have been less in recent decades (see fig. 4), and either do not have discernible effects on freshwater inflows to Sabine Lake, or any effects have been offset by climatic trends. Coastal backwater effects are strongest at Sabine Lake, declining in importance upstream. These effects are evident, however, as far upstream as Ruliff and beyond.

Overbank flow—and the associated alluvial sedimentation—is increasingly common further downstream of Toledo Bend. The most important feature of the lowermost, deltaic portion of the river is the complex and changing patterns and routing of flow. A majority of flow between Cutoff Bayou and the Sabine/Old River confluence is carried by the Old River channel. The potential geomorphic causes and implications of this are addressed in the next section.

Sediment transport data are scarce, but records from the Ruliff station indicate low sediment yields that are considerably less than delivery of sediment to the fluvial system. This in turn suggests significant alluvial sediment storage, which is consistent with the extensive and active alluvial floodplains in the lower Sabine, and increasing overbank flow occurrence and decreasing stream power further downstream.

5.3.1.2 Geomorphic Equilibrium in Southeast Texas Rivers, Final Report, November, 2007

The TWDB retained Jonathan D. Phillips, PhD to address the geomorphic equilibrium of the coastal plain portions of the Brazos/Navasota, Trinity, and Sabine Rivers, Texas (Phillips 2007). Equilibrium concepts are of major theoretical importance in fluvial geomorphology, but also have critical applied implications. River management, assessment, engineering, and classification are often based on concepts of geomorphic equilibrium, and implicit or explicit assumptions that fluvial systems are in, or develop towards, some form of equilibrium.

However, the assumption of equilibrium (or tendencies toward it) is not always valid and is increasingly criticized as a reasonable assumption for models and assessments. Further, equilibrium is variously and sometimes poorly defined. The purpose of this study was to critically review the concept of equilibrium in fluvial systems in general, and in the specific context of southeast Texas. Rigorous definitions of geomorphic equilibrium were developed and applied to the study rivers, with particular reference to fluvial response to environmental change, and to implications for the TIFP.

Conclusions

The conclusions of this study were notable in regards to this SB 3 effort and are repeated here.

> *Relaxation time equilibrium may be present in the rivers of southeast Texas, and the presence (or absence) of RTE is useful in assessing river conditions and in the application of analytical techniques and models. Characteristic form and steady-state equilibrium are far less common, and clearly cannot be assumed. In general, no inherent tendency toward any stronger form of equilibrium – characteristic forms, steady-states, grade, etc. – can be assumed, at least not in the form of any single characteristic or stable equilibrium state.*
>
> *Equilibria are arguably useful as a reference condition, but should not be assumed to necessarily be any more common, important, or "natural" than disequilibrium or nonequilibrium states. Managers cannot assume that there is any single normal, natural, or otherwise normative condition for the alluvial rivers of the study area, and should recognize the possibility – indeed, the likelihood – of multiple modes of adjustment and potential responses to disturbance.*

5.3.2 Science Advisory Committee Recommendations

The SAC provided guidance for the inclusion of fluvial sediment transport as a possible overlay to the HEFR approach for determination of an environmental flow regime required by Texas SB 3. Although numerous sources associate the majority of fluvial sediment transport with high-pulse flows, the discussion and guidance provided by the SAC are not contingent on an exclusive association of sediment transport with HEFR-based high-pulse flows. In many cases, a healthy sediment regime can be associated either with overbank, high-pulse, or even base flows. The SAC provided a rationale and context to justify inclusion of a sediment transport overlay to the environmental flows allocation process, discussed various methods of assessment (including use of historical data), and recommended the effective discharge approach to assess sediment transport at gaging stations as further discussed below.

An analysis of effective discharge of suspended-sediment load (SSL), bedload, bed-material load, and/or total load at streamflow gaging stations is recommended by the SAC to potentially be used to modify HEFR-based flow prescriptions for establishing environmental flows. Specifically, a SAM (Hydraulic Design Package) analysis of effective discharge of bed-material load is suggested for assessments of instream habitat conditions and dynamics. For the majority of locations, the high-pulse flow or overbank-flow categories are expected to be associated with the cumulative majority of sediment transport over time. Sediment transport, although relatively straightforward in its association with discharge, does not encompass the breadth of fluvial geomorphic processes. Furthermore, concepts of steady-state equilibrium challenge assumptions that a constant discharge value is responsible for the cumulative majority of sediment transport over time. Finally, practitioners utilizing effective discharge for rivers in Texas are warned to be cognizant of the contemporary sediment-transport regime and historical channel adjustments at each location considered. Assignment of an effective discharge to altered or regulated rivers is recognized as being problematic and implementation efforts could be harmful if a holistic perspective (e.g., sediment trapped behind reservoirs, non-representative cross section to estimate bedload transport, etc.) is not considered.

The SAM Hydraulic Design Package is proposed as a very useful desktop tool to assist practitioners in modeling sediment transport and determining effective discharge at streamflow-gaging stations. It conveniently facilitates the choice of a sediment-transport model equation based on user input, and can be used to compare annual sediment loads for existing and HEFR-based hydrologic conditions. Although SAM is a useful tool to compare observed sediment-transport loads and effective discharge with HEFR-based conditions, little can be done using readily available desktop methods to prescribe a "sediment-load regime" that would adequately maintain instream ecology. The chief reason for this is the paucity of historically-observed geomorphic and sediment-transport data for rivers in Texas, contrasting with the availability of streamflow data for HEFR-based flow-regime analyses. Further, various fluvial processes (e.g., channel bar deposition and modification, channel migration, floodplain sedimentation) initiate and/or occur over a range of flows and, therefore, are dependent on sufficient rates of sediment transport during those flows. The unavailability of data for Texas rivers obfuscates the determination of optimized sediment concentrations or loads for these physically- and ecologically-relevant flows. At minimum, the practitioners responsible for environmental-flow prescriptions at a given site should be cautious if bed-material load is shown to be considerably reduced as a result of an implementable schedule of flows.

5.3.3 SAM Application

Under the SB 3 process for the Sabine-Neches BBEST, the TWDB performed an SAM analysis of effective discharge of sediment transport at several USGS gaging stations with in the Neches and Sabine basins (Sabine-Neches BBEST Geomorphology Overlay Discipline Report, Appendix XIV). At each gaging station, the effective discharge was computed using the methodology described in Biedenharn, Copeland et al. (2000) for three different flow scenarios:

1. The unadjusted historical period of record (HPOR);

2. HPOR modified by assuming present day operation of diversions and storage in the basin (also called TCEQ WAM Run 8); and
3. HPOR modified by assuming future operations of full permitted diversions and reservoir storage without any regulation or adjustment for proposed environmental flow regime permit controls (also called TCEQ WAM Run 3).

The results of these analyses are summarized in the table below and are outlined in more detail in Appendix XIV. It should be recognized that an analysis of effective discharge does not encompass nor entirely explain the breadth of fluvial geomorphic processes. Sediment transport, however, is a fairly straightforward process to relate with streamflow, and collection of sediment-transport data commonly occurs simultaneously with streamflow at a gaging station. Furthermore, computation of effective discharge based on bed-material load is the widely accepted method for evaluating changes in channel morphology. Effective discharge of suspended load offers comparatively less insight toward assessments of instream habitat conditions and dynamics.

TABLE 13. EFFECTIVE DISCHARGE AND HIGH FLOW PULSES

	WAM Run 8 Effective Discharge in cfs	Number of Days Flow is in Effective Discharge Bin	Highest Seasonal High flow Pulse	Duration of Highest Seasonal High Flow Pulse	HEFR Overbank Flow	HEFR Overbank Flow Frequency	Annual Duration of HEFR Overbank Flow Frequency
Sabine River Basin							
Ruliff	21760	19	9880	22	29000	1 per year	60
Bon Wier	19997	9	20600	17	28700	1 per year	28
Beckville	5960	15	7200	24	16100	1 per 2 years	45
Gladewater	5650	8	5,570	24	18,100	1 per 2 years	22
Neches River Basin							
Evadale	17622	5	8700	22	19500	1 per year	38
Rockland	5500	12	6910	22	18500	1 per 2 years	41
Chireno	1264	12	1200	12	7520	1 per 2 years	27

TABLE 14. EFFECTIVE DISCHARGE FOR RUN 8 AND RUN 3

Location	Run 8 Effective Discharge	WAM Run 8 Annual Water yield AC-FT	WAM Run 8 Annual Sediment Yield Tons	Run 3 Effective Discharge	WAM Run 3 Annual Water yield AC-FT	WAM Run 3 Annual Sediment Yield Tons	Sediment Function used
Sabine River Basin							
Ruliff	21760	6,146,000	284,688	21,065	4,222,000	144,000	ENGELUND-HANSEN
Bon Wier	19997	4,919,000	81,674	13,812	3,066,000	43,643	YANG,D50
Beckville	5960	1,731,000	111,579	5,961	1,393,000	81,675	ENGELUND-HANSEN
Gladewater	5650	1,213,000	300,433	5,437	969,000	206,775	ENGELUND-HANSEN
Neches River Basin							
Evadale	17622	4,718,000	279,335	16,202	4,237,000	221,440	YANG,D50
Rockland	5500	1,706, 000	154,333	5,406	1,469,000	130,108	YANG,D50
Chireno	1264	314,000	12,510	*	*		YANG,D50

5.3.4 Conclusions

In spite of the presence of major reservoirs within the Neches and Sabine River systems, recent geomorphological studies by the TWDB under the SB 2 program indicate that these systems are likely functioning normally for Gulf Coast riverine systems with regard to sediment transport. Except for relatively short reaches immediately below the reservoirs, the measurement of sediment concentration and transport are at levels that would be expected and desired for these systems, indicating a present level of health and a sound ecological environment as it relates to fluvial geomorphology. No adjustments to the HEFR regime for fluvial geomorphology were considered to be appropriate by the Sabine-Neches BBEST based on the detailed study for these systems provided by the TWDB under SB2 and on the limited analysis using the SAM application. Based on comparisons of the Effective Discharge for WAM Run 8 to the HEFR proposed by Sabine-Neches BBEST, evidence indicates that high-pulse flows and overbank flows will provide sufficient flow to maintain the existing dynamic equilibrium within these two riverine basins.

As expected, comparisons of WAM Run 8 to WAM Run 3 at each of the gaging stations analyzed for this study show a decrease in volume of water and sediment flow passing each gage. At Ruliff, the most downstream gage used in this study on the Sabine River, Run 3 average water volume is about 66% of the Run 8 volume and the sediment load for Run 3 is about 50% less on average than the Run 8 sediment load. The effective discharge at Ruliff remains about 21,000 cfs for both Run 3 and Run 8. This implies the channel geometry may change over time within this reach of the river because of the lesser amounts of flow and sediment transport in the channel; however, this change does not suggest inadequate sediment transport. Depending on the how the flow and sediment diversions occur upstream of Ruliff, the channel could remain relative stable or could change gradually. The effective discharge for Run 3 at Bon Wier is reduced by about 30% and the channel in this area could be impacted similar to Ruliff. The difference between the Effective Discharge and annual water and sediment yield for Beckville and Gladewater gages on the Sabine River, for the Evadale and Rockland gages on the Neches River, and for the Attoyac Bayou at Chireno gage do not indicate significant changes in channel bathymetry will likely occur as a result of the future upstream diversions. Further analysis at Ruliff and Bon Wier is advisable to better address the potential changes associated with such a large change in overall average flow. However, this is a worse than worst case scenario at Bon Wier and Ruliff since future conditions include like amounts of diversions directly from the reservoir for Louisiana which is a highly unlikely condition.

5.4 Application of Water Quality in Environmental Flows

Although water quality is an important aspect of environmental flow recommendations development, its application as an overlay to flow regimes identified by hydrologic analyses is not necessarily straightforward. Section 5.4 addresses the application of water quality to environmental flow recommendations for the Sabine and Neches River basins. Included are discussions of water quality regulations as applicable to environmental flows, the availability of water quality data in the basins, and the relationship of water quality to flow.

5.4.1 Regulatory Perspectives in Water Quality

The Clean Water Act (CWA) of 1972,[25] with a stated goal to "restore and maintain the physical, chemical, and biological integrity of the nation's waters", set in motion a regulatory framework that would enable a substantial change in the character of the nation's surface waters. The intervening years since the passage of the CWA have seen dramatic improvements in surface water quality throughout the country, primarily through reductions in pollutant discharges from point sources of pollution, such as industrial and municipal wastewater treatment facilities.

Certain water quantity data, such as flow or discharge, are available at each of the 12 USGS gages selected[26] for the Sabine and Neches River basins on, essentially, a daily basis. However, the development of environmental flows recommendations for these watersheds suffers from a lack of sufficient data to describe water quality conditions at subsistence flows. TCEQ's TCRP[27] addresses the need for water quality data with water samples being collected at a number of stations throughout the Sabine-Neches Study Area monthly or quarterly.

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[25] Clean Water Act (CWA) | Agriculture | US EPA, http://www.epa.gov/oecaagct/lcwa.html, retrieved November 7, 2009

[26] The 12 gages selected for study are all in freshwater and largely non-industrial areas upstream from the tidal portions of the Lower Sabine and Neches River Basins.

[27] TCEQ, Texas Clean Rivers Program: An Introduction, http://www.tceq.state.tx.us/compliance/monitoring/crp/. Both the LNVA and SRA-TX are TCRP Partners (see http://www.lnva.dst.tx.us/ and http://www.sratx.org/srwmp/tcrp/, respectively). Retrieved November 7, 2009

Linking water quality and environmental flows also requires consideration of the Texas Surface Water Quality Standards (TSWQS)[28] as currently applied. In streams and rivers, TSWQS for the protection of aquatic life are based on flows at or above a minimum flow level known as the 7Q2 flow – defined as the minimum daily flow for a 7-day period with a return period of two years. Although TSWQS do not apply at flows below the 7Q2, this does not imply that water quality cannot be maintained at flows lower than 7Q2.

The application of the TSWQS should not be confused with the development of environmental flow recommendations, particularly at subsistence flows or in base flow ranges. Subsistence flows and some base flows in the Sabine-Neches Study Area are well below the published 7Q2 flow. Available data demonstrates that water quality is generally good at flow levels at least as low as subsistence flows. It is neither necessary nor appropriate to use the 7Q2 flow, as published in the TSWQS, as a default subsistence flow in the environmental flow regime; as such, 7Q2 will not be so used in the SB 3 environmental flow recommendations for the Sabine and Neches River basins.

Appendix XII-1 summarizes Sabine and Neches Basin water quality impairments appearing on the 2008 Texas 303(d) List. None of the 12 gages selected for SB 3 consideration are listed as impaired for any water quality parameter that would be expected to be affected in any great extent by the level of environmental flow in the stream at the gage, or by future diversions of water from the stream at these locations.

5.4.2 Available Water Quality Data

Water quality data for the Sabine and Neches Rivers are made available primarily through the TCRP – administered by the governing river authorities for each basin – SRA-TX for the Sabine River Basin and LNVA and the ANRA for the Neches River Basin.

At the selected gages or nearby TCRP sampling locations, a variety of water quality parameters are routinely monitored under the TCRP, including dissolved oxygen (DO), water temperature, pH, alkalinity, total phosphorus, chlorophyll-a, conductivity, total dissolved solids, turbidity, and fecal coliform. The data reflect grab samples collected at the sites generally on a quarterly or monthly basis, although some parameters are monitored more frequently. This report has focused primarily on water quality data available at the selected gage sites in order to evaluate the relationship between flow and water quality. In the case of nutrient data, however, TCRP sampling stations near the selected gage locations were included.

In the case of DO, the lack of diurnal data that would show the true distribution of DO over the course of the day could present a problem for evaluating the potential impact of low DO on aquatic life in the streams. Fish, for example, can exist in water with DO concentrations of around 3 mg/L for short periods of time. However, prolonged exposure to low DO concentrations will adversely impact aquatic life. Studies designed to collect diurnal DO data[29] are underway as of this writing in the lower Sabine River Basin.

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[28] TCEQ, Texas Surface Water Quality Standards, http://www.tceq.state.tx.us/nav/eq/eq_swqs.html, retrieved November 7, 2009

[29] As part of the Federal Energy Regulatory Commission Relicensing process for hydropower production at the Toledo Bend Dam, the Toledo Bend Project Joint Operation has deployed data sondes at several locations below Toledo Bend reservoir in the river to study water quality on a continuous basis.

5.4.3 Flow and Water Quality Relationships

The USGS gages monitor flow on a continuous basis (i.e., 15 minute intervals); thus, flow-quality relationship can be established if there is a sufficient number of water quality data points collected when the flow gage is operational -- water quality data were, thereby, linked to river flow assessed as daily average discharge in cfs. The period of record for flow at each gage is generally significantly longer than that for water quality; and the water quality data periods of record are not equal for all gages, but range from as early as 1960 to 2009. There is no water quality data at any of these gages prior to 1960. Table 15 (page 96) summarizes the number of water quality data points available for each of the 12 selected gages in the Sabine-Neches Study Area.

Data collected at the 12 USGS gage locations were generally used for this analysis; however, data from both the USGS gages and nearby TCRP sampling stations were sometimes utilized to develop a sufficient number of flow-quality points for total phosphorus and chlorophyll-a. The TCRP stations selected were a short distance upstream or downstream from a gage and were not influenced by tributaries. Data agglomeration was performed in order to capture a sufficient number of total phosphorus and chlorophyll-a data for a more complete evaluation. Nutrient values from 1972 to 2008 were used in this analysis.

Using these data, the relationship of water quality to flow was evaluated. A graph of flow (on the abscissa) and quality (on the ordinate) was constructed for each parameter in Table 15. These graphs are contained in Appendix XII-1. For each gage, the subsistence flow, dry summer base flow, and wet winter base flow are shown, as well. The purpose of showing the subsistence flow and range of base flows is to highlight where water quality data collection has occurred with respect to these selected flows at each gage. Appendix XII-1 also provides a discussion of the observed relationship between the various water quality parameters and flow at the various gages.

TABLE 15. SUMMARY OF WATER QUALITY DATA AVAILABLE AT SELECTED GAGES IN THE SABINE AND NECHES RIVER BASINS

Gage Identification	Number of Available Water Quality Data Points for Each Water Quality Parameter [1]										
	Dissolved Oxygen	Water Temperature	pH	Alkalinity	Total Phosphorus	Chlorophyll-a	Field Conductivity	Laboratory Conductivity	Total Dissolved Solids	Turbidity	Fecal Coliform
Sabine Basin											
Big Sandy Creek near Big Sandy	93	215	NA	NA	26	11	117	190	11	11	1
Sabine near Gladewater	441	446	88	NA	12	NA	309	193	NA	NA	NA
Sabine near Beckville	294	317	123	NA	13	NA	292	236	NA	48	NA
Sabine near Bon Wier	377	1,965	281	121	20	55	1,266	2,293	73	NA	NA
Big Cow Creek near Newton	27	31	NA	NA	13	NA	30	16	NA	NA	NA
Sabine near Ruliff	920	1,172	1,025	643	25	45	793	684	264	90	164
Neches Basin											
Neches near Neches	194	320	197	115	47	38	184	441	43	NA	NA
Neches near Rockland	328	380	356	95	20	20	190	517	37	48	NA
Angelina near Alto	39	41	58	36	44	36	41	23	55	NA	NA

Gage Identification	Number of Available Water Quality Data Points for Each Water Quality Parameter [1]										
	Dissolved Oxygen	**Water Temperature**	**pH**	**Alkalinity**	**Total Phosphorus**	**Chlorophyll-a**	**Field Conductivity**	**Laboratory Conductivity**	**Total Dissolved Solids**	**Turbidity**	**Fecal Coliform**
Attoyac Bayou near Chireno	79	78	81	55	NA	NA	68	71	12	NA	NA
Neches at Evadale	494	528	806	307	94	40	355	742	292	107	132
Village Creek near Kountze	48	163	193	79	42	NA	89	233	8	NA	NA

(1) The data used for each gage are data collected at the specific gage, except for total phosphorus and chlorophyll-*a*. Data for these parameters came from the gages plus other nearby TCRP sampling stations.

5.4.4 Selection of Water Quality Parameters for Environmental Flow Recommendations

Although not all available water quality data provide information useful to the development of environmental flows, a few stand out as viable candidates because of their close relationship to maintenance of aquatic life. The SAC document "Essential Steps for Biological Overlays in Developing SB 3 Instream Flow Recommendations" (SAC 2009a) identifies water temperature, DO, pH, conductivity, and turbidity as parameters that are important to survival, growth, and reproduction of aquatic organisms. This document goes on, however, to focus on water temperature and DO as the primary parameters supporting survival and reproduction of aquatic life. The other parameters may constrain or limit the distribution and abundance of aquatic organisms.

Both DO and water temperature are easily and accurately measured with field equipment and as a result there are a significant number of data points available for each at the 12 gages. Furthermore, in comparison to most available water quality data, DO and water temperature have, by far, the greatest number of data points at the widest range of flows.

