Sabine/Neches BBEST Biological Overlay Approach
November 30, 2009

Fluvial Ecosystem Realm –

For determining environmental flow recommendations for the fluvial realm of the Sabine and Neches river basins (tributary streams and mainstem rivers), our BBEST's biological overlays subcommittee adopted the basic approach recommended by the state's Environmental Flows Science Advisory Committee (SAC. Aug. 31, 2009. Essential Steps for Biological Overlays in Developing Senate Bill 3 instream flow recommendations. Report # SAC-2009-05, Appendix I[1]) which involves defining and estimating subsistence flow, base flow, high flow pulses, and overbanking flow pulses. A brief outline of this approach, include excerpts from the SAC guidance document, and descriptions with justifications of the Sabine/Neches BBEST's analyses leading to its recommendations for environmental flows are presented in this document.

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:

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.

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

Our 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. We 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

[1] Appendix references are to the Sabine-Neches BBEST Recommendations Report (November 2009) Appendices, available at http://www.sratx.org/BBEST/RecommendationsReport/index.html.

multiple regions. BIO-WEST was contracted to provide synopses of our focal species for both fluvial and estuarine systems (BIO-WEST 2009a, 2009b, attached as Appendix X).

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 (Freese and Nichols, memo to BBEST, subject: Analysis of BBEST Stream Gages, Sept. 8, 2009, Appendix IX), 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 (2002). An analysis of wetland and riparian vegetation communities was performed by the National Wildlife Federation (NWF) and Greater Edwards Aquifer Alliance (GEAA) (Appendix XVII), and our 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, 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 (two held in Beaumont and one in College Station). The SAC recommended use of a flow regime framework consisting of subsistence flows, base flows, high flow pulses, and overbanking flows.

The Sabine-Neches Fluvial Ecosystems – Current Conditions and Responses of Focal Species to Flow Components –

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 (Acreman and Dunbar 2004, Richter et al. 2003, 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.

The concept of subsistence flow represents the lowest threshold that defines periods when certain flow diversions would be reduced or in some cases halted as conditions degrade in response to drought. Two of the key objectives in identifying subsistence flows are ensuring that water quality is maintained and key habitats are available and accessible by focal species and/or guilds. Data from water quality monitoring programs at the gages selected were compared to flows established through hydrologic analysis (Sabine-Neches BBEST Environmental Flows Recommendation Report and Appendix XII, Water Quality Overlay Appendices). Water quality can become an issue during periods of severe drought, but we obtained little evidence that this is a significant problem in streams and rivers of east Texas (It must be noted that little water quality data exist for flows in the subsistence flow ranges generated from our HEFR hydrological analysis). This may be due to the fact that east Texas is dominated by sandy soils and the streams carry relatively low loads of suspended particulate organic matter, and thus may have relatively low biological oxygen demand. Water quality and flow relationships are discussed in more detail in the water quality overlay section of this report.

During subsistence flow conditions, larger fishes (e.g., channel and blue catfish, smallmouth buffalo, blue sucker, gars, freshwater drum, largemouth and spotted bass) refuge in the deeper and larger pools of the main channel and side channels (anastomoses) of the lower reaches. Some floodplain aquatic habitats may dry up completely, but deeper oxbows may support populations of bass, gars, crappies, sunfishes, and small fishes (e.g., pugnose minnows, blackstripe top minnows). Under subsistence flow conditions in tributary streams, fishes may be forced to occupy isolated pools within reaches of the main channel. During these periods when fishes are concentrated at high per-unit-area densities in reduced volumes of habitat with reduced flow and connectivity, predation is more intense, and populations become reduced. Only a few of the fish species attempt reproduction under these conditions (e.g. Sabine shiner, ironcolor shiner, western mosquitofish), but even for these species with relatively high and continuous reproductive effort, recruitment success is very low in the crowded biotic communities.

Specific habitat area-streamflow relationships and the underlying modeling should be evaluated to construct new recommendations and refinements to hydrologically derived subsistence flows. This kind of analysis was performed for the lower Colorado River in Texas (BIO-WEST 2008a). The goal of the refinement to the subsistence flow recommendation was to reduce risks that any given fish habitat guild (each representative of multiple species) would be without essential habitat during periods of subsistence flow.