Some consideration was given to the selection of nutrient or nutrient-related data (i.e., total phosphorus and chlorophyll-a) as parameters for consideration in developing environmental flow recommendations. However, at this time, there is an insufficient body of data available for these parameters, particularly at base and subsistence flows, to effectively use them.

Therefore, based on these factors, DO and water temperature were considered by the Sabine-Neches BBEST as the primary water quality parameters in development of environmental flow recommendations. Appendix XII-2 summarizes DO and water temperature data for each gage. Using these parameters, environmental flow regime recommendations were evaluated for consistency with water quality.

5.4.5 Integrating Water Quality into Environmental Flow Recommendations

An environmental flow regime may cover a wide range of flows from subsistence and base flows on the lower end to high-flow pulses and overbank flows on the upper end. Water quality problems may exist at any or all of the flows. The question is, however; is there a critical range to consider with respect to DO and water temperature? If so, can water quality considerations be limited to this critical range? The graphs seen in Appendix XII-2 indicate that the relationship between flow and water quality is generally weak. Water quality in both the Sabine and Neches River basins typically meets Stream Standards within the range of flows for which data have been collected. This is true of DO and water temperature as well. Based on the data, DO concentrations throughout the range of flows are generally well above TSWQS criteria. Water temperature is more related to season than to flow, and is within an acceptable range for supporting aquatic life.

However, almost all of the available water quality data have been collected in the streams at flows at or above what has been identified as subsistence flow. As flows increase, the availability of data increases, but even the lower end of base flows generally have some data limitations. The available data suggest that water quality will generally be adequate to support an appropriate aquatic ecosystem even at subsistence flow. Therefore, while it can be presumed that water quality at flow levels expected in the stream most of the time will be good, extending that presumption to flows below subsistence levels could be problematic.

Subsistence flows lower or higher than those recommended for the basins could be justified, if sufficient data were available for evaluation. It is important, therefore, to prioritize additional sampling trips to better characterize water quality conditions during extreme low flow periods; and, as such, additional water quality study at low and subsistence flow is recommended.

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6 DEVELOPMENT OF ENVIRONMENTAL FLOWS RECOMMENDATIONS/ RECOGNITIONS/ UNRESOLVED ISSUES

SB 3 charged each BBEST with recommending an environmental flow regime adequate to support a sound ecological environment for each group's river basin and bay system. Over the allotted timeframe of 12 months, following available SAC guidance and SB 3 criteria, the Sabine-Neches BBEST, its flow discipline subcommittees, and the group's consultants used the best available science for the Sabine-Neches Basin Study Area to devise its flow regime recommendations.

During the course of the past year, it has become clear that the Sabine-Neches BBEST recommendation charge requires further clarity. Taking its charge from the "theoretical" to the "practical", the Sabine-Neches BBEST was able to make some specific environmental flow recommendations, while in other cases (for example overbank flows) the group agreed to recognize the ecological value of such flows but not recommend them. As indicated below, this process also involves unresolved issues, the need for future studies, and ultimately, adaptive management to address the unresolved issues. Section 6 contains the summation of the work of the Sabine-Neches BBEST with these observations.

- **Recommendations** – The Sabine-Neches BBEST has reached consensus and can agree by defining recommendations as a course of action that is recommended as advisable. For example, some elements of the flow regime such as subsistence flows may be recommended with an advisable course of action.
- **Recognition** – For some issues, the Sabine-Neches BBEST may be able to move forward with recognition of the value of a particular element of the flow regime where for example overbank flows provide a defined value to the ecological environment, but it has recognized that it cannot recommend them since they have the potential to cause extensive damage to private property and endanger the public.
- **Unresolved Issues** –The Sabine-Neches BBEST has been given a charge that contains an immense scope of work with limited resources and presents a huge challenge to accomplish in a very limited time frame; the group agrees that there are unresolved issues for which it will recommend future studies. For example, the group agrees that it has set a certain bar for subsistence flows and at the same time agree that these flows are placeholders pending future studies and work which would provide the information to fill data gaps.
- **Future Studies** – Agreement that available science in some areas is insufficient to draw the necessary conclusions at this time, and there is a need for future studies designed to address these unanswered questions.
- **Adaptive Management** – Adaptive management is a tool that provides for future corrections as they are defined and agreed to through specific studies.

6.1 Instream Flow Regime Application

6.1.1 Introduction

This section of the Recommendations Report summarizes key elements and considerations in the development and application of environmental flow regimes for the Sabine and Neches River Basins in accordance with the provisions of SB 3 of the 80th Texas Legislature. The Sabine-Neches BBEST expects that the TCEQ will consider direct translation of seasonal subsistence and base flow values within recommended flow regimes into environmental flow standards and, ultimately, consider such values as potential permit conditions applicable to new surface water appropriations. Permit conditions may be defined as a set of rules specifying when impoundment or diversion of streamflows is authorized under a specific water rights permit. The following subsections focus on key elements of a flow regime and relevant observations of the Sabine-Neches BBEST, example application of a flow regime, and consideration of attainment frequencies in flow regime application.

6.1.2 Elements of a Recommended Flow Regime

6.1.2.1 Subsistence Flows

Subsistence flows were initially calculated as the median of the lowest 10 percent of historical base flows by season using HEFR. Resulting subsistence flow values, and particularly those derived for the summer season, were compared to geographically proximate water quality sampling data maintained by TCEQ. Frequent violations of stream standards for dissolved oxygen and temperature have not occurred and would not be expected to occur at the statistically-derived subsistence flow values. Nevertheless, in order to maintain essential environmental features of fluvial ecosystems (e.g., minimal instream habitat to avoid extirpations of aquatic populations, moisture content of hyporheic zones for riparian vegetation) during periods of stress due to drought, the Sabine-Neches BBEST recommends that all seasonal subsistence flows be greater than or equal to the statistically-derived subsistence flow for the summer season at each reference gage location. Twenty-two cfs is used as the summer and fall seasonal subsistence flow at Beckville for compliance with Sabine River Compact minimum flow requirements at the state line (the statistically-derived values for the summer and fall seasons were 20 cfs and 19 cfs, respectively). As HEFR application generally did not produce a winter subsistence flow, the Sabine-Neches BBEST recommends, in the absence of data to indicate otherwise, use of the minimum daily flow value recorded during the winter season so long as it is greater than or equal to the subsistence flow for the summer season at each reference gage location.

Analysis of available hydrologic, biologic, geomorphic, and water quality data; and the exercise of best professional judgment, suggest that recommended subsistence flows will provide aquatic habitat, longitudinal connectivity, dissolved oxygen, and temperature sufficient to ensure survival of endemic species for transient periods. Active data collection and monitoring under subsistence flow conditions is recommended to more quantitatively assess the potential effects of extended periods of subsistence flows on native species.

It is the consensus of the Sabine-Neches BBEST that translation of seasonal subsistence flows into environmental flow standards and permit conditions should not result in more frequent occurrence of flows less than the recommended seasonal subsistence values as a result of the issuance of new surface water appropriations or amendments.

6.1.2.2 Base Flows

Seasonal base flow values for dry, average, and wet conditions were calculated using default HEFR application assumptions as the respective 25th percentile, median, and 75th percentile base flow values for each season. Resulting base flow values were compared to geographically proximate water quality sampling data maintained by TCEQ. Frequent violations of TSWQS criteria for dissolved oxygen and temperature have not occurred and would not be expected to occur at the statistically-derived base flow values.

Analysis of available hydrologic, biologic, geomorphic, and water quality data; and the exercise of best professional judgment, suggest that recommended base flows will provide variable flow conditions, suitable and diverse aquatic habitat, longitudinal connectivity, soil moisture, and water quality sufficient to sustain native species for extended periods.

The Sabine-Neches BBEST recognizes under implementation of these initial environmental flow thresholds for seasonal base flows, there would be water available for human uses (see analysis below). Our recommended base-flow thresholds allow for diversion and storage of water at all flow levels exceeding the base flow threshold as determined for a given condition (dry, average, wet). Thus, there may be extensive periods when flows are less than the historical levels associated with base-flow types of conditions. Also, because variation in rainfall and surface runoff results in natural flow variability in rivers of the Northern Gulf of Mexico Coastal Plains, periods of low flow during drought will cause flows to fall below the base flow threshold for the dry condition (discussed above under Section 6.1.2.1 Subsistence Flows). However, the implication of an environmental base-flow recommendation is that flows lower than these thresholds should not be the *direct* result of issuance of new surface water appropriations or amendments except under dry hydrologic conditions. ***The Sabine-Neches BBEST has proposed base-flow thresholds for environmental protection based on current scientific understanding of fluvial and estuarine ecosystems and the best data, studies, and interpretations available at this time. It is anticipated that as new studies and monitoring information become available, these base flow thresholds may be revised.***

6.1.2.3 Pulse Flows

Peak flow rates for high flow pulses with frequencies of two (2) per season and one (1) per season were calculated using the frequency-based method in HEFR. All recommended peak flow rates are limited to the Overbank Threshold identified in FNI HEFR Memo Table 2 (FNI 2009b) unless NWS data from FNI HEFR memo Table 3 (FNI 2009b) indicates bankfull or flooding conditions at a lower flow. Pulse durations were derived by the default (ln-ln) regression method in HEFR. Pulse volumes were derived by the default (quadratic) regression method in HEFR for reference gage locations where reasonable values were obtained for all seasons. Pulse volumes for all seasons at Ruliff and Evadale, however, were derived by the alternative (ln-ln) regression method. Similarly, the volume for the summer pulse with a frequency of 2 per season at Rockland was derived by the alternative (ln-ln) regression method.

Analysis of available hydrologic, biologic, geomorphic, and water quality data; and the exercise of best professional judgment, suggest that recommended pulses will provide high in-channel flows of short duration, recruitment events for organisms, lateral connectivity, channel and substrate maintenance, limitation of upland vegetation encroachment into riparian zones, and in-channel water quality restoration after prolonged low flow periods as necessary for long-term support of a sound ecological environment.

The Sabine-Neches BBEST understands that translation of seasonal pulse flows of specified frequencies into environmental flow standards and permit conditions may result in less frequent occurrence of high flow pulses as a result of the issuance of new surface water appropriations or amendments. Hence, the Sabine-Neches BBEST has derived recommended high flow pulses on the basis of historical seasonal frequencies and analysis of ecological processes associated with high flow pulses, but recognizes and accepts that the ultimate attainment frequency associated with each seasonal pulse event within the flow regime will often be less than that based on the historical frequency of occurrence derived by HEFR7.1 and shown in Figure 23 through Figure 34. Natural climatic variation will determine that the environmental flow targets for high flow pulses frequently will not be met. Several examples are provided below (Section 6.1.4). ***The Sabine-Neches BBEST recognizes such reductions in high flow pulses will be a consequence of the interaction between water use and natural variation in precipitation. The Sabine-Neches BBEST views these reductions as an acceptable environmental risk at this time and accepts that they are subject to review as new studies and information become available.***

6.1.2.4 Overbank Flows

Peak flow rates for overbank flow events with a frequency of one (1) per two (2) years were calculated using the frequency-based method in HEFR for all reference gage locations as shown in Figure 23 through Figure 34. Overbank event durations were derived by the default (ln-ln) regression method in HEFR. Overbank event volumes were derived by the default (quadratic) regression method in HEFR. On the basis of research conducted by NWF (Appendix XVII), overbank events with a frequency of one (1) per two (2) years were replaced with events having a frequency of one (1) per year at the Bon Wier, Ruliff, and Evadale reference gage locations as these more frequent events are of sufficient magnitude to exceed the bankfull condition and provide for substantial inundation of riparian bottomland hardwood areas.

Analysis of available hydrologic, biologic, geomorphic, and water quality data; and the exercise of best professional judgment, suggest that overbank flows will provide high flows exceeding channel capacity, life phase cues for organisms, riparian vegetation diversity maintenance, conditions conducive to seedling development, floodplain connectivity, lateral channel movement, floodplain maintenance, recharge of floodplain water table, flushing of organic material into the channel, nutrient deposition in the floodplain, and restoration of water quality in isolated floodplain water bodies as necessary for long-term support of a sound ecological environment. ***Overbank flows may, however, cause extensive damage to private property and endanger the public. Therefore, the Sabine-Neches BBEST recognizes the ecological benefits of these events, but cannot recommend that such events be produced. Hence, the Sabine-Neches BBEST does not recommend that overbank flows be included as part of an environmental flow standard or as future permit conditions due to concerns associated with flooding and liability.***

6.1.3 Definition of Hydrologic Condition (Wet/Average/Dry)

The Sabine-Neches BBEST considered instantaneous or cumulative flow, Palmer Drought Severity Indices, and reservoir storage as potential means of defining hydrologic conditions. Additional information regarding each method is available in Attachment B to FNI's September 17, 2009 memorandum regarding Water Availability Analyses (Appendix XI). Ultimately, the Sabine-Neches BBEST selected reservoir storage as the recommended means of defining hydrologic conditions as it provides recognition of drought persistence in the contexts both natural variability and water supply operations.

Hydrologic condition at any specific location is defined on the basis of cumulative water supply storage in major reservoirs located upstream and the frequency of occurrence of such storage subject to full use of authorized water rights (TCEQ Run3). Wet conditions are associated with cumulative upstream storage that would be exceeded less than 25 percent of the time during a season. Similarly, dry conditions are associated with cumulative upstream storage that would be exceeded more than 75 percent of the time during a season. Average conditions would apply at times when neither wet nor dry conditions are applicable. For the purposes of defining hydrologic conditions, only major reservoirs from which a significant component of the firm yield is being used should be considered. Reservoirs supporting steam-electric power generation should not be considered for definition of hydrologic conditions. ***The Sabine-Neches BBEST recommends that the applicable hydrologic condition for the entire season be defined on the basis of an assessment of hydrologic condition at the beginning of the first day of the season thereby recognizing both drought persistence and practical operations.***

6.1.4 Example Application of a Flow Regime

An important consideration in providing recommendations of environmental flow regimes is the understanding of how such regimes might be applied to new surface water appropriations. Hence, the Sabine-Neches BBEST's understanding… of potential flow regime application is summarized in the following series of examples for Big Sandy Creek near Big Sandy, Texas in the Sabine River Basin (Figure 23). Successive examples focus on dry, average, and wet hydrologic conditions and move from low to high flow situations subject to each hydrologic condition. Examples are referenced by "Line #" in Table 16, below.

TABLE 16. INSTREAM FLOW REGIME APPLICATION: BIG SANDY CREEK EXAMPLE

Instream Flow Regime Application
Big Sandy Creek Example

Line #	Season	Hydrologic Condition	Seasonal Pulse	Inflow (cfs)	Pass (cfs)	Impound or Divert (cfs)	Line Notes
1	Winter	Dry	n/a	15	15	0	Pass all inflow.
2	Winter	Dry	n/a	25	20	5	Pass seasonal Subsistence flow.
3	Winter	Dry	n/a	75	66	9	Pass Dry Base flow.
4a	Winter	Dry	n/a	400	66	334	Pass Dry Base flow. Seasonal pulse does not apply September through February.
4b	Spring	Dry	0	400	313	87	2 per Season Pulse applies. Pass inflow up to 313 cfs for 13 days or 5062 acft.
4c	Spring	Dry	1	400	30	370	Seasonal pulse met. Pass Dry Base flow.
4d	Summer	Dry	0	75	50	25	2 per Season Pulse applies. Pass inflow up to 50 cfs for 6 days or 671 acft.
4e	Summer	Dry	1	75	14	61	Seasonal pulse met. Pass Dry Base flow.
4f	Fall	Dry	n/a	150	20	130	Pass Dry Base flow. Seasonal pulse does not apply September through February.
5	Winter	Average	n/a	75	75	0	Pass all inflow.
6	Winter	Average	n/a	150	106	44	Pass Average Base flow.
7	Winter	Average	0 or 1	400	358	42	2 per Season Pulse applies. Pass inflow up to 358 cfs for 10 days or 5932 acft.
8	Winter	Average	0 or 1	1000	358	642	Pulse day 2. Pass inflow up to 358 cfs for 9 days or 5932 acft.
9	Winter	Average	2	1000	106	894	Seasonal pulses met. Pass Average Base flow.
10	Winter	Wet	n/a	100	100	0	Pass all inflow.
11	Winter	Wet	0	200	163	37	Pass Wet Base flow.
12	Winter	Wet	0	1000	942	58	1 per Season Pulse applies. Pass inflow up to 942 cfs for 16 days or 14,544 acft.
13	Winter	Wet	0	900	900	0	Pulse day 2. Pass inflow up to 942 cfs for 15 days or 14,544 acft.
14	Winter	Wet	1	1000	163	837	Seasonal pulse met. Pass Wet Base flow.

General Notes

1) Flows passed for senior water rights count towards satisfaction of specified subsistence, base, and pulse flow rates and volumes.
2) The applicable hydrologic condition for the entire season is defined on the basis of assessment of hydrologic condition at the beginning of the first day of the season thereby recognizing both drought persistence and practical operations.
3) Each season is independent of the preceding and subsequent seasons with respect to high flow pulse frequency.
4) Overbank flows may cause extensive damage to private property and endanger the public. Therefore, the S&NBBEST recognizes the ecological benefits of these events, but cannot recommend such events be produced.
5) With regard to recommended high flow pulses in the Spring and Summer seasons under Dry hydrologic conditions, it is noted that the Spring season should be shifted to March through May and the summer season should be shifted to June through August. See Recommendation 8 in Section 2.1.8.

6.1.4.1 Dry Hydrologic Conditions

1. If inflow is less than the seasonal subsistence value, then all inflow must be passed and none impounded or diverted (Line #1).
2. If inflow is less than the seasonal base value and greater than the seasonal subsistence value, then the seasonal subsistence value must be passed and the balance may be impounded or diverted to the extent available subject to senior water rights (Line #2.
3. If inflow is less than the seasonal high flow pulse peak value with a frequency of two (2) per season and greater than the seasonal base value, then the seasonal base value must be passed and the balance may be impounded or diverted to the extent available subject to senior water rights (Line #3).
4. Under dry conditions (extended dry period as defined by the reservoir storage threshold), there is no requirement to pass high flow pulses for the environment during the months of September through February (Lines #4a and #4f, General Note #5). This assumes such occurrences to be naturally rare events based on the historical record.
5. During the months of March through May, if inflow is greater than the Spring seasonal high flow pulse peak value with a frequency of two (2) per season and less than one (1) high flow pulse has occurred within the three month period, then all inflow up to the high flow pulse peak value must be passed until either the recommended duration or volume for the Spring season has been achieved. The balance of inflow may be impounded or diverted to the extent available subject to senior water rights (Line #4b). Each season is independent of the preceding and subsequent seasons with respect to high flow pulse frequency.
6. During the months of March through May, if inflow is greater than the Spring seasonal high flow pulse peak value with a frequency of two (2) per season and one (1) qualifying high flow pulse has occurred within the three month period, then the Spring seasonal base flow value must be passed and the balance may be impounded or diverted to the extent available subject to senior water rights (Line #4c).
7. During the months of June through August, if inflow is greater than the Summer seasonal high flow pulse peak value with a frequency of two (2) per season and less than one (1) high flow pulse event has occurred within the three month period, then all inflow up to the peak value must be passed until either the recommended duration or volume for the Summer season has been achieved. The balance of inflow may be impounded or diverted to the extent available subject to senior water rights (Line #4d). Each season is independent of the preceding and subsequent seasons with respect to high flow pulse frequency.
8. During the months of June through August, if inflow is greater than the Summer seasonal high flow pulse peak value with a frequency of two (2) per season and one (1) qualifying high flow pulse event has occurred within the three month period, then the Summer seasonal base value must be passed and the balance may be impounded or diverted to the extent available subject to senior water rights (Line #4e).

6.1.4.2 Average Hydrologic Conditions

1. If inflow is less than the seasonal base value, then all inflow must be passed and none impounded or diverted (Line #5).
2. If inflow is less than the seasonal peak value with a frequency of two (2) per season and greater than the seasonal base value, then the seasonal base value must be passed and the balance may be impounded or diverted to the extent available subject to senior water rights (Line #6).
3. If inflow is greater than the seasonal high flow pulse peak value with a frequency of two (2) per season and less than two (2) high flow pulses have occurred within the season, then all inflow up to the peak value must be passed until either the recommended duration or volume has been achieved. The balance of inflow may be impounded or diverted to the extent available subject to senior water rights (Lines #7 and #8). Each season is independent of the preceding and subsequent seasons with respect to high flow pulse frequency. If two qualifying high flow pulses do not occur or more than two qualifying high flow pulses do occur within a season, then the recommended high flow pulse frequency for the following season remains two (2) per season.
4. If inflow is greater than the seasonal high flow pulse peak value with a frequency of two (2) per season and two (2) qualifying high flow pulses have occurred within the season, then the seasonal base value must be passed and the balance may be impounded or diverted to the extent available subject to senior water rights (Line #9).

6.1.4.3 Wet Hydrologic Conditions

1. If inflow is less than the seasonal base value, then all inflow must be passed and none impounded or diverted (Line #10).
2. If inflow is less than the seasonal peak value with a frequency of one (1) per season and greater than the seasonal base value, then the seasonal base value must be passed and the balance may be impounded or diverted to the extent available subject to senior water rights (Line #11).
3. If inflow is greater than the seasonal high flow pulse peak value with a frequency of one (1) per season and less than one (1) high flow pulse has occurred within the season, then all inflow up to the peak value must be passed until either the recommended duration or volume has been achieved. The balance of inflow may be impounded or diverted to the extent available subject to senior water rights (Lines #12 and #13). Each season is independent of the preceding and subsequent seasons with respect to high flow pulse frequency. If one qualifying high flow pulse does not occur or more than one qualifying high flow pulse does occur within a season, then the recommended high flow pulse frequency for the following season remains one (1) per season.
4. If inflow is greater than the seasonal high flow pulse peak value with a frequency of one (1) per season and one (1) qualifying high flow pulse has occurred within the season, then the seasonal base value must be passed and the balance may be

impounded or diverted to the extent available subject to senior water rights (Line #14).

6.1.4.4 General Considerations

Under all hydrologic conditions, the Sabine-Neches BBEST recommends that flows passed for senior water rights count towards satisfaction of any specified subsistence, base, and pulse flow rates and volumes. It is anticipated that the level of flow regime complexity incorporated into permit conditions will be consistent with the size of the potential impoundment or diversion project. For example, permit conditions applicable to a major reservoir on the mainstem of a river might be fairly comprehensive, while permit conditions associated with a small run-of-river diversion might include only selected components of the flow regime.

6.1.5 Attainment Frequencies in Flow Regime Application

To the extent that the Sabine and Neches River Basins and the Sabine Lake Estuary presently represents a sound ecological environment, the Sabine-Neches BBEST agrees with the observation in SAC guidance documentation that recommendations based solely on the preservation of the full range of historical flow components (and their historical frequencies of occurrence) logically might be considered to represent the maximum flow quantities supporting a sound ecological environment. Based on review and analysis of currently available information (hydrology, sediment dynamics, water quality, biology), the Sabine-Neches BBEST recognizes that some lesser quantities of flow and/or lesser frequencies of occurrence may be adequate for environmental protection. For example, fluvial sediment transport overlay analyses by TWDB staff acting at the request of the Sabine-Neches BBEST have demonstrated that flows based on full use of all authorized water rights (as compared to historical uses and uses representative of current conditions) are adequate to avoid undesirable channel degradation.

Attainment frequency guidelines may be defined as the recommended frequencies of occurrence of various flow components expressed as a percentage of time that specified flow magnitudes are expected to be equaled or exceeded during specified seasonal or annual time periods with existing and proposed water use activities fully operational. In the context of an environmental flow regime or standard, attainment frequency guidelines can be applicable to base, pulse, and/or overbank flows; however, the need to achieve minimum subsistence flows generally applies all of the time to the extent upstream flows are available.

Some have suggested that it is appropriate to consider the effects of flow regime application under an “infinite infrastructure” scenario. This infinite infrastructure scenario assumes that, once a particular set of environmental flow requirements has been implemented, the only flow remaining in a stream or passing into an estuarine system is the environmental flow prescription itself. In other words, all other streamflow would be fully consumed by existing or proposed water development projects. The occurrence of such flow conditions has been demonstrated to be highly impracticable and essentially impossible, either with full use of existing water rights or with new project development.

Hence, the Sabine-Neches BBEST has focused on the consideration of finite infrastructure examples such as full use of existing water rights or construction and operation of a project similar to the once proposed Big Sandy Reservoir on Big Sandy Creek.

It is important to recognize that both realistic operations of water supply systems and the prior appropriation water rights system play very important roles in the maintenance and reliable occurrence of flows under dry hydrologic conditions to the extent such flows are naturally available. Clearly, the bed and banks delivery of reliable water supplies from large reservoir projects to downstream points of diversion contributes to the maintenance of flow in the intervening stream segment. Under dry hydrologic conditions, such water deliveries may exceed seasonal subsistence and approach seasonal base flows within a recommended flow regime. Similarly, hydropower releases from major reservoirs may contribute at higher levels within a recommended flow regime. The prior appropriation system also functions to ensure the occurrence of instream flows upstream of a major reservoir or run-of-river water right, particularly the critical maintenance of such flows in the range between subsistence and base under dry hydrologic conditions. As major reservoirs are not full and run-of-river rights may not be fully satisfied under dry hydrologic conditions, junior water rights and future applicants for surface water appropriation located upstream would be required to pass inflows for downstream water rights. The Sabine-Neches BBEST believes that it is imperative that TCEQ recognize the contributions of downstream runoff, water deliveries, hydropower releases, and inflow passage to honor downstream water rights towards maintenance of recommended flow regimes supportive of a sound ecological environment.

As a quantitative example to illustrate the translation of a flow regime into permit conditions and demonstrate the potential effects on instream flows and their frequency of occurrence, the Sabine-Neches BBEST has considered construction and long-term operations of the once proposed Big Sandy Creek Reservoir. ***It is noted that this reservoir project is not recommended to meet projected needs for additional water supply in the current State Water Plan and that its construction would occur, if ever, well beyond the 50-year state water planning horizon.*** For the purposes of this illustrative example, however, it is assumed that this reservoir would be located at the reference gage location on Big Sandy Creek, have a storage capacity of 76,179 acre-feet at the top of the conservation pool, and be operated with direct diversions of the firm yield subject to application of the recommended flow regime (Figure 23 HEFR Matrix for Big Sandy Creek Near Big Sandy, Texas, page 118) in the form of permit conditions described herein. The assumed simulation period is 1940 through 1996 and seasonal hydrologic conditions are defined by reservoir storage in accordance with Table 4 of FNI's September 17, 2009 memorandum regarding Water Availability Analyses (FNI 2009c).

Figure 19, Figure 20, and Figure 21 illustrate daily regulated flows passing the Big Sandy reference gage location with and without Big Sandy Creek Reservoir operations subject to potential application of the recommended flow regime for selected years representative of wet (1946), average (1959), and dry (1956) hydrologic conditions, respectively. These figures each include streamflow sequences based on three scenarios:

1. USGS historical gaged streamflow as used to derive the recommended flow regime;
2. Regulated streamflow with Big Sandy Creek Reservoir in operation subject to recommended flow regime application; and
3. Regulated streamflow with Big Sandy Creek Reservoir in operation subject to recommended flow regime application and senior water rights associated with Toledo Bend Reservoir pursuant to a pending application for amendment.

It is assumed, and fundamentally supported by recommended definition, that Toledo Bend Reservoir would not be full under dry hydrologic conditions. Hence, if the pending application for amendment is ultimately approved, all inflows to Big Sandy Creek Reservoir could be passed to honor senior water rights in Toledo Bend Reservoir under dry hydrologic conditions. Finally, Figure 22 shows historical and regulated frequencies of streamflow passing the Big Sandy reference gage location. For perspective, Figure 22 also shows regulated streamflow frequencies assuming “infinite infrastructure” with only flows specified in the flow regime remaining unconsumed.

FIGURE 19. APPLICATION EXAMPLE - PROPOSED BIG SANDY RESERVOIR - WET CONDITIONS

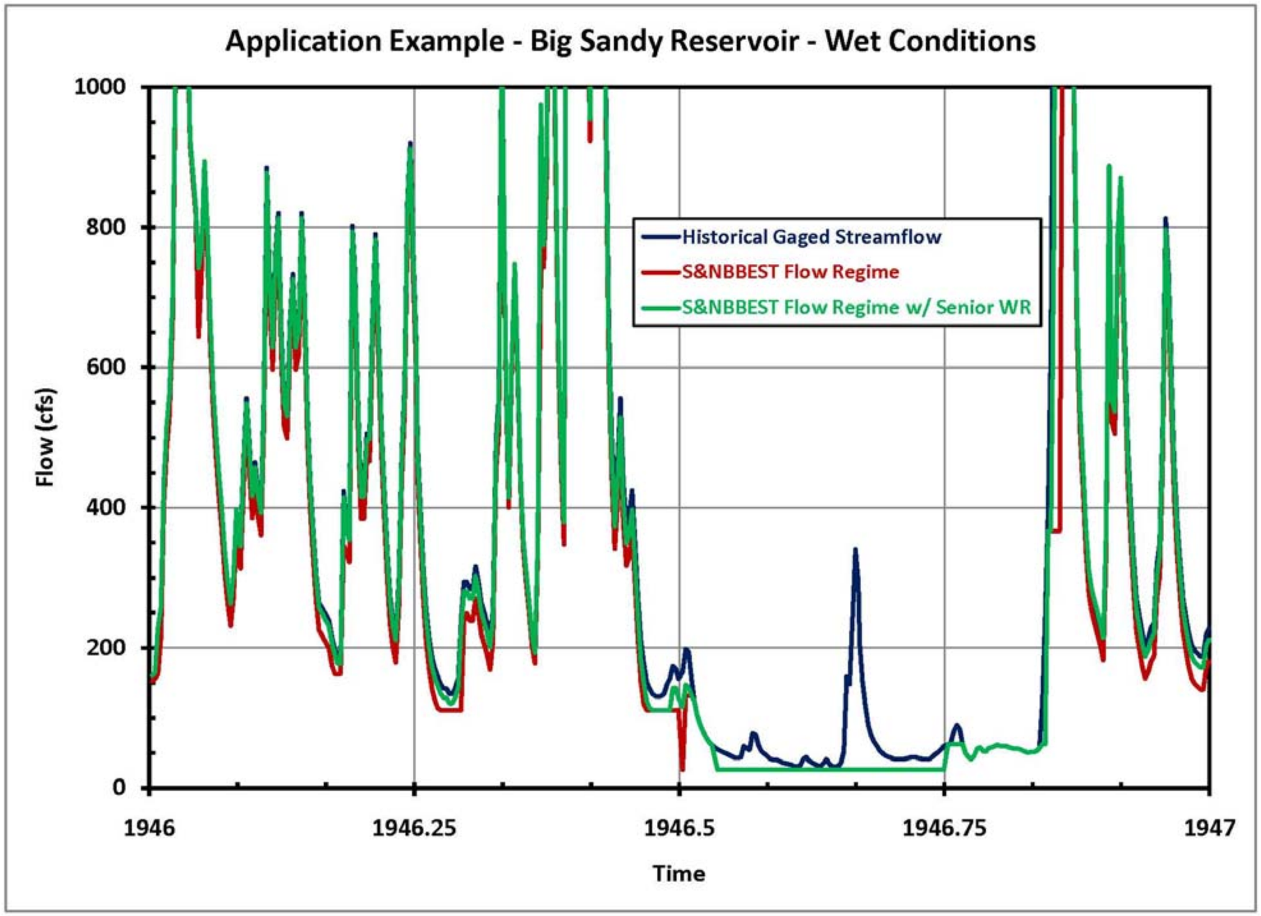


FIGURE 20. APPLICATION EXAMPLE - PROPOSED BIG SANDY RESERVOIR - AVERAGE CONDITIONS

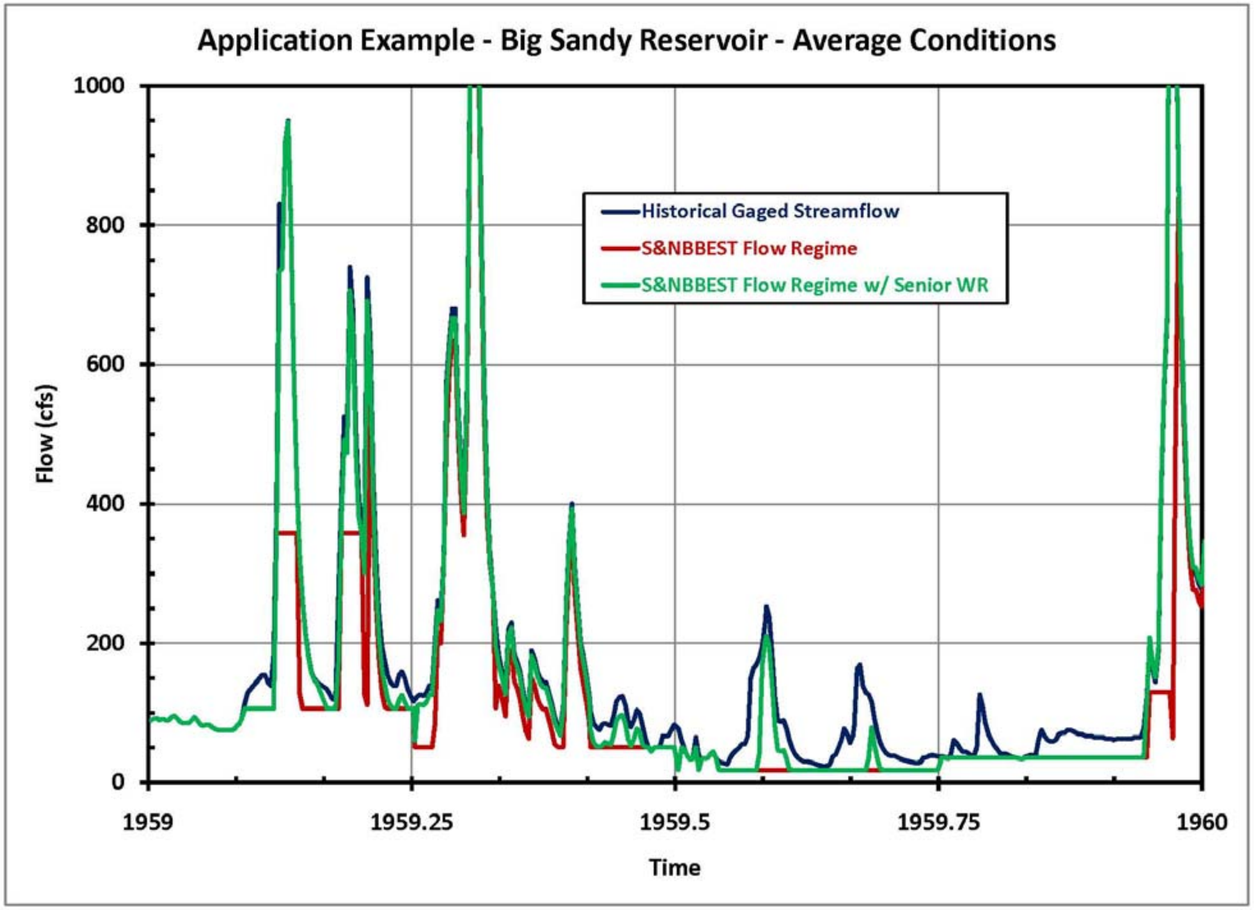


FIGURE 21. APPLICATION EXAMPLE - PROPOSED BIG SANDY RESERVOIR - DRY CONDITIONS

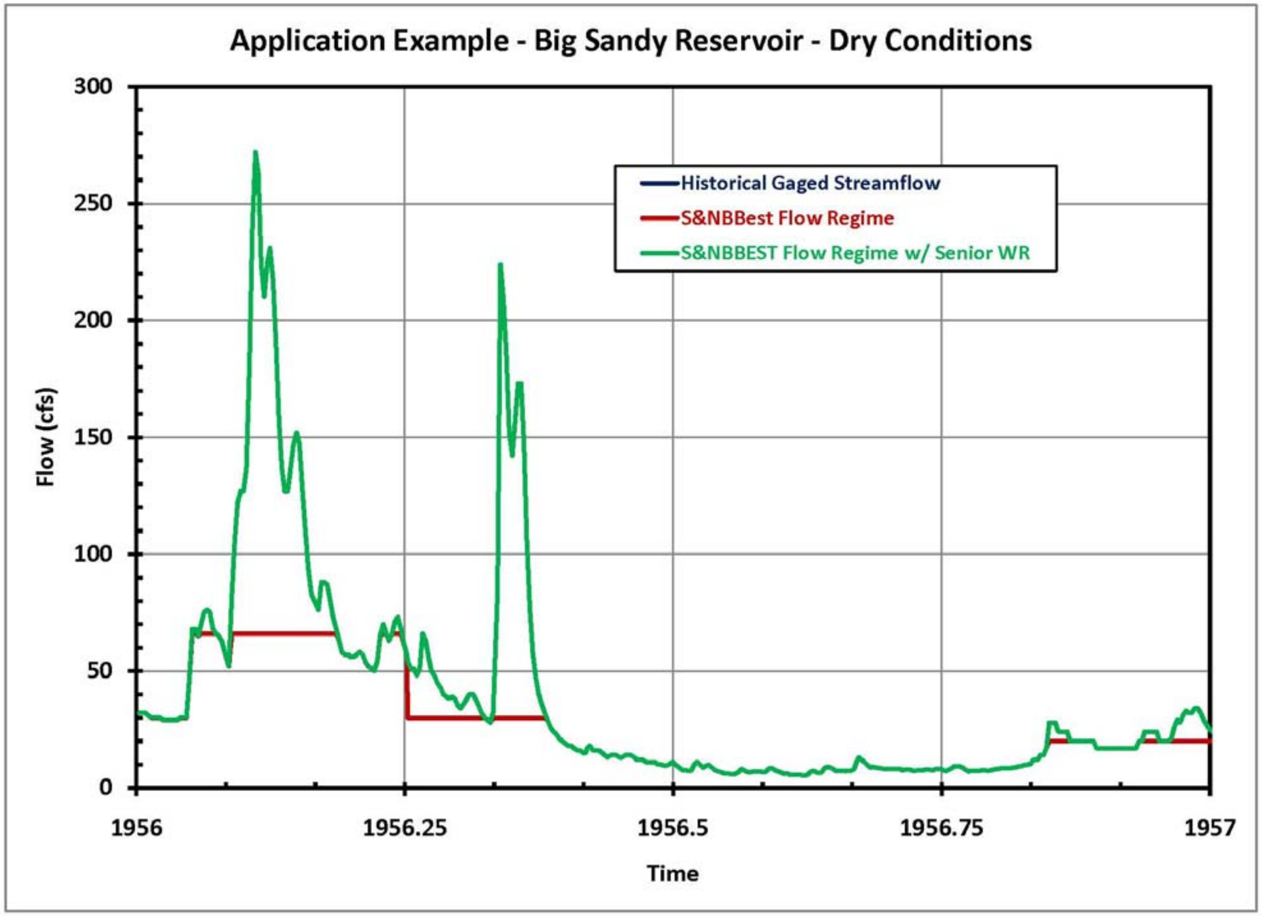
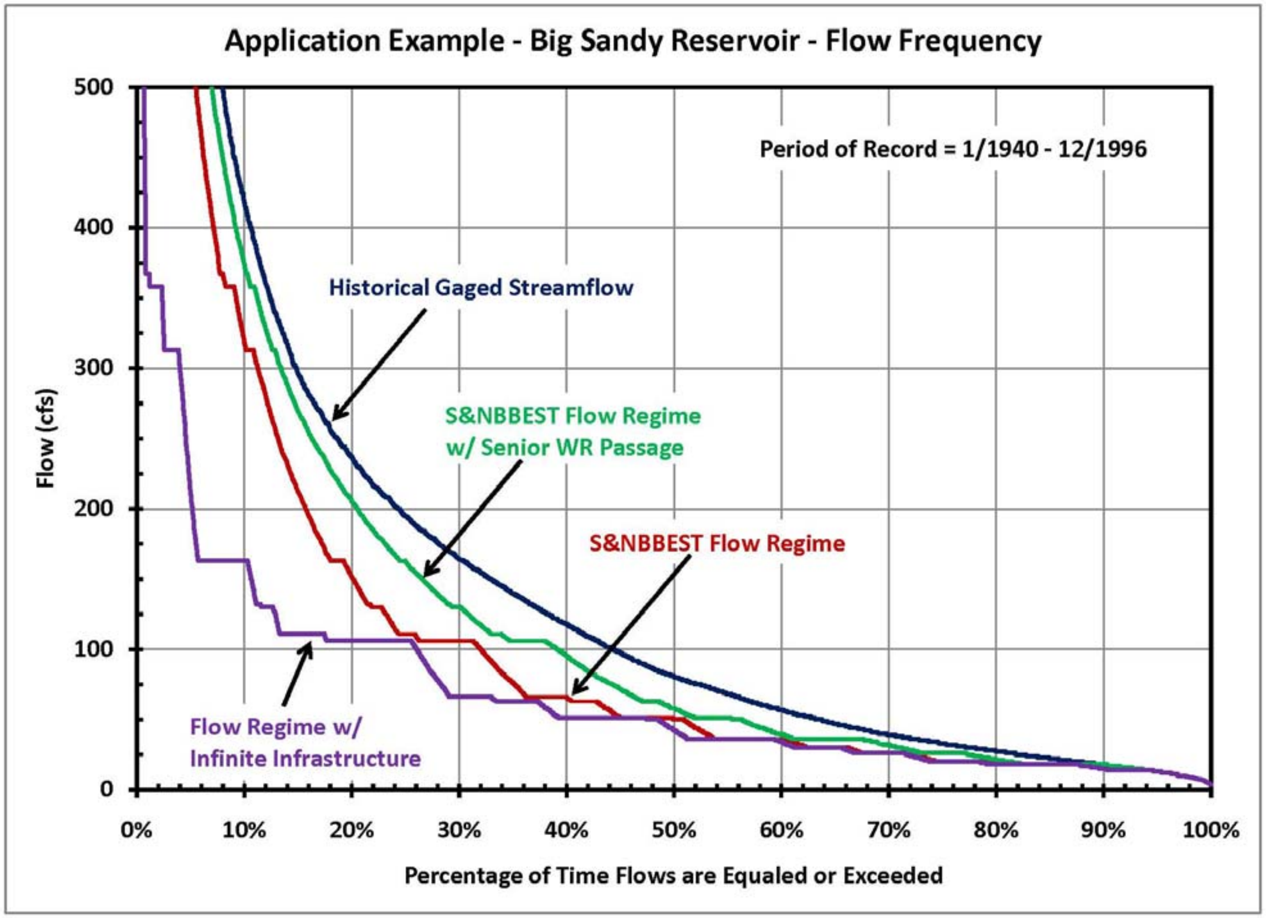


FIGURE 22. APPLICATION - PROPOSED BIG SANDY RESERVOIR - FLOW FREQUENCY



Key observations upon review of Figure 19, Figure 20, Figure 21, and Figure 22 include the following:

1. Leveling of the regulated streamflow frequency curves is apparent at specified flow values (potential permit conditions) within the recommended flow regime.
2. Flows at the seasonal subsistence level occur no more frequently than they did historically in the spring, summer, and fall seasons.
3. Flows at the winter subsistence level occur no more frequently than they did historically if inflow passage for senior water rights is accounted for in accordance with the pending application to amend the water right for Toledo Bend Reservoir.
4. With regard to higher flows expected to be equaled or exceeded about half the time, the assumption of infinite infrastructure represents a condition that is quite different from that with implementation of a major reservoir project on Big Sandy Creek, even though such implementation is far beyond the planning horizon.