Few site-specific studies have been performed in the Sabine and Neches river basins to inform our recommendations for subsistence flows. Werner (1982a, 1982b) performed an analysis of hydraulic habitat in the lower Sabine River and lower Neches River reaches. For both systems, he employed the Physical Habitat Simulation (PHABSIM) component of the Instream Flow Incremental Methodology (Bovee and Milhous 1978) to estimate habitat available for life stages of focal fish species under a range of discharge levels. Werner relied on literature-based suitability curves rather than developing site-specific indices. By weighting the results to reflect the needs of the most habitat-restricted life stages and species, he derived recommended "maintenance flow" for two segments of each river. 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 our BBEST from HEFR analysis of hydrological data. Nonetheless, Werner's findings are valuable for comparison with our flow value ranges for subsistence and dry-year base flows, and for examination of estimates of weighted usable habitat area for various species under different flow levels. 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 our HEFR hydrological analysis.

Although no other specific instream flow studies have been completed in our basins, our evaluation of biological/ecological responses to flow variation was greatly aided by data collected over broader spatial and temporal scales (e.g., Evans and Noble 1979, Moriarty and Winemiller 1997, Bonner and Runyan 2007, Bart 2008, and see other studies summarized in BIO-WEST 2009a). No species of fishes, mussels, or wetland/floodplain plants appear to have been extirpated from the basins due to severe reductions in subsistence flows during drought periods. Due to summertime hydropower releases (when energy demand is high), the lower reaches of the mainstem Sabine and Neches rivers has higher flows during exceptionally dry summers compared to what occurred under these conditions historically. Major changes in minnow communities in the lower Sabine River documented by both Bart (2008) 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. The Texas Parks and Wildlife Department (TPWD) document, Ecologically Significant River & Stream Segments of Region I (East Texas) Regional Water Planning Area (2005) provides a good overview of the current state of many of these tributaries.

Reduction and possible extirpation of naturally reproducing populations of paddlefish (*Polyodon spathula*) in the two mainstem rivers likely was caused by 1) blockage of migration routes in the mainstem rivers, 2) elimination of shoals used for spawning, and/or 3) disruption of the natural high flow pulse regime by dams (Pitman 1991). Elimination of appropriate late-winter to early spring high flow pulses interferes with spawning cues, access and/or availability of spawning habitats (shoals located in upper reaches of the mainstems), transport of fertilized and eggs and larvae, and connectivity of the river channel with productive backwater habitats used for zooplankton feeding by juveniles and adults. For lack of specific studies to address the subsistence flow component, our ecological analysis began with the HEFR subsistence estimates from each gage. These were compared with recorded minimum flows, percentiles of seasonal flows, the 5th percentile of all flows, the current flow standard used by state and federal agencies for water quality risk assessment under severe low-flow conditions (7Q2, 7Q10), as well as Werner's (1982a, 1982b) findings and recommendations. These steps leading to our BBEST consensus recommendations appear below.

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 (Reference Table 1 in the SAC Biological Overlays Guidance document). 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 were used (see Section 2, Development of Information for Biological Overlay, of SAC 2005-05, Appendix I, and BIO-WEST 2009a, Appendix IX). For example, data on fish spawning seasons was used to evaluate the timing of higher base flows and other flow components. Information on basic habitat use for different life stages of a species indicates the pattern and range of flows needed across seasons. Our suite of focal species was evaluated in this and other ways to establish patterns for evaluating hydrologically derived base-flow estimates during different seasons and across dry, average, and wet years.

Habitat-flow assessments produce a measure of habitat such as weighted usable area or diversity as a function of stream flow and may be useful in evaluating hydrology-derived base flows. Such tools can be used to compare habitat time series using different HEFR settings, hydrologic records, and algorithms. The only site-specific studies from the Neches and Sabine basins available to our BBEST were those of Werner (1982a, 1982b), and these are discussed below in the context of base and subsistence flow recommendations. Extensive and detailed habitat-hydrology research and modeling was performed recently for the lower Colorado River in Texas (BIO-WEST 2008a), and many of the fish species in that system are shared by the lower Neches and Sabine rivers. According the SAC, information from instream flow assessments on nearby systems or similar river types can be evaluated to ascertain if similar habitat-flow relationships would be expected.