The Sabine-Neches BBEST understands that consideration of one example of potential flow regime application does not address all potential ecological concerns at all locations throughout the Sabine and Neches River Basins. This example suggests that flow regime application in accordance with recommendations presented herein will likely support a sound ecological environment at many locations. However, since frequencies of attainment for various flows will be less than observed historically, additional study will be required to ascertain potential environmental effects of these recommendations.

6.1.6 Geographic Interpolation

The Sabine-Neches BBEST has provided flow regime recommendations at streamflow gaging stations located throughout the Sabine and Neches River Basins. These reference locations are, among other things, representative of major streams above and below existing reservoirs as well as tributary streams in the upper and lower portions of each river basin. The Sabine-Neches BBEST recommends that the TCEQ develop appropriate methods for interpolation of flow conditions applicable to future inter-adjacent permits and amendments from reference locations for which flow regimes supporting a sound ecological environment are established. Such methods should include, at a minimum, drainage area adjustments, but may also include consideration of springflow contributions, channel losses, aquifer recharge zones, soil cover complex, and other factors as necessary and appropriate. The Sabine-Neches BBEST understands that the TCEQ has initiated a research project focused on development of methods for geographic interpolation of flow regimes.

6.2 HEFR OUTPUT MATRICES FOR SELECTED STREAM FLOW GAGING STATIONS IN THE SABINE AND NECHES RIVER BASINS

6.2.1 SABINE BASIN

6.2.1.1 BIG SANDY CREEK NEAR BIG SANDY, TX

Sub-Basin Description This gage has a minimally controlled watershed with one small recreation reservoir, Lake Winnsboro. The drainage area above the gage is 231 sq-mi, of which 204 sq-mi (88%) is uncontrolled (FNI 2009a). Big Sandy Creek enters the Sabine River at river mile 412.42 (U.S. Army Corps of Engineers 1969)[30]. It is in TCEQ Stream Segment 0514, Big Sandy Creek: from the confluence with the Sabine River in Upshur County to a point 2.6 kilometers (1.6 miles) upstream of SH 11 in Hopkins County. This segment is characterized by low rolling hills with extensive forests and is in the South Central Plains Ecoregion. This area is largely rural with no cities over 5,000 (Sabine River Basin 2008 Summary Report, Sabine River Authority of Texas 2009b).

[30] The official U.S. Geological Survey river miles originate at the mouth of the Sabine River at Sabine Lake (RM 0.0) and terminate at the source (divide) at RM 579.40.

FIGURE 23. HEFR MATRIX FOR BIG SANDY CREEK NEAR BIG SANDY, TEXAS

USGS 08019500 Big Sandy Ck nr Big Sandy, TX

Full Period

	Winter (Jan, Feb, Mar)	Spring (Apr, May, Jun)	Summer (Jul, Aug, Sep)	Fall (Oct, Nov, Dec)
Overbank Flows	Qp: 2,930 cfs with Frequency 1 per 2 years Volume is 35,703 Duration is 30			
	Overbank flows may cause extensive damage to private property and endanger the public. Therefore, the Sabine-Neches BBEST recognizes the ecological benefits of these events, but cannot recommend such events be produced.			
High Flow Pulses	Qp: 942 cfs with Frequency 1 per season Volume is 14,544 Duration is 16	Qp: 950 cfs with Frequency 1 per season Volume is 12,852 Duration is 19	Qp: 132 cfs with Frequency 1 per season Volume is 2,054 Duration is 11	Qp: 367 cfs with Frequency 1 per season Volume is 6,055 Duration is 14
	Qp: 358 cfs with Frequency 2 per season Volume is 5,932 Duration is 10	Qp: 313 cfs with Frequency 2 per season Volume is 5,062 Duration is 13	Qp: 50 cfs with Frequency 2 per season Volume is 671 Duration is 6	Qp: 130 cfs with Frequency 2 per season Volume is 2,189 Duration is 9
	Translation of seasonal pulse flows of specified frequencies into environmental flow standards and permit conditions may result in less frequent occurrence of high flow pulses as a result of the issuance of new surface water appropriations or amendments. This reduced frequency of occurrence is deemed an acceptable environmental risk at this time, subject to review as new studies and information become available.			
Base Flows (cfs)	163	111	26	63
	106	51	18	36
	66	30	14	20
	Seasonal base flows represent thresholds for environmental protection based on current scientific understanding of fluvial and estuarine ecosystems. As new studies and monitoring information become available, these base flow thresholds may be revised.			
Subsistence Flows (cfs)	20	9	8	8
	Translation of seasonal subsistence flows into environmental flow standards and permit conditions should not result in more frequent occurrence of flows less than the recommended seasonal subsistence values as a result of the issuance of new surface water appropriations or amendments.			

6.2.1.2 SABINE RIVER NEAR GLADEWATER, TX

Sub-Basin Description The drainage for this gage is 2,791 sq-mi, of which 1,404 sq-mi (50%) is uncontrolled (FNI 2009a). This gage is at river mile 397.48 (U.S. Army Corps of Engineers 1969). It is in TCEQ Segment 0506, Sabine River Below Lake Tawakoni: from a point 100 meters (110 yards) downstream of US 271 in Gregg County to Iron Bridge Dam in Rains County.

FIGURE 24. HEFR MATRIX FOR SABINE RIVER NEAR GLADEWATER, TEXAS

USGS 08020000 Sabine Rv nr Gladewater, TX

Full Period

<table>
<tr><td rowspan="2">Overbank Flows</td><td colspan="12">Qp: 18,100 cfs with Frequency 1 per 2 years
Volume is 483,275
Duration is 44</td></tr>
<tr><td colspan="12">Overbank flows may cause extensive damage to private property and endanger the public. Therefore, the Sabine-Neches BBEST recognizes the ecological benefits of these events, but cannot recommend such events be produced.</td></tr>
<tr><td rowspan="3">High Flow Pulses</td><td colspan="3">Qp: 5,570 cfs with Frequency 1 per season
Volume is 194,743
Duration is 24</td><td colspan="3">Qp: 5,070 cfs with Frequency 1 per season
Volume is 140,612
Duration is 25</td><td colspan="3">Qp: 730 cfs with Frequency 1 per season
Volume is 13,480
Duration is 17</td><td colspan="3">Qp: 2,240 cfs with Frequency 1 per season
Volume is 66,875
Duration is 21</td></tr>
<tr><td colspan="3">Qp: 1,880 cfs with Frequency 2 per season
Volume is 48,599
Duration is 15</td><td colspan="3">Qp: 1,580 cfs with Frequency 2 per season
Volume is 51,150
Duration is 16</td><td colspan="3">Qp: 168 cfs with Frequency 2 per season
Volume is 2,752
Duration is 7</td><td colspan="3">Qp: 380 cfs with Frequency 2 per season
Volume is 1,098
Duration is 11</td></tr>
<tr><td colspan="12">Translation of seasonal pulse flows of specified frequencies into environmental flow standards and permit conditions may result in less frequent occurrence of high flow pulses as a result of the issuance of new surface water appropriations or amendments. This reduced frequency of occurrence is deemed an acceptable environmental risk at this time, subject to review as new studies and information become available.</td></tr>
<tr><td rowspan="4">Base Flows (cfs)</td><td colspan="3">836</td><td colspan="3">664</td><td colspan="3">78</td><td colspan="3">232</td></tr>
<tr><td colspan="3">472</td><td colspan="3">283</td><td colspan="3">46</td><td colspan="3">105</td></tr>
<tr><td colspan="3">277</td><td colspan="3">119</td><td colspan="3">34</td><td colspan="3">49</td></tr>
<tr><td colspan="12">Seasonal base flows represent thresholds for environmental protection based on current scientific understanding of fluvial and estuarine ecosystems. As new studies and monitoring information become available, these base flow thresholds may be revised.</td></tr>
<tr><td rowspan="2">Subsistence Flows (cfs)</td><td colspan="3">45</td><td colspan="3">22</td><td colspan="3">14</td><td colspan="3">17</td></tr>
<tr><td colspan="12">Translation of seasonal subsistence flows into environmental flow standards and permit conditions should not result in more frequent occurrence of flows less than the recommended seasonal subsistence values as a result of the issuance of new surface water appropriations or amendments.</td></tr>
<tr><td></td><td>Jan</td><td>Feb</td><td>Mar</td><td>Apr</td><td>May</td><td>Jun</td><td>Jul</td><td>Aug</td><td>Sep</td><td>Oct</td><td>Nov</td><td>Dec</td></tr>
<tr><td></td><td colspan="3">Winter</td><td colspan="3">Spring</td><td colspan="3">Summer</td><td colspan="3">Fall</td></tr>
</table>

6.2.1.3 SABINE RIVER NEAR BECKVILLE, TX

Sub-Basin Description The drainage area for this gage is 3,589 sq-mi, of which 2,044 sq-mi (57%) is uncontrolled (FNI 2009a). This gage is at river mile 327.00 (U.S. Army Corps of Engineers 1969). It is in TCEQ Segment 0505, Sabine River Above Toledo Bend Reservoir: from a point immediately upstream of the confluence of Murvaul Creek in Panola County to a point 100 meters (110 yards) downstream of US 271 in Gregg County. Segment 0505 is located in the South Central Plains Ecoregion and is characterized by extensive forests and somewhat level terrain. Land use is 57.6% forests, 32.6% agriculture and 13.5% wetlands. There are numerous industries, oilfields and six cities with populations greater than 5,000. There are more than 100 permitted discharges and it contains the highest concentration of population in the Sabine Basin. (Sabine River Authority of Texas 2009b).

FIGURE 25. HEFR MATRIX FOR SABINE RIVER NEAR BECKVILLE, TEXAS

USGS 08022040 Sabine Rv nr Beckville, TX

Full Period

	Winter (Jan–Mar)	Spring (Apr–Jun)	Summer (Jul–Sep)	Fall (Oct–Dec)
Overbank Flows	Qp: 16,100 cfs with Frequency 1 per 2 years Volume is 541,644 Duration is 45			
	Overbank flows may cause extensive damage to private property and endanger the public. Therefore, the Sabine-Neches BBEST recognizes the ecological benefits of these events, but cannot recommend such events be produced.			
High Flow Pulses	Qp: 7,200 cfs with Frequency 1 per season Volume is 302,174 Duration is 24	Qp: 7,030 cfs with Frequency 1 per season Volume is 220,513 Duration is 27	Qp: 1,120 cfs with Frequency 1 per season Volume is 19,863 Duration is 16	Qp: 3,250 cfs with Frequency 1 per season Volume is 100,717 Duration is 21
	Qp: 2,900 cfs with Frequency 2 per season Volume is 84,998 Duration is 15	Qp: 2,160 cfs with Frequency 2 per season Volume is 72,092 Duration is 15	Qp: 285 cfs with Frequency 2 per season Volume is 5,436 Duration is 6	Qp: 628 cfs with Frequency 2 per season Volume is 7,245 Duration is 9
	Translation of seasonal pulse flows of specified frequencies into environmental flow standards and permit conditions may result in less frequent occurrence of high flow pulses as a result of the issuance of new surface water appropriations or amendments. This reduced frequency of occurrence is deemed an acceptable environmental risk at this time, subject to review as new studies and information become available.			
Base Flows (cfs)	1580	1260	122	356
	807	526	74	141
	438	232	51	75
	Seasonal base flows represent thresholds for environmental protection based on current scientific understanding of fluvial and estuarine ecosystems. As new studies and monitoring information become available, these base flow thresholds may be revised.			
Subsistence Flows (cfs)	66	28	22	22
	Translation of seasonal subsistence flows into environmental flow standards and permit conditions should not result in more frequent occurrence of flows less than the recommended seasonal subsistence values as a result of the issuance of new surface water appropriations or amendments.			
	Jan Feb Mar	Apr May Jun	Jul Aug Sep	Oct Nov Dec
	Winter	Spring	Summer	Fall

6.2.1.4 Sabine near Bon Wier, TX

Sub-Basin Description The drainage area for this gage is 8,229 sq-mi, of which 842 sq-mi (10%) is uncontrolled (FNI 2009a). This gage is downstream of Toledo Bend Reservoir (river mile 156.45) at river mile 97.71 (U.S. Army Corps of Engineers 1969). It is in TCEQ Segment 0503, the Sabine River above Caney Creek: from a point immediately upstream of the confluence with Caney Creek in Newton County up to Toledo Bend Dam in Newton County. Segment 0503 is located in the South Central Plains Ecoregion. This region is locally termed the "piney woods." This region of mostly irregular plains represents the western edge of the southern coniferous forest belt. Timber is the main industry in Segment 0503, which is largely rural and only one city has a population greater than 5,000. (Sabine River Authority of Texas 2009b)

In the HEFR analyses for Sabine-Neches BBEST, below, the gage with the most discrepancies was the Bon Wier gage relative to the downstream (59 river miles) Ruliff gage (see Section 6.2.1.6, page 127). In most cases, it is expected that the downstream gage would have higher values than the upstream gage. However, the HEFR values for Bon Wier are almost always significantly higher than Ruliff. The reason for this discrepancy may stem from NWS bankfull and flood stage discharges, but it is unclear based on available information if threshold parameters should be changed and how this would translate into environment needs. The current FERC relicense studies may shed more light on this issue at the Bon Wier gage.

FIGURE 26. HEFR MATRIX FOR SABINE RIVER NEAR BON WIER, TEXAS

USGS 08028500 Sabine Rv nr Bon Wier, TX

Full Period

	Winter (Jan, Feb, Mar)	Spring (Apr, May, Jun)	Summer (Jul, Aug, Sep)	Fall (Oct, Nov, Dec)
Overbank Flows	Qp: 28,700 cfs with Frequency 1 per year Volume is 931,140 Duration is 28			
Overbank Flows	Overbank flows may cause extensive damage to private property and endanger the public. Therefore, the Sabine-Neches BBEST recognizes the ecological benefits of these events, but cannot recommend such events be produced.			
High Flow Pulses	Qp: 20,600 cfs with Frequency 1 per season Volume is 690,800 Duration is 17	Qp: 16,500 cfs with Frequency 1 per season Volume is 483,992 Duration is 21	Qp: 7,360 cfs with Frequency 1 per season Volume is 175,009 Duration is 14	Qp: 8,960 cfs with Frequency 1 per season Volume is 249,617 Duration is 17
High Flow Pulses	Qp: 13,800 cfs with Frequency 2 per season Volume is 421,966 Duration is 14	Qp: 6,700 cfs with Frequency 2 per season Volume is 151,163 Duration is 12	Qp: 5,880 cfs with Frequency 2 per season Volume is 132,571 Duration is 13	Qp: 2,590 cfs with Frequency 2 per season Volume is 40,957 Duration is 7
High Flow Pulses	Translation of seasonal pulse flows of specified frequencies into environmental flow standards and permit conditions may result in less frequent occurrence of high flow pulses as a result of the issuance of new surface water appropriations or amendments. This reduced frequency of occurrence is deemed an acceptable environmental risk at this time, subject to review as new studies and information become available.			
Base Flows (cfs)	15400	6680	1120	1110
Base Flows (cfs)	5870	1590	656	615
Base Flows (cfs)	1460	857	478	478
Base Flows (cfs)	Seasonal base flows represent thresholds for environmental protection based on current scientific understanding of fluvial and estuarine ecosystems. As new studies and monitoring information become available, these base flow thresholds may be revised.			
Subsistence Flows (cfs)	479	279	241	241
Subsistence Flows (cfs)	Translation of seasonal subsistence flows into environmental flow standards and permit conditions should not result in more frequent occurrence of flows less than the recommended seasonal subsistence values as a result of the issuance of new surface water appropriations or amendments.			

6.2.1.5 BIG COW CREEK NEAR NEWTON, TX

Sub-Basin Description Big Cow Creek near Newton has very little modification in its watershed and represents nearly natural conditions. The drainage area for this gage is 128 sq-mi, of which 128 sq-mi (100%) is uncontrolled (FNI 2009a). Big Cow Creek enters the Sabine River at river mile 76.00 (U.S. Army Corps of Engineers 1969). This gage is in TCEQ Segment 0513, Big Cow Creek: from the confluence with the Sabine River in Newton County to a point 4.6 Kilometers (2.9 miles) upstream of R 255 in Newton County. Segment 0513 is located in the Western Gulf Coast Plain Ecoregion. This region is characterized by small rolling hills to the north becoming relatively flat to the south. Segment 0513 is largely rural with no major industries or cities and will probably remain largely rural for the near future. (Sabine River Authority of Texas 2009b)

FIGURE 27. BIG COW CREEK NEAR NEWTON, TEXAS

USGS 08029500 Big Cow Crk nr Newton, TX

Full Period

Overbank Flows	Qp: 3,180 cfs with Frequency 1 per 2 years Volume is 18,325 Duration is 17			
	Overbank flows may cause extensive damage to private property and endanger the public. Therefore, the Sabine-Neches BBEST recognizes the ecological benefits of these events, but cannot recommend such events be produced.			
High Flow Pulses	Qp: 1,080 cfs with Frequency 1 per season Volume is 7,387 Duration is 10	Qp: 862 cfs with Frequency 1 per season Volume is 6,075 Duration is 10	Qp: 191 cfs with Frequency 1 per season Volume is 1,447 Duration is 7	Qp: 790 cfs with Frequency 1 per season Volume is 5,038 Duration is 9
	Qp: 693 cfs with Frequency 2 per season Volume is 4,911 Duration is 8	Qp: 350 cfs with Frequency 2 per season Volume is 2,545 Duration is 7	Qp: 109 cfs with Frequency 2 per season Volume is 873 Duration is 5	Qp: 322 cfs with Frequency 2 per season Volume is 2,232 Duration is 7
	Translation of seasonal pulse flows of specified frequencies into environmental flow standards and permit conditions may result in less frequent occurrence of high flow pulses as a result of the issuance of new surface water appropriations or amendments. This reduced frequency of occurrence is deemed an acceptable environmental risk at this time, subject to review as new studies and information become available.			
Base Flows (cfs)	106	74	48	64
	78	52	36	46
	56	38	28	36
	Seasonal base flows represent thresholds for environmental protection based on current scientific understanding of fluvial and estuarine ecosystems. As new studies and monitoring information become available, these base flow thresholds may be revised.			
Subsistence Flows (cfs)	28	20	20	20
	Translation of seasonal subsistence flows into environmental flow standards and permit conditions should not result in more frequent occurrence of flows less than the recommended seasonal subsistence values as a result of the issuance of new surface water appropriations or amendments.			
	Jan Feb Mar	Apr May Jun	Jul Aug Sep	Oct Nov Dec
	Winter	Spring	Summer	Fall

6.2.1.6 SABINE NEAR RULIFF, TX

Sub-Basin Description The drainage area for this gage is 9,329 sq-mi, of which 1,942 sq-mi (21%) is uncontrolled. This gage is downstream of Toledo Bend Reservoir (river mile 156.45) at river mile 40.20 (U.S. Army Corps of Engineers 1969). It is in TCEQ Segment 0502, Sabine River Above Tidal: from West Bluff in Orange County to the confluence with Caney Creek in Newton County. It measures a significant portion of the inflow into Sabine Lake (FNI 2009a). Segment 0502 is located in the Western Gulf Coast Plain Ecoregion. This region is characterized by small rolling hills to the north and becoming relatively flat to the south. Segment 0502 is largely rural with no major industries or cities and will probably remain largely rural for the near future (Sabine River Authority of Texas 2009b).

FIGURE 28. HEFR MATRIX FOR SABINE RIVER NEAR RULIFF, TEXAS

USGS 08030500 Sabine Rv nr Ruliff, TX

Full Period

<table>
<tr><td rowspan="2">Overbank Flows</td><td colspan="4">Qp: 29,000 cfs with Frequency 1 per year
Volume is 1,760,073
Duration is 60</td></tr>
<tr><td colspan="4">Overbank flows may cause extensive damage to private property and endanger the public. Therefore, the Sabine-Neches BBEST recognizes the ecological benefits of these events, but cannot recommend such events be produced.</td></tr>
<tr><td rowspan="3">High Flow Pulses</td><td>Qp: 9,880 cfs with Frequency 1 per season
Volume is 261,464
Duration is 22</td><td>Qp: 9,880 cfs with Frequency 1 per season
Volume is 253,851
Duration is 21</td><td>Qp: 6,600 cfs with Frequency 1 per season
Volume is 157,936
Duration is 19</td><td>Qp: 6,030 cfs with Frequency 1 per season
Volume is 110,471
Duration is 15</td></tr>
<tr><td>Qp: 1,600 cfs with Frequency 2 per season
Volume is 10,202
Duration is 3</td><td>Qp: 3,250 cfs with Frequency 2 per season
Volume is 42,883
Duration is 8</td><td>Qp: 3,380 cfs with Frequency 2 per season
Volume is 54,321
Duration is 11</td><td>Qp: 2,020 cfs with Frequency 2 per season
Volume is 17,662
Duration is 5</td></tr>
<tr><td colspan="4">Translation of seasonal pulse flows of specified frequencies into environmental flow standards and permit conditions may result in less frequent occurrence of high flow pulses as a result of the issuance of new surface water appropriations or amendments. This reduced frequency of occurrence is deemed an acceptable environmental risk at this time, subject to review as new studies and information become available.</td></tr>
<tr><td rowspan="4">Base Flows (cfs)</td><td>5063</td><td>3035</td><td>1430</td><td>1400</td></tr>
<tr><td>2565</td><td>1795</td><td>870</td><td>970</td></tr>
<tr><td>1520</td><td>1208</td><td>670</td><td>735</td></tr>
<tr><td colspan="4">Seasonal base flows represent thresholds for environmental protection based on current scientific understanding of fluvial and estuarine ecosystems. As new studies and monitoring information become available, these base flow thresholds may be revised.</td></tr>
<tr><td rowspan="2">Subsistence Flows (cfs)</td><td>949</td><td>436</td><td>396</td><td>396</td></tr>
<tr><td colspan="4">Translation of seasonal subsistence flows into environmental flow standards and permit conditions should not result in more frequent occurrence of flows less than the recommended seasonal subsistence values as a result of the issuance of new surface water appropriations or amendments.</td></tr>
<tr><td></td><td>Jan Feb Mar</td><td>Apr May Jun</td><td>Jul Aug Sep</td><td>Oct Nov Dec</td></tr>
<tr><td></td><td>Winter</td><td>Spring</td><td>Summer</td><td>Fall</td></tr>
</table>

6.2.2 Neches Basin

6.2.2.1 Neches River near Neches, TX

Sub-Basin Description The drainage area for this gage is 1,145 sq-mi, of which 306 sq-mi (27%) is uncontrolled. It is in TCEQ Segment 0604, Neches River Below Lake Palestine. (FNI 2009a) Segment 0604 begins at Blackburn Crossing Dam at Lake Palestine in Anderson/Cherokee County and extends to a point immediately upstream of the confluence of Hopson Mill Creek in Jasper/Tyler County. The uppermost portion of the segment (where this station is located) is characterized by dissected irregular plains with some low, rolling hills consisting of low to moderate gradient streams with sandy and silty substrates. It is part of the Tertiary Uplands of the South Central Plains Ecoregion.[31]

[31] Most of the segment description information for the Neches Basin stations is from the TCEQ, ANRA, and LNVA basin reports.

FIGURE 29. HEFR MATRIX FOR NECHES RIVER AT NECHES, TEXAS

USGS 08032000 Neches Rv at Neches, TX

Full Period

	Winter (Jan, Feb, Mar)	Spring (Apr, May, Jun)	Summer (Jul, Aug, Sep)	Fall (Oct, Nov, Dec)
Overbank Flows	Qp: 7,280 cfs with Frequency 1 per 2 years Volume is 172,590 Duration is 38			
	Overbank flows may cause extensive damage to private property and endanger the public. Therefore, the Sabine-Neches BBEST recognizes the ecological benefits of these events, but cannot recommend such events be produced.			
High Flow Pulses	Qp: 1,370 cfs with Frequency 1 per season Volume is 39,549 Duration is 13	Qp: 1,370 cfs with Frequency 1 per season Volume is 31,846 Duration is 15	Qp: 248 cfs with Frequency 1 per season Volume is 4,029 Duration is 7	Qp: 782 cfs with Frequency 1 per season Volume is 19,996 Duration is 12
	Qp: 833 cfs with Frequency 2 per season Volume is 19,104 Duration is 10	Qp: 820 cfs with Frequency 2 per season Volume is 20,405 Duration is 12	Qp: 113 cfs with Frequency 2 per season Volume is 1,339 Duration is 4	Qp: 345 cfs with Frequency 2 per season Volume is 5,391 Duration is 8
	Translation of seasonal pulse flows of specified frequencies into environmental flow standards and permit conditions may result in less frequent occurrence of high flow pulses as a result of the issuance of new surface water appropriations or amendments. This reduced frequency of occurrence is deemed an acceptable environmental risk at this time, subject to review as new studies and information become available.			
Base Flows (cfs)	814	524	108	172
	408	194	73	104
	178	87	42	73
	Seasonal base flows represent thresholds for environmental protection based on current scientific understanding of fluvial and estuarine ecosystems. As new studies and monitoring information become available, these base flow thresholds may be revised.			
Subsistence Flows (cfs)	51	21	12	13
	Translation of seasonal subsistence flows into environmental flow standards and permit conditions should not result in more frequent occurrence of flows less than the recommended seasonal subsistence values as a result of the issuance of new surface water appropriations or amendments.			

6.2.2.2 Neches River near Rockland, TX

Sub-Basin Description The drainage area for this gage is 3,636 sq-miles, of which 2,763 sq-mi (76%) is uncontrolled (FNI 2009a). It is in TCEQ Segment 0604, Neches River Below Lake Palestine. (FNI 2009a) This station is located in the lower portion of Segment 0604 in the Southern Tertiary Uplands of the South Central Plains Ecoregion. Mixed pine-hardwood forest and longleaf pine forests dominate the region. This area includes public land consisting of numerous State Parks, Recreation Areas, and National Forests.

FIGURE 30. HEFR MATRIX FOR NECHES RIVER AT ROCKLAND, TEXAS

USGS 08033500 Neches Rv at Rockland, TX

Full Period

<table>
<tr><td rowspan="2">Overbank Flows</td><td colspan="12">Qp: 18,500 cfs with Frequency 1 per 2 years
Volume is 661,717
Duration is 41</td></tr>
<tr><td colspan="12">Overbank flows may cause extensive damage to private property and endanger the public. Therefore, the Sabine-Neches BBEST recognizes the ecological benefits of these events, but cannot recommend such events be produced.</td></tr>
<tr><td rowspan="3">High Flow Pulses</td><td colspan="3">Qp: 6,910 cfs with Frequency 1 per season
Volume is 256,523
Duration is 22</td><td colspan="3">Qp: 5,600 cfs with Frequency 1 per season
Volume is 167,866
Duration is 23</td><td colspan="3">Qp: 615 cfs with Frequency 1 per season
Volume is 13,365
Duration is 11</td><td colspan="3">Qp: 2,240 cfs with Frequency 1 per season
Volume is 72,600
Duration is 17</td></tr>
<tr><td colspan="3">Qp: 3,080 cfs with Frequency 2 per season
Volume is 82,195
Duration is 14</td><td colspan="3">Qp: 1,720 cfs with Frequency 2 per season
Volume is 39,935
Duration is 12</td><td colspan="3">Qp: 195 cfs with Frequency 2 per season
Volume is 1,548
Duration is 5</td><td colspan="3">Qp: 515 cfs with Frequency 2 per season
Volume is 649
Duration is 8</td></tr>
<tr><td colspan="12">Translation of seasonal pulse flows of specified frequencies into environmental flow standards and permit conditions may result in less frequent occurrence of high flow pulses as a result of the issuance of new surface water appropriations or amendments. This reduced frequency of occurrence is deemed an acceptable environmental risk at this time, subject to review as new studies and information become available.</td></tr>
<tr><td rowspan="4">Base Flows (cfs)</td><td colspan="3">2500</td><td colspan="3">2160</td><td colspan="3">151</td><td colspan="3">381</td></tr>
<tr><td colspan="3">1390</td><td colspan="3">1020</td><td colspan="3">88</td><td colspan="3">168</td></tr>
<tr><td colspan="3">548</td><td colspan="3">382</td><td colspan="3">61</td><td colspan="3">82</td></tr>
<tr><td colspan="12">Seasonal base flows represent thresholds for environmental protection based on current scientific understanding of fluvial and estuarine ecosystems. As new studies and monitoring information become available, these base flow thresholds may be revised.</td></tr>
<tr><td rowspan="2">Subsistence Flows (cfs)</td><td colspan="3">67</td><td colspan="3">29</td><td colspan="3">21</td><td colspan="3">21</td></tr>
<tr><td colspan="12">Translation of seasonal subsistence flows into environmental flow standards and permit conditions should not result in more frequent occurrence of flows less than the recommended seasonal subsistence values as a result of the issuance of new surface water appropriations or amendments.</td></tr>
<tr><td></td><td>Jan</td><td>Feb</td><td>Mar</td><td>Apr</td><td>May</td><td>Jun</td><td>Jul</td><td>Aug</td><td>Sep</td><td>Oct</td><td>Nov</td><td>Dec</td></tr>
<tr><td></td><td colspan="3">Winter</td><td colspan="3">Spring</td><td colspan="3">Summer</td><td colspan="3">Fall</td></tr>
</table>

6.2.2.3 Angelina River near Alto, TX

Sub-Basin Description The drainage area for this gage is 1,276 sq-mi, of which 987 sq-mi (77%) is uncontrolled. It is in TCEQ Segment 0611, Angelina River Above Sam Rayburn Reservoir. Segment 0611 of the Angelina River extends from the aqueduct crossing 1.0 kilometer (0.6 mile) upstream of the confluence of Paper Mill Creek in Angelina/Nacogdoches County to the confluence of Barnhardt Creek and Mill Creek at FM 225 in Rusk County. The upper segment is part of the Tertiary Uplands located in the South Central Plains Ecoregion. The landscape is dissected by numerous small streams and primarily consists of rolling hills, gently to moderately sloping.

FIGURE 31. HEFR MATRIX FOR ANGELINA RIVER NEAR ALTO, TEXAS

USGS 08036500 Angelina Rv nr Alto, TX

Full Period

	Winter (Jan, Feb, Mar)	Spring (Apr, May, Jun)	Summer (Jul, Aug, Sep)	Fall (Oct, Nov, Dec)
Overbank Flows	Qp: 9,690 cfs with Frequency 1 per 2 years Volume is 204,931 Duration is 29			
	Overbank flows may cause extensive damage to private property and endanger the public. Therefore, the Sabine-Neches BBEST recognizes the ecological benefits of these events, but cannot recommend such events be produced.			
High Flow Pulses	Qp: 3,530 cfs with Frequency 1 per season Volume is 89,332 Duration is 18	Qp: 2,760 cfs with Frequency 1 per season Volume is 59,278 Duration is 20	Qp: 397 cfs with Frequency 1 per season Volume is 7,129 Duration is 13	Qp: 1,500 cfs with Frequency 1 per season Volume is 34,291 Duration is 16
	Qp: 1,620 cfs with Frequency 2 per season Volume is 37,114 Duration is 13	Qp: 1,100 cfs with Frequency 2 per season Volume is 24,117 Duration is 14	Qp: 146 cfs with Frequency 2 per season Volume is 2,632 Duration is 8	Qp: 588 cfs with Frequency 2 per season Volume is 12,038 Duration is 12
	Translation of seasonal pulse flows of specified frequencies into environmental flow standards and permit conditions may result in less frequent occurrence of high flow pulses as a result of the issuance of new surface water appropriations or amendments. This reduced frequency of occurrence is deemed an acceptable environmental risk at this time, subject to review as new studies and information become available.			
Base Flows (cfs)	971	518	69	176
	581	206	48	92
	252	82	36	47
	Seasonal base flows represent thresholds for environmental protection based on current scientific understanding of fluvial and estuarine ecosystems. As new studies and monitoring information become available, these base flow thresholds may be revised.			
Subsistence Flows (cfs)	55	18	11	16
	Translation of seasonal subsistence flows into environmental flow standards and permit conditions should not result in more frequent occurrence of flows less than the recommended seasonal subsistence values as a result of the issuance of new surface water appropriations or amendments.			

6.2.2.4 ATTOYAC BAYOU NEAR CHIRENO, TX

Sub-Basin Description The drainage area for this gage is 503 sq-mi, of which 489 sq-mi (97%) is uncontrolled. This gage has measured basically natural flow for most of this period of record and represents a major tributary in the Neches Basin with minimal control. It is in TCEQ Segment 0612, Attoyac Bayou. (FNI 2009a) Segment 0612 is from a point 3.9 kilometers (2.4 miles) downstream of Curry Creek in Nacogdoches/San Augustine County to FM 95 in Rusk County. This station is located in the middle of the segment which is in the Tertiary Uplands portion of the South Central Plains Ecoregion. Land cover is mixed forest, pasture, and pine plantations with timber production, livestock and poultry production as the most common land uses in the region.

FIGURE 32. HEFR MATRIX FOR ATTOYAC BAYOU NEAR CHIRENO, TEXAS

USGS 08038000 Attoyac Bayou nr Chireno, TX

1956-1984 Period

<table>
<tr><td rowspan="2">Overbank Flows</td><td colspan="12">Qp: 7,520 cfs with Frequency 1 per 2 years
Volume is 91,536
Duration is 27</td></tr>
<tr><td colspan="12">Overbank flows may cause extensive damage to private property and endanger the public. Therefore, the Sabine-Neches BBEST recognizes the ecological benefits of these events, but cannot recommend such events be produced.</td></tr>
<tr><td rowspan="3">High Flow Pulses</td><td colspan="3">Qp: 1,200 cfs with Frequency 1 per season
Volume is 19,704
Duration is 12</td><td colspan="3">Qp: 1,200 cfs with Frequency 1 per season
Volume is 18,062
Duration is 15</td><td colspan="3">Qp: 390 cfs with Frequency 1 per season
Volume is 5,384
Duration is 12</td><td colspan="3">Qp: 898 cfs with Frequency 1 per season
Volume is 16,133
Duration is 12</td></tr>
<tr><td colspan="3">Qp: 837 cfs with Frequency 2 per season
Volume is 13,871
Duration is 10</td><td colspan="3">Qp: 690 cfs with Frequency 2 per season
Volume is 10,618
Duration is 13</td><td colspan="3">Qp: 146 cfs with Frequency 2 per season
Volume is 1,888
Duration is 7</td><td colspan="3">Qp: 405 cfs with Frequency 2 per season
Volume is 6,353
Duration is 9</td></tr>
<tr><td colspan="12">Translation of seasonal pulse flows of specified frequencies into environmental flow standards and permit conditions may result in less frequent occurrence of high flow pulses as a result of the issuance of new surface water appropriations or amendments. This reduced frequency of occurrence is deemed an acceptable environmental risk at this time, subject to review as new studies and information become available.</td></tr>
<tr><td rowspan="4">Base Flows (cfs)</td><td colspan="3">339</td><td colspan="3">178</td><td colspan="3">48</td><td colspan="3">122</td></tr>
<tr><td colspan="3">188</td><td colspan="3">96</td><td colspan="3">28</td><td colspan="3">65</td></tr>
<tr><td colspan="3">107</td><td colspan="3">49</td><td colspan="3">20</td><td colspan="3">34</td></tr>
<tr><td colspan="12">Seasonal base flows represent thresholds for environmental protection based on current scientific understanding of fluvial and estuarine ecosystems. As new studies and monitoring information become available, these base flow thresholds may be revised.</td></tr>
<tr><td rowspan="2">Subsistence Flows (cfs)</td><td colspan="3">29</td><td colspan="3">10</td><td colspan="3">10</td><td colspan="3">10</td></tr>
<tr><td colspan="12">Translation of seasonal subsistence flows into environmental flow standards and permit conditions should not result in more frequent occurrence of flows less than the recommended seasonal subsistence values as a result of the issuance of new surface water appropriations or amendments.</td></tr>
<tr><td></td><td>Jan</td><td>Feb</td><td>Mar</td><td>Apr</td><td>May</td><td>Jun</td><td>Jul</td><td>Aug</td><td>Sep</td><td>Oct</td><td>Nov</td><td>Dec</td></tr>
<tr><td></td><td colspan="3">Winter</td><td colspan="3">Spring</td><td colspan="3">Summer</td><td colspan="3">Fall</td></tr>
</table>

6.2.2.5 NECHES RIVER AT EVADALE, TX

Sub-Basin Description The drainage area for this gage is 7,951 sq-mi, of which 378 sq-mi (5%) is uncontrolled. The Evadale gage is downstream of the Sam Rayburn/B.A. Steinhagen reservoir system and measures a significant portion of the inflow into Sabine Lake. It is in TCEQ Segment 0602, Neches River Below BA Steinhagen Lk (FNI 2009a). Segment 0602 is from the Neches River Saltwater Barrier in Jefferson/Orange County to the Town Bluff Dam in Jasper/Tyler County. The segment is primarily located in the Flatwoods portion of the South Central Plains Ecoregion. The segment is characterized by flat plains and low gradient streams with sandy and silty substrates. Five units of the Big Thicket National Preserve are located within the segment. Land uses include timber production, oil and gas production, and some pasture and cattle production.

FIGURE 33. HEFR MATRIX FOR NECHES RIVER AT EVADALE, TEXAS

USGS 08041000 Neches Rv at Evadale, TX

Full Period

	Winter (Jan, Feb, Mar)	Spring (Apr, May, Jun)	Summer (Jul, Aug, Sep)	Fall (Oct, Nov, Dec)
Overbank Flows	Qp: 19,900 cfs with Frequency 1 per year Volume is 812,910 Duration is 37			
Overbank Flows	Overbank flows may cause extensive damage to private property and endanger the public. Therefore, the Sabine-Neches BBEST recognizes the ecological benefits of these events, but cannot recommend such events be produced.			
High Flow Pulses	Qp: 8,700 cfs with Frequency 1 per season Volume is 246,099 Duration is 22	Qp: 8,700 cfs with Frequency 1 per season Volume is 246,099 Duration is 22	Qp: 3,680 cfs with Frequency 1 per season Volume is 69,561 Duration is 13	Qp: 4,160 cfs with Frequency 1 per season Volume is 71,531 Duration is 13
High Flow Pulses	Qp: 2,020 cfs with Frequency 2 per season Volume is 20,920 Duration is 6	Qp: 3,830 cfs with Frequency 2 per season Volume is 68,784 Duration is 12	Qp: 1,540 cfs with Frequency 2 per season Volume is 21,605 Duration is 9	Qp: 1,570 cfs with Frequency 2 per season Volume is 17,815 Duration is 7
High Flow Pulses	Translation of seasonal pulse flows of specified frequencies into environmental flow standards and permit conditions may result in less frequent occurrence of high flow pulses as a result of the issuance of new surface water appropriations or amendments. This reduced frequency of occurrence is deemed an acceptable environmental risk at this time, subject to review as new studies and information become available.			
Base Flows (cfs)	4988	3960	3230	2730
Base Flows (cfs)	2635	3210	2250	1570
Base Flows (cfs)	1750	1640	527	465
Base Flows (cfs)	Seasonal base flows represent thresholds for environmental protection based on current scientific understanding of fluvial and estuarine ecosystems. As new studies and monitoring information become available, these base flow thresholds may be revised.			
Subsistence Flows (cfs)	228	266	228	228
Subsistence Flows (cfs)	Translation of seasonal subsistence flows into environmental flow standards and permit conditions should not result in more frequent occurrence of flows less than the recommended seasonal subsistence values as a result of the issuance of new surface water appropriations or amendments.			