The studies by Werner (1982) are the only known site-specific, quantitative studies from the two basins that directly address base flows, but again, his focus on maintenance flows blended together the modern concept of subsistence and base flow components. To guide inferences about required base flows during dry, average, and wet years, we examined the findings from the extensive research conducted by BIO-WEST (2008a, 2008b). We know 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 1). The relative availability of habitat types generally undergoes a shift with a transition to average and wet year conditions (BIO-WEST 2008a, 2009a). 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. In other words, if base flows were to be held at the dry-year level on a chronic basis, significant reductions in populations of species belonging to certain guilds would be expected, and with time, these species would be generally replaced by species associated with the predominant habitat categories under this human imposed dry-year regime.

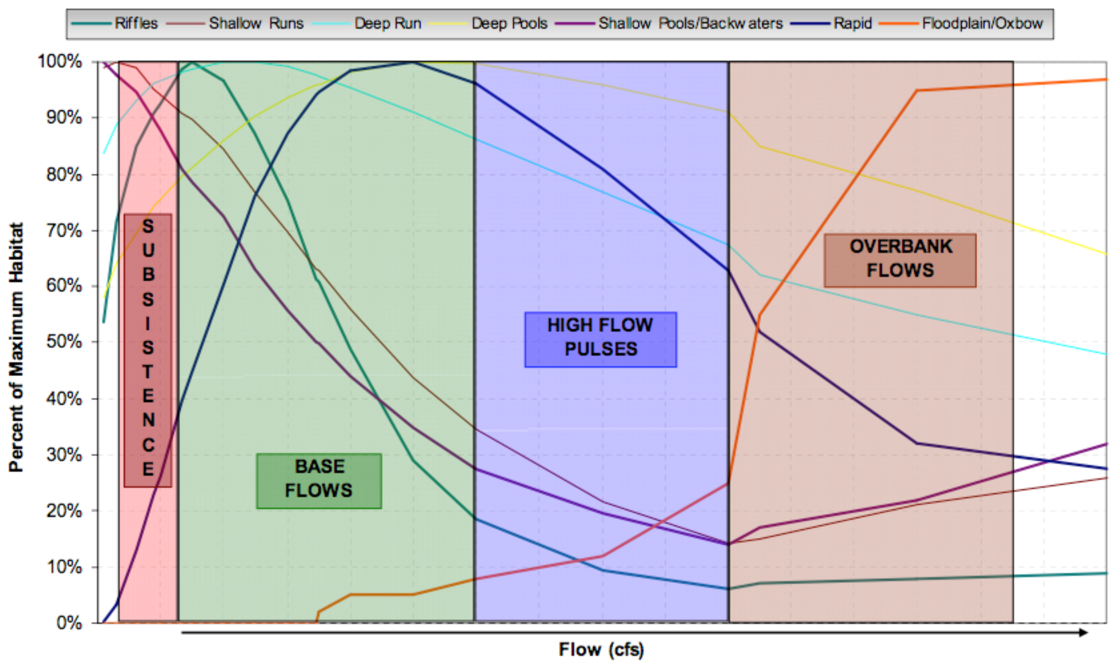


Figure 1. Habitat availability curves for seven fish habitat guilds in the lower Colorado River, Texas derived from recent instream flows research by BIO-WEST (2008a).

Studies modeling hydraulic habitat in other rivers, including the lower Colorado River in Texas, have estimated the shifting availability of habitats for fish guilds under different annual conditions (BIO-WEST 2008a, Figure 1). For example, riffle habitat was maximized at relatively low base flows while deep run habitat was maximized at relatively high base flows. These studies provide a strong conceptual framework for inferring the requirement for inter-annual variation in base flow levels for the Sabine and Neches rivers since many fish species including our focal species are shared by the Colorado, Neches, and Sabine rivers.

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 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 et al. 2009).

High Flow Pulses –

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 magnitude and duration of high flow pulses can also be double checked with known life history requirements. An example, well documented in Mosier and Ray (1992) and BIO-WEST (2008a), involves blue sucker *Cycleptus elongatus* spawning on the Colorado River, Texas. Information from these studies was used in assessments on the lower Colorado River but also can be used to inform flow requirements in other river systems, such as the lower Neches and Sabine rivers, where blue sucker currently exist (recently confirmed in the Sabine, and likely are present in the Neches).