6.2.2.6 Village Creek near Kountze, TX

Sub-Basin Description The drainage area for this gage is 860 sq-mi, of which 860 sq-mi (100%) is uncontrolled. This gage is unaffected by hydropower and measures a significant portion of the inflow into Sabine Lake. It is in TCEQ Segment 0608, Village Creek (FNI 2009a). Segment 0608 is from the confluence with the Neches River in Hardin County to the confluence of Big Sandy Creek and Kimball Creek in Hardin County. The segment is located in the Flatwoods and Southern Tertiary Uplands of the South Central Plains Ecoregion. Land uses include timber production, oil and gas production, pasture and cattle production, recreation, and wildlife habitat.

FIGURE 34. HEFR MATRIX FOR VILLAGE CREEK NEAR KOUNTZE, TEXAS

USGS 08041500 Village Crk nr Kountze, TX

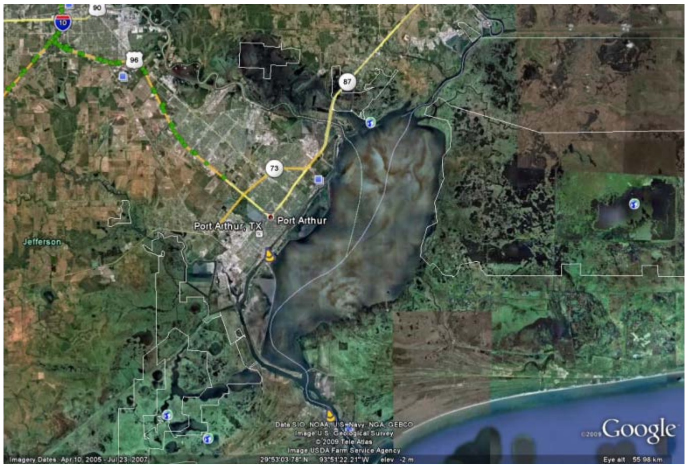
Full Period

	Winter (Jan, Feb, Mar)	Spring (Apr, May, Jun)	Summer (Jul, Aug, Sep)	Fall (Oct, Nov, Dec)
Overbank Flows	Qp: 12,400 cfs with Frequency 1 per 2 years Volume is 170,313 Duration is 29			
Overbank Flows	Overbank flows may cause extensive damage to private property and endanger the public. Therefore, the Sabine-Neches BBEST recognizes the ecological benefits of these events, but cannot recommend such events be produced.			
High Flow Pulses	Qp: 2,070 cfs with Frequency 1 per season Volume is 38,134 Duration is 13	Qp: 2,070 cfs with Frequency 1 per season Volume is 31,650 Duration is 15	Qp: 814 cfs with Frequency 1 per season Volume is 11,418 Duration is 13	Qp: 2,070 cfs with Frequency 1 per season Volume is 31,143 Duration is 13
High Flow Pulses	Qp: 2,010 cfs with Frequency 2 per season Volume is 36,927 Duration is 13	Qp: 1,380 cfs with Frequency 2 per season Volume is 23,093 Duration is 13	Qp: 341 cfs with Frequency 2 per season Volume is 6,159 Duration is 8	Qp: 712 cfs with Frequency 2 per season Volume is 11,426 Duration is 9
High Flow Pulses	Translation of seasonal pulse flows of specified frequencies into environmental flow standards and permit conditions may result in less frequent occurrence of high flow pulses as a result of the issuance of new surface water appropriations or amendments. This reduced frequency of occurrence is deemed an acceptable environmental risk at this time, subject to review as new studies and information become available.			
Base Flows (cfs)	672	335	135	236
Base Flows (cfs)	424	189	91	138
Base Flows (cfs)	240	106	70	89
Base Flows (cfs)	Seasonal base flows represent thresholds for environmental protection based on current scientific understanding of fluvial and estuarine ecosystems. As new studies and monitoring information become available, these base flow thresholds may be revised.			
Subsistence Flows (cfs)	83	49	41	41
Subsistence Flows (cfs)	Translation of seasonal subsistence flows into environmental flow standards and permit conditions should not result in more frequent occurrence of flows less than the recommended seasonal subsistence values as a result of the issuance of new surface water appropriations or amendments.			

6.2.3 Sabine-Neches Estuary (Sabine Lake)

6.2.3.1 Estuary Description

Numerous man-made alterations have influenced the current ecological condition in the Sabine-Neches Estuary and the lower tidal reaches of the Sabine and Neches Rivers. These systems are generally sound, exhibiting good overall water quality and diverse fish and wildlife communities (Tatum 2009). The Sabine-Neches Estuary receives more fresh water than all other estuaries on the Texas Gulf Coast (see Table 17, page 143) and provides enough fresh water to Sabine Lake for the focal species studied there (NWF 2009). Sediment transport and concentration are within a range that is indicative of a sound ecological environment (Section 5.3, page 86). However, navigation channels and marsh canals are limiting the effectiveness of these fresh water inflows and sediment loads (Boesch, Josselyn et al. 1994, and references therein). See also Estuary History (page 30), Section 5.2.1 Fluvial Ecosystem Realm (page 62), and Figure 5 Sabine and Neches Rivers and Sabine-Neches Estuary (Sabine Lake) (page 25).



The Sabine-Neches BBEST considered information presented indicating the Sabine-Neches Estuary has an uncommonly large volume of freshwater inflows applied to its relatively small size (Table 17, below). The SAC "Report on Water for Environmental Flows" (Science Advisory Committee 2004) provided the following summary statement and data table for the Sabine-Neches Estuary (Section 4.3.1, page 4-5):

> *Sabine Lake, a lagoonal embayment, which encompasses the estuaries of the Neches and Sabine Rivers, is located on the state line with Louisiana, receives the highest inflow per unit volume of the Texas bays, and has abundant freshwater marshes around its periphery. Salinities generally remain low and in many areas promote the growth of plants that thrive in freshwater. The Salt Bayou marsh complex, where ducks, juvenile shrimp, and fish thrive, contains over 60,000 acres of valuable habitat. Many of these intermediate marshes in the Sabine Lake system have been damaged or lost due to saltwater intrusion resulting from ship channels, brine disposal from historic oilfield exploration and production, and relative sea level rise. Extensive marsh restoration efforts are ongoing around Sabine Lake. The pending deepening and widening of the Sabine-Neches Waterway and continuing relative sea level rise will result in more saltwater entering the bay from the Gulf with unknown consequences to the health of the bay and its freshwater marshes.*

TABLE 17. SUMMARY INFORMATION FOR MAJOR TEXAS ESTUARIES

Bay	Surface Area (acres)	Drainage Area as % of Texas	Drainage Area (sq. miles)	Average Annual Freshwater Inflow (acre-feet)	Average Salinity ppt (a)	Number Of Fish Species (b)
Sabine Lake	60,000	7	18,000	14,000,000	5	115
Galveston Bay	350,000	12	33,000	10,000,000	15	163
Matagorda Bay	270,000	16	44,000	3,100,000	20	181
San Antonio Bay	130,000	4	11,000	2,300,000	15	180
Aransas-Copano Bay	130,000	1	2,700	440,000	15	174
Corpus Christi Bay	120,000	6	17,000	600,000	30	187
Laguna Madre	370,000	4	10,000	610,000	35	192

(a) Orlando, et al, 1993—Average salinities have been rounded to the nearest 5 ppt.
(b) Texas Parks and Wildlife Department Coastal Fisheries monitoring data from 1977 to 1997.

6.2.3.2 SAC Guidance on Modeling Inflow Recommendations to the Sabine-Neches Estuary

The SAC provides guidance on some methods that were reviewed for possible application in recommending inflows to meet needs of an estuarine environment, specifically, in the Sabine-Neches Study Area case, for the Sabine-Neches Estuary. Three such methods include the State Methodology (which was used by the State to develop recommendations for inflows and is discussed in more detail in Section 5.2 Biology (Ecological Review), page 62 and Appendix XIII), the Salinity zone approach (discussed below), and the HEFR analyses (discussed below). According to "Methodologies for Establishing a Freshwater Inflow Regime for Texas Estuaries" (SAC 2009d):

> *The salinity-zone approach assesses the suitability of the distribution of salinity within an estuary for a specific organism. … It therefore is a combination of salinity-preference/tolerance limits and salinity mapping, and requires data depicting both classes of information. … Its novelty is in the geographical display of the salinity information within the estuary in a form that is relevant to the organism of concern, … An alternative is to employ the predictions of salinity from a hydrodynamic/ salinity-transport model at a specified inflow regime.*

Strengths of the salinity zone approach

- Provides quantitative measure of the extent of the desirable salinity range within the estuary;
- Is not as sensitive to minor variations in inflow and associated isohaline locations;

- Allows capability to combine salinity zone with other geographical features of the estuary, e.g. shallow-water zones, marshes, etc.; and
- Affords graphic display capability to easily communicate results.

Weaknesses of the salinity zone approach

- Is dependent upon the accuracy with which isohaline patterns may be delineated.
- In the case of the TPWD verification analysis, is based upon TxBLEND-generated isohalines, which is not yet a well-validated model. (Note that the calibration results support the use of TxBLEND for this purpose, validation of the model is in progress, and that other models could equally well be used.)

The salinity zone approach is the basis for much of the work done in the NWF study of *R. cuneata* and other species Study (Appendix XVI). The bottom line from the NWF study was that some species such as blue crab, oysters, and *R. cuneata*, could have increased suitability indices under average conditions but some concerns were expressed for marsh species (recognizing open water modeled salinities were used for marsh species habitat) and for some of the species under subsistence flow conditions. It is also of note that subsistence flows at the time of the NWF analysis were later adjusted from a single, year-round value, to seasonal values, which are expected to improve subsistence flow conditions that were modeled in the NWF study. Furthermore, the NWF study did not include passage of seasonal base flows under dry hydrologic conditions.

The SAC recognized the use of HEFR as an estuary inflows recommendation tool and provided some insight into its utility and some situations where it might not be fully effective (SAC 2009d):

Strengths of HEFR include

- Hydrologic data are relatively robust and consistent at multiple locations, compared to other potential datasets. HEFR shares this strength with other hydrologic methods;
- Hydrology has been considered the master variable in regards to environmental instream flows and may also be considered a very important variable with regards to estuarine inflows. HEFR shares this strength with other hydrologic methods.
- HEFR is computationally efficient, allowing for repeated tests and exploratory analyses;
- There is significant flexibility in setting parameters to parse the hydrograph as well as summary statistics of the flow regime components;
- HEFR outputs have the same format as expected results from the TIFP studies;
- HEFR provides an initial set of recommendations that reflect key aspects of the natural flow regime including multiple flow components and hydrologic conditions (Poff, Allan et al. 1997).

Weaknesses of HEFR include

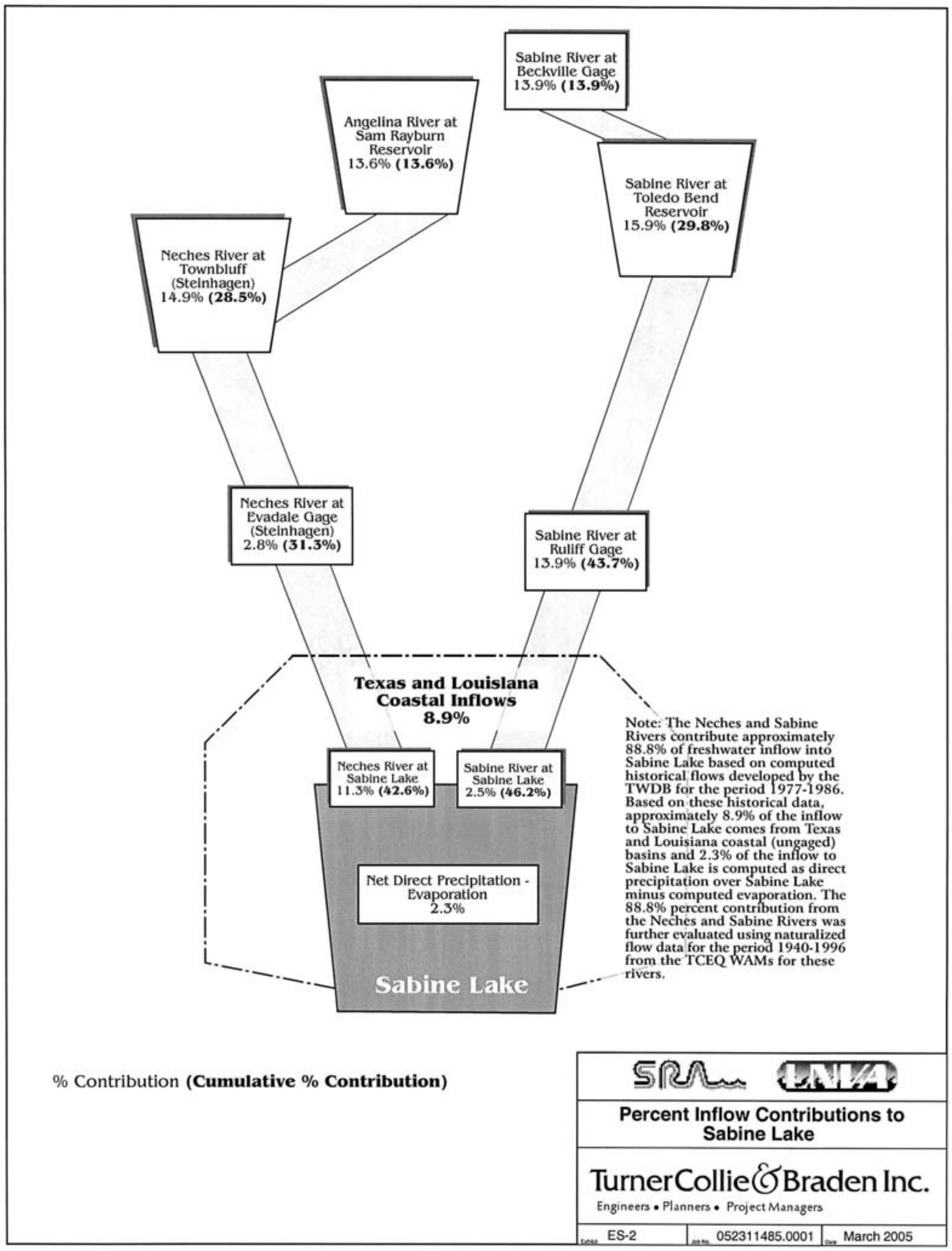
- HEFR is largely designed to mirror some fraction of historical hydrology and is not based on a defined flow alteration - ecological response relationship. In a similar vein, HEFR has not been validated against biological, geomorphological, and water quality data. HEFR shares this weakness with other hydrologic methods.
- HEFR is not suitable where hydrologic data are lacking and cannot be synthesized. HEFR shares this weakness with other hydrologic methods.

- There is no track record of application of HEFR, especially in an estuary setting, and there are few precedents for some of the decisions that must be made.
- HEFR would not provide useful results in minor bays or lagoons with little inflow.

The HEFR analysis methodology was used by the Sabine-Neches BBEST in its inflows recommendations. The Sabine-Neches BBEST recognized ongoing work in Sabine Lake and the surrounding marshes towards a goal to minimize the impacts of manmade saltwater intrusion routes into the marshes (discussed more fully in Section 0 ***This page intentionally blank***

Estuary History, page 30) and chose to recommend HEFR inflows from the most downstream gages as inflows sufficient to meet estuary needs if there was no compelling evidence to indicate otherwise (Figure 35, below).

FIGURE 35. PERCENT INFLOW CONTRIBUTIONS TO SABINE LAKE



6.2.3.3 U.S. Army Corps of Engineers Sabine-Neches Estuary Project

The Sabine-Neches BBEST further recognized ongoing efforts by the USACE in modeling salinity in the estuary as a part of their ongoing considerations for further deepening the Sabine-Neches Ship Canal. The USACE has spent approximately $15 million since 2000 on modeling and feasibility studies for a project that proposes to deepen the channel from forty feet to forty-eight feet plus advanced dredging from the Gulf of Mexico, through Sabine Lake and up to the Port of Beaumont. Much of the USACE work is still in draft documents undergoing edit and review and was not available for reference by the Sabine-Neches BBEST. However, some main points can still be made regarding this substantial work and its application to the Sabine-Neches BBEST's process. Extensive three-dimensional hydro-dynamic salinity modeling with salinity and flow data collected for the project was used to predict salinity changes from the project. In addition, the USACE included increased upstream water demands, return flows, and reservoir storage capacities based on 2007 Texas State Water Plan (Texas Water Development Board. 2007) data and WAM Run 8 in its salinity and inflow model to predict future conditions to year 2060. In addition to freshwater inflow modeling, the USACE modeled predicted future sea level rise and its impacts on salinity. The Sabine-Neches BBEST understands some additional analyses were requested since that meeting and modeling results may change. The USACE is proposing to utilize dredge material to assist in the mitigation and restoration of habitat loss due to incremental salinity increases from the project. Other habitat protection measures being undertaken, for example, in Louisiana, include rock weir control structures to reduce saltwater intrusion into fresh and intermediate marshes through manmade navigation channels. The USACE project is the culmination of nine years of work and is far beyond the scope of analysis the Sabine-Neches BBEST had time or resources to perform. The Sabine-Neches BBEST suggests information from USACE work will soon be available to supplement its knowledge of the estuary and will assist in determination of future assessment needs and evaluation of estuarine habitat mitigation/restoration programs as they relate to adaptive management (a draft report is scheduled to be released for public review on December 17, 2009, and a final report is expected in August 2010).

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7 GLOSSARY OF TERMS AND ACRONYMS

7Q10 - The lowest average stream flow for seven consecutive days with a recurrence interval of 10 years

7Q2 - The lowest average stream flow for seven consecutive days with a recurrence interval of two years, as statistically determined from historical data. In Texas, the minimum flow at which the Surface Water Quality Standards generally apply.

ANRA - Angelina Neches River Authority

Base flows - the component of an instream flow regime that represents normal flow conditions (including variability) between precipitation events. Base flows provide a range of suitable habitat conditions that support the natural biological community of a specific river sub-basin.

BBASC - Bay and Basin Area Stakeholder Committee

BBEST - Bay and Basin Expert Science Team

cfs - cubic feet per second - U.S. customary unit volumetric flow rate, which is equivalent to a volume of 1 cubic foot flowing every second.

CWA - Clean Water Act

Environmental flow analysis - for Senate Bill 3 - application of a scientifically derived process for predicting the response of an ecosystem to changes in instream flows or freshwater inflows.

Environmental flow regimes - for Senate Bill 3 - schedules of flow quantities that reflect seasonal and yearly fluctuations for specific areas of watersheds, 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.

Estuary condition - the suite of physical and chemical variables potentially important, either directly or indirectly, to the functioning of an estuary ecosystem.

DEM – Digital Elevation Model

DO - the amount of oxygen gas dissolved in a given quantity of water at a given temperature and atmospheric pressure. Dissolved oxygen is a requirement for the metabolism of aerobic organisms and also influences inorganic chemical reactions. Oxygen dissolves into water by diffusion from the surrounding air, is introduced through rapid movement (aeration), or is produced as a byproduct of photosynthesis.

EFAG - Environmental Flows Advisory Group

EFC - Environmental Flow Components

EPA - Environmental Protection Agency

ETRWPG - East Texas Regional Water Planning Group

FERC - Federal Energy Regulatory Commission

FNI - Freese and Nichols, Inc

GEAA - Greater Edwards Aquifer Alliance

GIWW - Gulf Intracoastal Waterway

Habitat preference - some aspect of the habitat that a species will use out of proportion to its availability.

Habitat requirement - some aspect of the habitat without which a species cannot survive over the long term.

Habitat specialists - species that require specific substrates, current velocities, or depths.

HEFR - Hydrology-Based Environmental Flow Regime - A methodology that provides a relatively flexible computational approach for developing a flow regime matrix that is consistent with the TIFP multi-tiered framework for describing essential flow requirements.

High flow pulses - the component of an instream flow regime that represents short-duration, in-channel, high flow events following storm events. These flows maintain riparian areas and provide lateral connectivity between the river channel and active floodplain. They may also provide life-cycle cues for various species.

HPOR – Historical Period of Record

HUC - Hydrologic Unit Code - The United States is divided and sub-divided into successively smaller hydrologic units which are classified into four levels: regions, sub- regions, accounting units, and cataloging units. The hydrologic units are arranged within each other, from the smallest (cataloging units) to the largest (regions). Each hydrologic unit is identified by a unique code (a HUC) consisting of two to eight digits based on the four levels of classification in the hydrologic unit system.

IFIM - Instream Flow Incremental Methodology

IHA - Indicators of Hydrologic Alteration - a software program that provides useful information for those trying to understand the hydrologic impacts of human activities or trying to develop environmental flow recommendations for water managers. This program was developed by scientists at the Nature Conservancy to facilitate hydrologic analysis in an ecologically- meaningful manner.

ILP - Integrated License Process

Instream flow recommendations - instream flow conditions (i.e., the magnitude and timing of flow events) necessary to maintain an ecologically sound environment in rivers and streams as developed by applying the best available methods. Recommendations are in the form of an instream flow regime that includes subsistence flows, base flows, high flow pulses, and overbank flows.

LDWF - Louisiana Department of Wildlife and Fisheries

ln – Natural Logarithm

LNVA - Lower Neches Valley Authority

Lyons Method - Desk-top method for establishing environmental flows. Specifies 40 percent of the monthly median flow from October to February and 60 percent of the monthly median flow from March to September as minimum flows, with the 60 percent level chosen to be more protective of the riverine ecosystem during the spring and summer periods, considered most critical to the warmwater fishes found in Texas. Default TCEQ method for permitting new, relatively small water rights or for amending certain existing water rights.

MaxC – the State Methodology model solution with the maximum total (annual) catch and satisfies applicable constraints; this inflow lies between MinQ and MaxQ

MaxQ – the maximum inflow which satisfies all the salinity and biological constraints of the State Methodology model

MBFIT - Modified Base Flow Index with Threshold method - hydrographic separation algorithm

MinQ – the minimum inflow that meets the salinity and biological constraints of the State Methodology model

NPDES - National Pollutant Discharge Elimination System

NRC - National Research Council

NWF – National Wildlife Federation

NWS – National Weather Service

Obligate riverine species - requires flowing water habitat for all or part of their life cycle.

Overbank flows - the component of an instream flow regime that represents infrequent, high flow events that exceed the normal channel. These flows maintain riparian areas and provide lateral connectivity between the river channel and active floodplain. They may also provide life-cycle cues for various species.

PAD – Pre-Application Document

PHABSIM - Physical Habitat Simulation (Software)

RWPG - Regional Water Planning Group

SAC - Science Advisory Group

SAM – Sediment Transport Model

SB1 – Senate Bill 1

SB2 - Senate Bill 2

SB3 - Senate Bill 3

Sabine-Neches BBEST - Sabine and Neches Rivers and Sabine Lake Bay and Basin Expert Science Team

SNWW - Sabine Neches Waterway

SRA-LA - Sabine River Authority of Louisiana

SRA-TX - Sabine River Authority of Texas

SRCA - Sabine River Compact Administration

SRC - Sabine River Compact

SSL - Suspended-Sediment Load

Subsistence flows - the component of an instream flow regime that represents infrequent, naturally occurring low flow events that occur for a seasonal period of time. They maintain sufficient water quality and provide sufficient habitat to ensure organism populations capable of recolonizing the river system once normal, base flows return.

TBPJO - Toledo Bend Project Joint Operation

Thalweg - (sometimes called the "valley line") is a line drawn to join the lowest points along the entire length of a streambed or valley in its downward slope, defining its deepest channel. It thus marks the natural direction (the profile) of a watercourse. The thalweg is almost always the line of fastest flow in any river. The term is also sometimes used to refer to a subterranean stream that percolates under the surface and in the same general direction as the surface stream.

TIFP - Texas Instream Flows Program

TCEQ - Texas Commission on Environmental Quality

TCRP – Texas Clean Rivers Program

TPWD - Texas Parks and Wildlife Department

TSWQS - Texas Surface Water Quality Standards

TWC – Texas Water Code

TWDB - Texas Water Development Board

TX-HAT - Texas Hydrologic Assessment Tool

UNRMWA - Upper Neches River Municipal Water Authority

USACE - United States Army Corp of Engineers

USFWS - U.S. Fish and Wildlife Service

USGS - U.S. Geological Survey

WAM - Water Availability Model

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AECOM (2009). Cutoff Bayou Investigation.

The hydrologic flow conditions in the lower Sabine River Basin are complexly interrelated. That is evidenced by the historic and present flow distribution between the Texas and Louisiana channels occurring near Cutoff Bayou. Recent observations indicate that during low flow conditions, distribution appears to favor Louisiana with greater quantities of water. If recently observed trends were to continue, there is potential for flow during normal flow, and especially during low flow, conditions to be essentially eliminated in the Sabine River within Texas below Cutoff Bayou. These conditions may establish the Old River in Louisiana as the sole conveyance channel to the Gulf of Mexico through that reach. The purpose of this preliminary investigation is to determine what engineered measures might be taken to change this trend and to re-establish the historical flow distribution observed at the Cutoff Bayou area.

Annear, T., I. Chisholm, et al. (2004). Instream Flows for Riverine Resource Stewardship, revised edition. Cheyenne, Wyoming. Retrieved November 6, 2009, from http://www.atlasbooks.com/marktplc/00710.htm.

This book provides a detailed description of riverine ecosystem management concepts and strategies for aquatic resource managers and others involved in the determination of instream flow needs and water management. This revised edition is fully illustrated and cites over 600 references to provide a comprehensive treatment of riverine ecology, the role of the public, and legal aspects of river management. The book contains 46 policy statements related to program development and study design and includes descriptions and critical opinions of 34 instream flow methods.

Bart, H. L. (2008). Extraction, analysis, and summary of fish community data from the Sabine River System (Louisiana, Texas). Final Report to Sabine River Authority of Texas. Retrieved November 5, 2009, from ftp://ftp.sratx.org/pub/BBEST/Library/BBEST_027.pdf.

Data from periodic fish surveys of the Sabine River covering a 60 year time period were extracted from the fish collection database of the Tulane University Museum of Natural History.

Biedenharn, D. S., R. R. Copeland, et al. (2000). Effective discharge calculation: A practical guide. U. S. Army and C. o. Engineers. Washington, D.C.

BIO-WEST (2008a). Lower Colorado River, Texas. Instream Flow Guidelines. Colorado River Flow Relationships to Aquatic Habitat and State Threatened Species: Blue Sucker. Technical report prepared for the Lower Colorado River Authority and San Antonio Water System. Round Rock, Texas. Retrieved October 1, 2009, from http://www.lcra.org/library/media/public/docs/lswp/findings/BIO_LSWP_IFguidelines_FINAL.pdf.

This study was developed to assess potential impacts or benefits resulting from the LCRA-SAWS Water Project (LSWP) and address the environmental principles applied to the project.

BIO-WEST (2008b). Preliminary instream flow assessment for the Lower San Antonio River (Interim subsistence and Base-Dry instream flow guidelines development), Report to the San Antonio River Authority.

BIO-WEST (2009a). Estuarine Focal Species Summary Report. Retrieved November 8, 2009, from http://www.sratx.org/BBEST/RecommendationsReport/LinkedDocuments/FINAL_Estuarine_Report_Sabine_BBEST_31Aug09.pdf.

This document provides a summary of ecological information on focal plant and animal species within the Sabine-Neches Estuary (Sabine Lake) to support environmental flow recommendations by the Sabine/Neches Basin and Bay Expert Science Team (BBEST).

BIO-WEST (2009b). Fluvial Focal Species Summary Report. Retrieved November 8, 2009, from http://www.sratx.org/BBEST/RecommendationsReport/LinkedDocuments/FINAL_Fluvial_Report_Sabine_BBEST_31Aug09.pdf.

This document provides a summary of ecological information on focal aquatic and riparian species within the Sabine River and Neches River watersheds to support instream flow recommendations by the Sabine/Neches Basin and Bay Expert Science Team (BBEST).

Boesch, D. F., M. N. Josselyn, et al. (1994). "Scientific assessment of coastal wetland loss, restoration and management in Louisiana." Journal of Coastal Research(Special Issue No. 20).

Bonner, T. and D. T. Runyan (2007). Fish assemblage changes in three Western Gulf Slope drainages. Final Report to the Texas Water Development Board (2205-483-033). Final Report to Sabine River Authority of Texas. Retrieved November 5, 2009, from ftp://ftp.sratx.org/pub/BBEST/Library/BBEST_006.pdf.

Analyzed existing biological data for the Lower Sabine River sub-basin (as well as two other sub-basins in the state) and constructed an annotated species list. Also evaluated changes in the fish assemblage over time.

Dilts, E., P. Leonard, et al. (2005). Development of an Integrated Flow Regime Recommendation for the Cheoah River, N.C. Proceedings of the 2005 Georgia Water Resources Conference, University of Georgia. Retrieved November 3, 2009, from http://www.uga.edu/water/publication/uploads/DiltsE-GWRCpaper.pdf.

Hydrologic pattern and variability are key determinants of aquatic community structure and stability, but instream flow recommendations commonly fail to reflect these critical components of a natural flow regime, focusing instead on provision of static, minimum flows. Restoration of a true, natural flow regime is often not possible given the existing constraints on stream systems and the competing interests of multiple water users. However, sustained biological diversity and ecosystem function are dependent on the maintenance of intra- and interannual flow regimes and natural functions. Providing an integrated flow regime that is patterned on a natural flow regime should therefore be more ecologically beneficial than other flow regime alternatives that ignore natural hydrologic pattern and variability. The principles of a natural flow regime were applied to the development of an integrated flow regime recommendation for the Cheoah River, North Carolina. The integrated flow regime recommendation consisted of a seasonally variable, aquatic base flow component and a natural-like high flow component, which was characterized by seasonally variable frequency, magnitude, and duration high flow events. The integrated flow regime recommendation was designed to balance the water demands of hydropower generation and reservoir-based recreation, while still achieving resource agency aquatic habitat restoration objectives and providing opportunities for whitewater boating.

Dyson, M., G. Bergkamp, et al., Eds. (2003). The essentials of environmental flows, International Union for Conservation of Nature and Natural Resources. Retrieved November 2, 2009, from http://cmsdata.iucn.org/downloads/flow.pdf.

Environmental Flows Advisory Committee (2006). Final Report. Austin, Texas. Retrieved September 15, 2009, from http://www.twdb.state.tx.us/EnvironmentalFlows/pdfs/REPORT/EFAC_FINAL_REPORT.pdf.

Evans, J. W. and R. L. Noble (1979). "The longitudinal distribution of fishes in an east Texas stream." American Midland Naturalist **101**: 333-343.

FNI (2009a). Analysis of BBEST Stream Gages. Fort Worth, Texas, Freese Nichols, Inc. Retrieved November 8, 2009, from http://www.sratx.org/BBEST/RecommendationsReport/index.html#Topic19.

The Sabine and Neches Rivers and Sabine Lake Bay Basin and Bay Expert Science Team (BBEST) selected six United States Geological Survey (USGS) stream gages in the Sabine River Basin and six USGS stream gages in the Neches River Basin for hydrologic analyses. These gages will serve as the hydrologic basis for flow regime recommendations developed to satisfy the Senate Bill 3 (SB3) environmental flows process. This memorandum describes pertinent data regarding the stream gages, discusses the adequacy of these gages to evaluate flow trends in the Sabine and Neches River Basins and into Sabine Lake, and offers some analyses of flow trends observed at these gages.

FNI (2009b). Hydrology-Based Environmental Flow Regime (HEFR) Analyses for Sabine-Neches Bay and Basin Expert Science Team (BBEST). Fort Worth, Texas, Freese Nichols, Inc. Retrieved November 8, 2009, from http://www.sratx.org/BBEST/RecommendationsReport/index.html#Topic21.

The Senate Bill 3 Science Advisory Committee for Environmental Flows (SAC) developed a draft guidance document Use of Hydrologic Data in the Development of Instream Flow Recommendations for the Environmental Flows Allocation Process and the Hydrology-Based Environmental Flow Regime (HEFR) Methodology to guide the basin advisory groups in developing flow recommendations. One of the options in this document is employing the Hydrology-Based Environmental Flow Regime (HEFR) methodology to determine an environmental flow regime based on historical hydrology. The Sabine Neches Bay and Basin Expert Science Team (BBEST) hired Freese and Nichols, Inc. (FNI) to conduct hydrologic analyses at twelve gages in the Sabine and Neches River Basins and inflows into Sabine Lake, including HEFR analyses.

FNI (2009c). Water Availability Analyses for Sabine-Neches Bay and Basin Expert Science Team (BBEST). Fort Worth, Texas, Freese Nichols, Inc. Retrieved November 8, 2009, from http://www.sratx.org/BBEST/RecommendationsReport/index.html#Topic24.

This memorandum describes an analysis of water available for environmental flows performed by Freese and Nichols, Inc., (FNI) for the Sabine & Neches Rivers and Sabine Lake Bay and Basin Expert Science Team (BBEST). These analyses employed the Texas Commission on Environmental Quality (TCEQ) Water Availability Models (WAM) for the Sabine and Neches River Basins, as modified for use by the Region I Water Planning Group.

Hardy, T. B., C. Addley, et al. (2006). Evaluation of Interim Instream Flow Needs in the lower Klamath River, Phase II, Final Report. Washington D.C., Prepared for: U.S. Department of the Interior**:** 229 pp.

Harrel, R. (2009). Comment on Draft Sabine-Neches BBEST Environmental Flows Recommendations Report. J. W. Tatum.

Howells, R. G., R. W. Neck, et al. (1996). Freshwater Mussels of Texas. Austin, Texas, Texas Parks and Wildlife Press.

This publication provides an introduction to the unionid mussels of Texas with descriptions of each and a general overview of the family, as well as a brief description of other bivalves which may occur in fresh waters of the state.

Kuhn, N. L. and G. Chen (2005). Freshwater Inflow Recommendation for the Sabine Lake Estuary of Texas and Louisiana. Austin, Texas. Retrieved November 6, 2009, from http://midgewater.twdb.state.tx.us/bays_estuaries/Publications/Freshwater%20Inflow%20Recommendation%20for%20the%20Sabine%20Esturary%20of%20Texas%20and%20Louisiana%20-%202005.pdf.

Freshwater inflows are integral to the proper functioning of Texas bays and estuaries. These inflows provide a key source of nutrients and sediments, and also create the salinity gradient within the bay system, which is the defming characteristic of an estuary. Texas Parks and Wildlife Department (TPWD) and the Texas Water Development Board (TWDB) have been charged by the Texas Legislature with determining the freshwater inflows that provide suitable salinity, nutrient and sediment loading regimes (i.e., support a sound estuarine environment) for Texas bays. This report presents the results of the freshwater inflow analysis for the Sabine Lake system.

Kwak, T. J. (1988). "Lateral movement and use of flood plain habitat by fishes of the Kankakee River, Illinois." American Midland Naturalist **120**: 241-249.

Longley, W. L., Ed. (1994). Freshwater Inflows to Texas Bays and Estuaries: Ecological Relationships and Methods for Determination of Needs, Texas Water Development Board. Retrieved September 17, 2009, from http://midgewater.twdb.state.tx.us/bays_estuaries/Publications/FreshwaterInflows-%20Ecological%20Relationships%20and%20Methods%20for%20Determination%20of%20Needs%20-%201994.pdf.

This report integrates the results of recent studies with earlier information to provide a comprehensive overview of the importance of freshwater inflows to Texas estuaries. The report emphasizes the relationship of inflows with the chemical composition and physical nature of estuarine ecosystems, bay habitat distribution, physiological processes, biological productivity, and abundance of fish and shellfish populations. In addition, the report presents a methodology for determining the amount and timing of beneficial inflows needed to maintain the productivity of economically important fisheries species, and the estuarine life on which they depend. This procedure deals effectively with competing inflow requirements among organisms and includes provisions for achieving management goals for specific estuarine habitats and species.

Maidment, D., P. Montagna, et al. (2005). Scientific Principles for Definition of Environmental Flows. Environmental Flows Conference. Texas State University, San Marcos, Texas. Retrieved September 15, 2009, from http://www.ce.utexas.edu/prof/maidment/nrc/TexasInstream/EnvironmentalFlowsConference/EnvFlowPrinciples.pdf.

The purpose of this memorandum is to describe some scientific principles for the establishment of environmental flow requirements in Texas streams, rivers, bays and estuaries.

Moriarty, L. J. and K. O. Winemiller (1997). "Spatial and temporal variation in fish assemblage structure in Village Creek, Hardin County, Texas." Texas Journal of Science **49**(3): Supplement 85-110.

Morton, R. A. (1996). Geological and Historical Development of Sabine Lake-An Overview. Sabine Lake Conference: Where Texas and Louisiana Come Together. Beaumont, Texas. . Retrieved November 7, 2009, from ftp://ftp.sratx.org/pub/BBEST/Library/SabineLakeConferenceSept1996/.

National Research Council Committee (2005). The Science of Instream Flows: A Review of the Texas Instream Flow Program. Washington, D.C., The National Academies Press. from http://books.nap.edu/catalog.php?record_id=11197.

Three state agencies the Texas Water Development Board (TWDB), the Texas Parks and Wildlife Department (TPWD), and the Texas Commission on Environmental Quality (TCEQ) asked a committee of the National Research Council (NRC) to review the Programmatic Work Plan (PWP) and Technical Overview Document (TOD) that outline the state s instream flow initiative. The committee suggested several changes to the proposed plan, such as establishing clearer goals, modifying the flow chart that outlines the necessary steps for conducting an instream flow study, and provide better linkages between individual studies of biology, hydrology and hydraulics, physical processes, and water quality.

NETRWPG (2006). Regional Water Plan
Region D - North East Texas Regional Water Planning Group. Retrieved September 28, 2009, from http://www.twdb.state.tx.us/RWPG/main-docs/2006RWPindex.asp.

This report gives the results of the Second Round planning process for Region D, one of the regions created to implement Senate Bill One. This region is made up of all or part of 19 counties in northeast Texas, including Bowie, Camp, Cass, Delta, Franklin, Gregg, Harrison, Hopkins, Hunt, Lamar, Marion, Morris, Rains, Red River, Smith, Titus, Upshur, Van Zandt and Wood.

NWF (2009). Salinity Suitability Analyses of Rangia cuneata and Other Characteristic Species and Communities of the Sabine-Neches Estuary in Order to Develop a Freshwater Inflow

Regime. Austin, Texas, National Wildlife Federation. Retrieved November 8, 2009, from http://www.sratx.org/BBEST/RecommendationsReport/LinkedDocuments/NWF-SabNechEstuaryFocalSpeciesAnalyses-103109-fnl.pdf.

The analyses presented herein were designed to support the efforts of the Sabine-Neches BBEST to develop an estuarine inflow regime for the Sabine-Neches Estuary (Sabine Lake). Focus was on a suite of four specific species and two marshland communities, all with well-established and published salinity tolerance (a.k.a. salinity suitability) information.

Opdyke, D. (2009). "HEFR: An Overview, with Emphasis on the Most Important Decision Points, April 28, 2009." Presentation to SB3 Sabine-Neches BBEST. Retrieved November 19, 2009, 2009, from http://www.tceq.state.tx.us/assets/public/permitting/watersupply/water_rights/eflows/20090428_hefrppt.pdf.

Paille, R. (1996). Water Exchange Patterns and Salinity of Marshes Between Calcasieu and Sabine Lakes. Sabine Lake Conference: Where Texas and Louisiana Come Together. Beaumont, Texas. Retrieved November 6, 2009, from ftp://ftp.sratx.org/pub/BBEST/Library/SabineLakeConferenceSept1996/.

The Sabine National Wildlife Refuge is located between Calcasieu and Sabine Lake, midway between the GulfIntracoastal Waterway (GIWW) to the north and the Gulf of Mexico to the south. Salinity of refuge and adjacent marshes has been monitored routinely by refuge personnel since 1966. Water flow patterns were monitored via routine visual observations during 1991 and 1992.

Phillips, J. D. (2003). "Toledo Bend reservoir and geomorphic response in the lower Sabine River." River Research and Applications **19** (2): 137 - 159. Retrieved November 8, 2009, from http://www3.interscience.wiley.com/journal/102523968/abstract?CRETRY=1&SRETRY=0.

Downstream geomorphic responses of stream channels to dams are complex, variable, and difficult to predict, apparently because the effects of local geological, hydrological, and operational details confound and complicate efforts to apply models and generalizations to individual streams. This sort of complex geomorphic response characterizes the Sabine River, along the Texas and Louisiana border, downstream of the Toledo Bend dam and reservoir. Toledo Bend controls the flow of water and essentially prevents the flux of sediment from three-quarters of the drainage basin to the lower Sabine River. Although the channel is scoured immediately downstream of the dam, further downstream there is little evidence of major changes in sediment transport or deposition, sand supply, or channel morphology attributable to the impoundment. Channels are actively shifting, banks are eroding, and sandbars are migrating, but not in any discernibly different way than before the dam was constructed. The Sabine River continues to transport sand downstream, and alluvial floodplains continue to accrete. The relatively small geomorphic response can be attributed to several factors. While dam releases are unnaturally flashy and abrupt on a day-to-day basis, the long-term pattern of releases combined with some downstream smoothing creates a flow regime in the lower basin which mimics the pre-dam regime, at least at monthly and annual time scales. Sediment production within the lower Sabine basin is sufficient to satisfy the river's sediment transport capacity and maintain pre-dam alluvial sedimentation regimes. Toledo Bend reservoir has a capacity: annual inflow ratio of 1.2 and impounds 74% of the Sabine drainage basin, yet there has been minimal geomorphic response in the lower river, which may seem counterintuitive.

However, the complex linked geomorphic processes of discharge, sediment transport and loads, tributary inputs, and channel erosion include interactions which might increase as well as decrease sediment loads. Furthermore, if a stream is transport-limited before impoundment, the reduced sediment supply after damming may have limited impact. Copyright © 2003 John Wiley & Sons, Ltd.

Phillips, J. D. (2007). Geomorphic Equilibrium in Southeast Texas Rivers. Project Report for the Texas Water Development Board and Texas Instream Flow Program, TWDB contract number 0605830636. Lexington, KY. Retrieved November 4, 2009, from http://www.twdb.state.tx.us/RWPG/rpgm_rpts/0605830636_geomorphicEquilibrium.pdf.

This report is based on a study of the geomorphic equilibrium of the coastal plain portions of the Brazos, Trinity, and Sabine Rivers, and of river systems of southeast Texas more generally. River and stream management, assessment, engineering, and classification is often based on concepts of geomorphic equilibrium, and implicit or explicit assumptions that fluvial systems are in, or develop towards, some form of equilibrium. The purpose of this study is to determine the extent to which that is indeed the case in the study area.

Phillips, J. D. and M. C. Slattery (2007). Geomorphic Processes, Controls, and Transition Zones in the Lower Sabine River. Project Report for the Texas Water Development Board and Texas Instream Flow Program, TWDB contract number 0600010595. Retrieved November 4, 2009, from http://www.twdb.state.tx.us/RWPG/rpgm_rpts/0600010595_Sabine.pdf.

This report is based on a cooperative research study of the geomorphology of the Lower Sabine River, Texas (and Louisiana). The study focussed on delineating major geomorphic process zones, identification of major geomorphic controls, and determination the location and primary controls over key “hinge points” or transition zones.

Phillips, J. D. and M. C. Slattery (2006). "Sediment storage, sea level, and sediment delivery to the ocean by coastal plain rivers." Progress in Physical Geography **30**: 513-530.

Poff, N. L., J. D. Allan, et al. (1997). "The Natural Flow Regime: A Paradigm for River Conservation and Restoration." BioScience **47**(11): 769-784. Retrieved November 3, 2009, from http://www.nature.org/initiatives/freshwater/files/natflow.pdf.

The ecological integrity of river ecosystems depends on their natural dynamic character.

Poff, N. L. and J. V. Ward (1989). "Implications of streamflow variability and predictability for lotic community structure: a regional analysis of streamflow patterns." Canadian Journal of Fisheries and Aquatic Sciences **46**(10): 1805-1818. Retrieved November 3, 2009, from http://rydberg.biology.colostate.edu/~poff/Public/poffpubs/Poff1989(CJFAS_flow_var).pdf.

Long-term discharge records (17-81 yr) of 78 streams from across the continental United States were analyzed to develop a general quantitative characterization of streamflow variability and predictability. Based on (1) overall flow variability, (2) flood regime patterns, and (3) extent of intermittency, 11 summary statistics were derived from the entire record for each stream. Using a non hierarchical clustering technique, nine stream types were identified: harsh intermittent, intermittent flashy, intermittent runoff, perennial flashy, perennial runoff, snowmelt, snow + rain, winter rain, and mesic groundwater. Stream groups separated primarily on combined measures of intermittency, flood frequency, flood predictability, and overall flow predictability, and they showed reasonable geographic affiliation. A conceptual model that incorporates the nine stream clusters in a hierarchical structure is presented. Also, the positions of the 78 streams in a continuous three-dimensional flow space illustrate the wide range of ecologically important hydrologic variability that can constrain ecological and evolutionary processes in streams. Long-term daily streamflow records are a rich source of information with which to evaluate temporal and spatial patterns of lotic environments across many physiographic and ecographic regions. Relative positions of streams in flow space provide a conceptual framework for evaluating a priori the relative importance of abiotic and biotic factors in regulating population and community processes and patterns.

Ravichandran, M., M. Baskaran, et al. (1995). "Geochronology of sediments in the Sabine-Neches estuary, Texas, U.S.A." Chemical Geology **125**: 291-306.

Richter, B. D., J. L. M. A.T. Warner, et al. (2006). "A collaborative and adaptive process for developing environmental flow recommendations." River Research and Applications **22**: 297-318.

Richter, B. D., J. V. Baumgartner, et al. (1996). "A Method for Assessing Hydrologic Alteration Within Ecosystems." Conservation Biology **10**(4): 1163-1174. Retrieved November 3, 2009, from http://www.tufts.edu/water/pdf/iha_meth.pdf.

Hydrologic regimes play a major role in determining the biotic composition, structure, and function of aquatic, wetland, and riparian ecosystems. But human lan and water uses are substantially altering hydrologic regimes around the world. Improved quantitative evaluations of human-induced hydrologic changes are needed to advance research on the biotic implications of hydrologic alteration and to support ecosystem management and restoration plans. We propose a method for assessing the degree of hydrologic alteration attributable to human influence within an ecosystem. This method, referred to as the "Indicators of Hydrologic Alteration," is based upon an analysis of hydrologic data available either from existing measurement points within an ecosystem (such as at stream gauges or wells) or model-generated data. ... This method is intended for use with other ecosystem metrics in inventories of ecosystem integrity, in planning ecosystem management activities, and in setting and measuring progress toward conservation or restoration goals.

Richter, B. D., et al (2003). "Ecologically sustainable water management: managing river flows for ecological integrity." Ecological Applications **13**: 206-224.

Robertson, C. R., S.C. Zeug, and K.O. Winemiller (2008). "Associations between hydrological connectivity and resource partitioning among sympatric gar species (Lepisosteidae) in a Texas river and associated oxbows." Ecology of Freshwater Fish **17**: 119-129.

Robinson, A. T., R. W. Clarkson, et al. (1998). "Dispersal of Larval Fishes in a Regulated River Tributary." Transactions of the American Fisheries Society **127**: 772-786. Retrieved November 3, 2009, from http://afsjournals.org/doi/abs/10.1577/1548-8659(1998)127%3C0772:DOLFIA%3E2.0.CO%3B2.

We investigated longitudinal distributions, nearshore movements, and drift of larval native fishes (humpback chub Gila cypha, speckled dace Rhinichthys osculus, bluehead sucker Catostomus discobolus, and flannelmouth sucker Catostomus latipinnis) in the Little Colorado River, a tributary to the regulated Colorado River in Grand Canyon, Arizona, to determine spawning sites, larval dispersal patterns, and amount of drift into the mainstem Colorado River. Larval distributions and drift indicated native fishes spawned throughout the terminal 14.2 km of the Little Colorado River. In addition, distribution, drift, and trap data suggest an active component to dispersal for all four native species. Drift of larval native fish was greater near shore than midchannel, and except for speckled dace larvae, which were prone to drift at night, larval native fish did not exhibit diel periodicity in drift. During a 46-d period in 1993, we estimated that over 370,000 native fish larvae drifted out of the Little Colorado River into the Colorado River. Regulated discharge from Glen Canyon Dam has all but eliminated spring–summer ponding of tributary mouths that occurred when ascending flows in the Colorado River coincided with descending and base flows in tributaries; thus, drifting larvae are allowed to pass directly into the Colorado River. Survival of larvae now transported into the Colorado River is probably poor because of perennially cold water temperatures and instability of nearshore habitats.

Rypel, A. L., W. R. Haag, et al. (2009). "Pervasive hydrologic effects on freshwater mussels and riparian trees in southeastern floodplain ecosystems." Wetlands **29**: 487-504.

Sabine River Authority of Texas (1999). Comprehensive Sabine Watershed Management Plan. Orange, Texas. Retrieved September 8, 2009, from http://www.sratx.org/srwmp/comprehensive_plan/.

Sabine River Authority of Texas (2009a). Preliminary Investigation Saltwater Barrier. Retrieved October 6, 2009, from ftp://ftp.sratx.org/pub/BBEST/Library/BBEST_020.pdf.

The lower Sabine River forms the boundary between Louisiana and Texas before emptying into Sabine Lake, an important tidal estuary of the Gulf of Mexico. Saltwater intrusion has altered the tidal landscape of the lower Sabine River Basin and will continue to make an impact if a solution is not implemented. The U. S. Army Corps of Engineers' Sabine-Neches Waterway deepening and widening project will accelerate saltwater intrusion and associated impacts.

Sabine River Authority of Texas (2009b). Sabine River Basin 2008 Summary Report. Retrieved October 7, 2009, from http://www.sratx.org/srwmp/tcrp/state_of_the_basin/summary_reports/default.asp.

This is the five year Texas Clean Rivers Program assessment report for the Sabine River Basin. The purpose of the assessment as defined by the Texas Clean Rivers Act (TCRA) is not to mandate exhaustive and detailed water quality studies, but to identify significant issues affecting water quality in each watershed (river basin) of the state and to provide sufficient information for the TCEQ, river authorities, and other governmental entities to take appropriate corrective action to maintain and improve water quality in each basin. The TCRA also required the TCEQ to establish by rule the level of detail required for each watershed and river basin assessment. The ongoing assessment program is known as the Clean Rivers Program (CRP).

Sabine River Authority of Texas and Lower Neches Valley Authority (2006). Sabine Lake: Ecological Condition of the Sabine-Neches Estuary. **Executive Summary**. Retrieved October 6, 2009, from ftp://ftp.sratx.org/pub/EcoConditionsReport/.

Sabine River Compact Administration (2008). Fifty-Fourth Annual Report. Retrieved October 12, 2009, from ftp://ftp.sratx.org/pub/BBEST/Library/BBEST_086.pdf.

This Annual Report has the following content: Members of the Administration; Officers of the Administration; Standing Committees; Meetings; Fiscal; General Activities;Hydrologic Conditions;Hydrologic Stations; Official Gaging Stations; Appendix A. Audit Report; Appendix B. Gaging Station Records; Appendix C. The Sabine River Compact; Appendix D. By-Laws; Appendix E. Rules and Regulations; and Appendix F. Toledo Bend Reservoir ALERT System.

SAC (2009a). Essential Steps for Biological Overlays in Developing Senate Bill 3 Instream Flow Recommendations. Retrieved November 8, 2009, from http://www.sratx.org/BBEST/RecommendationsReport/LinkedDocuments/biologyoverlay.pdf.

The Biological Overlay document provides guidance on: 1) Assimilating biological information needed to develop a biological overlay within the context of SB 3; 2) Applying biological information to inform the geographic scope of instream flow recommendations; 3) Addressing decision points required before and during hydrology-based modeling; 4) Applying a biological overlay for the purpose of refining and/or confirming preliminary hydrology-based instream flow recommendations; and 5) Using the biological overlay document in a hydrology-based environmental flow determination.

SAC (2009b). Fluvial Sediment Transport as an Overlay to Instream Flow Recommendations for the Environmental Flows Allocation Process. Retrieved November 8, 2009, from http://www.sratx.org/BBEST/RecommendationsReport/LinkedDocuments/sac_2009_04_sedtransport(2).pdf.

This document reviews various methods for assessing suspended-load and bedload transport, and recommends that the BBESTs consider application of the SAM Hydraulic Design Package for estimating effective discharge. A detailed example is presented, cautioning that it presents a worst-case scenario in which annual flow volumes are strictly limited to the HEFR-prescribed results in all respects.

SAC (2009c). Geographic Scope of Instream Flow Recommendations**:** 23. Retrieved November 8, 2009, from http://www.sratx.org/BBEST/RecommendationsReport/LinkedDocuments/GeoScope-20090403.pdf.

The purpose of this paper is to address the geographic scope of environmental flow regime recommendations for the Senate Bill 3 (SB 3) process. The question of geographic scope for the SB 3 process is a matter of recommending the number and spatial distribution of locations where flow regime recommendations will be developed. This document does not address implementation of flow recommendations.

SAC (2009d). Methodologies for Establishing a Freshwater Inflow Regime for Texas Estuaries Within the Context of the Senate Bill 3 Environmental Flows Process. Retrieved November 8, 2009, from http://www.sratx.org/BBEST/RecommendationsReport/LinkedDocuments/eirmethods_rev_13_060209(2).pdf.

This document provides background information and discussion of various methods that can be used to develop freshwater inflow recommendations for Texas bays and estuaries. While a few germane references to the literature are made, this document is not intended to be a tutorial on the physics and ecology of estuaries, nor on the range of modeling techniques of potential application. Rather, it attempts to present a succinct summary of methods that are presently sufficiently developed and suitable for application to Texas estuaries, for consideration by the Basin and Bay Expert Science Teams (BBESTs).

SAC (2009e). Nutrient and Water Quality Overlay on Hydrology-Based Instream Flow Recommendations. Retrieved November 8, 2009, from http://www.sratx.org/BBEST/RecommendationsReport/LinkedDocuments/WQ%20Overlay_11-3-2009.pdf.

Water quality is the focus of this overlay document. Numeric and narrative criteria developed by the state address matter carried in suspension and solution, such as dissolved and suspended solids, as well as nutrients, toxics, indicator bacteria, temperature, pH, dissolved oxygen, and other parameters. Under some circumstances all might play a role in the determination of an environmental flow regime. Changes in a flow regime can be expected to produce changes in water quality conditions. The challenge is to ensure that the recommended flow regime protects water quality, particularly during low or subsistence flow conditions, and also considers water quality needs during higher flow conditions.

SAC (2009f). Use of Hydrologic Data in the Development of Instream Flow Recommendations for the Environmental Flows Allocation Process and the Hydrology-Based Environmental Flow Regime (HEFR) Methodology (DRAFT). Retrieved November 8, 2009, from http://www.sratx.org/BBEST/RecommendationsReport/LinkedDocuments/hydrologicmethods04202009.pdf.

This document provides an overview of how hydrologic data may be used in the identification of instream flow recommendations pursuant to the requirements of SB 3. As such, it describes one piece of the collaborative process envisioned by SB 3 for the identification of flows to maintain a sound ecological environment in rivers and streams.

Scaife, W. W., R. E. Turner, et al. (1983). "Coastal Louisiana Recent Land Loss and Canal Impacts." Environmental Management **7**(5): 433-442. Retrieved November 3, 2009, from http://www.springerlink.com/content/q1442h01164n7rr7/fulltext.pdf?page=1.

Annual coastal land loss in the sedimentary deltaic plain of southern Louisiana is 102 km 2, which is correlated with manmade canal surface area. The relationships between land loss and canals are both direct and indirect and are modified by the deltaic substrate, distance to the coast, and availability of new sediments. Loss rates are highest in the youngest of the former deltas nearest the coast; they are lowest in the more consolidated sediments far from the coast. The average estimate for land loss at zero canal density in the six regression equations developed was 0.09% _+ 0.13% annually, the present land loss rates approach 0 8% annually Although additional analyses are needed, we conclude that canals are causally related to a significant portion of the total coastal land loss rates The relation probably involves an interruption of local and regional hydrologic regimes. Reduction of the present acceleration in land loss rates is possible by managing present canals more effectively, by not permitting new ones, and by changing the design of new canals to allow more natural water flow.

Science Advisory Committee (2004). Report on Water for Environmental Flows. Austin, Texas: 158. Retrieved September 15, 2009, from http://www.twdb.state.tx.us/EnvironmentalFlows/pdfs/SAC%20FINAL%20REPORT_102704.pdf.

Sharitz, R. R. and W. J. Mitsch, Eds. (1993). Southern floodplain forests. Biodiversity of the Southeastern United States Lowland Terrestrial Communities. New York, Wiley.

Solis, R. S., W. L. Longley, et al. (1994). Influence of inflow on sediment deposition in delta and bay systems. Freshwater Inflows to Texas Bays and Estuaries. W. L. Longley. Austin, Texas, Texas Water Development Board: 56 - 70.

Strayer, D. L. (2008). Freshwater Mussel Ecology: A Multifactor Approach to Distribution and Abundance. , University of California Press, Berkeley.

Sutherlin, J. (1996). Historical Development of the Marsh System on the West Side of Sabine Lake. Sabine Lake Conference: Where Texas and Louisiana Come Together. Beaumont, Texas. Retrieved November 6, 2009, from ftp://ftp.sratx.org/pub/BBEST/Library/SabineLakeConferenceSept1996/.

> Restoring hydrology, which in effect should restore function and productivity in coastal marshes, is a priority mission of the Upper Coast Wetland Ecosystem Project within the Texas Parks and Wildlife Department. Interior coastal wetlands and marshes associated with Sabine Lake are of special concern to TPWD. For wetland hydrology to be restored, a thorough understanding of historical changes within the natural drainage systems must exist. Taylor's Bayou and the Neches and Sabine Rivers are the 3 major drainages associated with Sabine Lake in Jefferson and Orange Counties. Taylor's Bayou and its tributaries drain the vast majority of Jefferson County. The Neches and Sabine Rivers drain vast areas of east Texas and west Louisiana, and both empty into Sabine Lake.

Tatum, J. W. (2009). Sabine-Neches Estuary and Lower Tidal Sabine River: A System in Transition. Sabine and Neches Rivers and Sabine Lake Bay and Bay Expert Science Team Meeting. Lake Palestine, Texas. Retrieved October 6, 2009, from http://www.tceq.state.tx.us/assets/public/permitting/watersupply/water_rights/eflows/02202009snslb_tatumwhitepaper.pdf.

> Topics of this white paper include: description of Sabine-Neches Estuary (Sabine Lake); History / Timeline of Sabine Lake; Need for Habitat Restoration / Protection; Hydrology of Sabine Lake; and Tidal River Hydrology / Habitat.

TCB|AECOM (2006). Sabine Lake: Ecological Condition of the Sabine-Neches Estuary. Retrieved October 6, 2009, from ftp://ftp.sratx.org/pub/EcoConditionsReport/.

> In 2002, the Sabine River Authority of Texas and the Lower Neches Valley Authority Boards of Directors, recognizing the critical need to balance water use and to protect the environment, authorized the development of initial baseline studies to help characterize the long-term, environmental flow needs of the Sabine and Neches River Basins and to evaluate how to meet these needs. The Ecological Condition of the Sabine-Neches Estuary report documents the baseline studies conducted and serves as the definitive compendium or reference source for the estuary including the identification and compilation of research studies, investigations, modeling efforts, future projects, and historical conditions of Sabine Lake and the Sabine-Neches Estuary.

Technical Review Group (2008). Review of Desk-top Methods for Establishing Environmental Flows in Texas Rivers and Streams. Kirk Winemiller, TRG Chair. Austin, Texas. Retrieved November 6, 209, from http://www.tceq.state.tx.us/assets/public/permitting/watersupply/water_rights/txefsacdesktop.pdf.

This Technical Review Group convened in August of 2007 to review and assess existing information and documents regarding instream environmental flow requirements and desk-top and other methodologies with the goal of making recommendations to the State as to how its current desk-top procedures could be improved to provide more appropriate estimates of environmental flow needs for rivers and streams.

Texas Commission on Environmental Quality (2008a). "Sabine and Neches Rivers and Sabine Lake Bay Basin and Bay Area Stakeholder Committee and Basin and Bay Expert Science Team ". Retrieved October 6, 2009, from http://www.tceq.state.tx.us/permitting/water_supply/water_rights/eflows/sabinenechessabinelakebay.html.

This Web site lists Sabine and Neches Rivers and Sabine Lake Bay Basin and Bay Area Stakeholder Committee and Basin and Bay Expert Science Team members as well as meeting materials.

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Relating to the development, management, and preservation of the water resources of the state; providing penalties.

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> Sabine mileages were taken from late 1930 Tobin aerial mosaics and were reexamined in 1946 using AAA photographs and aerial photos of the flood of April 1945. New mileages have been inserted using most recent USGS quadrangle maps. These are the official U.S. Geological Survey river miles for the Sabine River Basin, Texas.

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> The goal of the LCA Plan is to reverse the current trend of degradation of the coastal ecosystem. The plan maximizes the use of restoration strategies that reintroduce historic flows of river water, nutrients, and sediment to coastal wetlands, and that maintain the structural integrity of the coastal ecosystem. Execution of the LCA Plan would make significant progress towards achieving and sustaining a coastal ecosystem that can support and protect the environment, economy, and culture of southern Louisiana and thus, contribute to the economy and well-being of the Nation. Benefits to and effects on existing infrastructure, including navigation, hurricane protection, flood control, land transportation works, agricultural lands, and oil and gas production and distribution facilities were considered in the formulation of coastal restoration plans.

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> This report represents the Fish and Wildlife Service's (FWS) examination of the freshwater flows required to meet habitat needs of the resident fish and recreational demands that occur in the Neches River below B.A. Steinhagen Lake.

Werner, F. T. (1982b). Instream Needs for the Sabine River below Toledo Bend. U.S. Fish and Wildlife Service Report. Houston, Texas**:** 34 p. Retrieved November 5, 2009, from ftp://ftp.sratx.org/pub/BBEST/Library/BBEST_064.pdf.

> The lower Sabine River is drained by an undammed stretch of the Sabine River (156.5 miles) which separates Texas and Louisiana between Toledo Bend and Sabine Lake

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9 APPENDICES

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