The role of high flow pulses for supporting aquatic and riparian/floodplain plants and animals has been discussed extensively by river scientists (Junk et al. 1989, Poff et al. 1997, Winemiller et al. 2000, Lytle and Poff 2004, Richter et al. 1997, 2003, 2006, Zeug et al. 2005, 2009, Zeug and Winemiller 2007, 2008), and this evidence was summarized in the SAC Biological Overlays Guidance Document (SAC 2009-05, Appendix I). High flow pulses provide environmental cues that elicit reproductive behavior (migration, spawning), produce lateral connectivity allowing movement of organisms between the main channel and off-channel aquatic habitats (floodplain lakes, oxbows, sloughs, ephemeral ponds), and foraging opportunities in newly flooded riparian habitats (e.g., Kwak 1988).

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.) We relied on NWS estimates of overbank flooding and a specific analysis by the National Wildlife Federation and the Greater Edwards Aquifer Alliance.

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.).

Spotted bass feed opportunistically in flooded marginal and off-channel habitats—juveniles in particular. Like other sunfishes (family Centrarchidae), this species is a substrate nester and requires relatively stable flows during spring (stable high or low flows) during the 1-3 weeks the male guards the nest (nesting period—Feb-May).
For the sabine shiner and ironcolor shiner, most reproduction takes place during spring when high pulses likely stimulate spawning; all size classes likely exploit terrestrial-derived food resources in flooded marginal areas during any time of the year, but late spring to fall probably is the most significant period in this respect.

The flathead catfish (juveniles), dusky darter, harlequine darter, and freckled madtom probably do not respond to high pulses by entering marginal or off-channel habitats, however they feed on drifting invertebrates, and during flow pulses they probably receive increased food resources in the form of dislodged aquatic macroinvertebrates and terrestrial insects.

During early spring (late Feb-early March), white bass migrate upstream in schools and enter tributary streams where they spawn in flowing waters in small groups. The largest populations reside in reservoirs during other times of the year, a few individuals also inhabit larger pools of lower river mainstems during the non-reproductive period. Higher flows stimulate larger migrations that penetrate further upstream. High pulse flows also enhance passive transport of the eggs and larvae of these broadcast spawners, maintain dissolved oxygen levels during development, and probably allow juveniles to move into and out of marginal lentic habitats where they feed on abundance food resources. Winemiller et al. (2000) captured juvenile white bass from oxbow lakes in the floodplain of the Brazos River.

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. Spawning is episodic during early spring, and eggs are scattered and drift some distance to settle into habitats where they larvae develop and then feed on zooplankton. In the case of alligator gars, spawning takes place over submerged vegetation of perhaps sticks. In the case of paddlefish and suckers, spawning takes place in the main channel and eggs drift into pools. In all three species, the larval and early juvenile stages probably require lentic backwaters for feeding and survival. High flow pulses provide more of this habitat. It is unknown to what extent juveniles move into off-channel habitats, but likely this is very important for young paddlefish and alligator gar. Flood pulses also are needed during other times of the year to connect off-channel habitats with the channel so that adult paddlefish and alligator gar can move in and out for feeding (Robertson et al. 2008). Oxbows and sloughs have much greater aquatic primary and secondary productivity than main-channel habitats (Winemller et al. 2000).

As described above for white bass, high flow pulses cue and enhance spawning migrations during early spring. As described above for spotted bass, 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 a duration of 3 weeks, because this provides these fishes sufficient time to construct a nest, spawn, and guard the eggs and lavae until they are large enough to swim effectively.

Based on research on the Brazos River that focused on flows and connections between the river channel and oxbow lakes (Zeug and Winemiller 2005), it is clear that white crappie prosper greatly within the lentic and highly productive environment of oxbows. It should be noted that several other common species have the similar requirements (e.g shads), but crappies are a highly suitable indicator species for this particular function.

The shoal chub, ghost shiner and emerald shiner are minnows characteristic of large mainstem rivers. Shoal chubs and ghost shiners require broad sandbanks for foraging; the availability of submerged bank habitats increases during high flows, and high flows transport eggs/larvae of these broadcast spawners. Responses to flow pulses by populations of the dusky darter, harlequine darter, and freckled madtom (also juvenile flathead catfish) within the mainstems of the lower river reaches would likely be similar to those described above for tributary and headwater stream populations.

Sabine/Neches Fish Species with Spawning Synchronized to Flow Pulses During Late Winter–Spring (Feb–June)

Within-channel, water-column spawners (N= 26)

S/N 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)

S/N 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).

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. Our terrestrial focal species having aspects of their life cycle dependent on periodic high flood pulses are the overcup oak and water tupelo. These bottomland hardwood tree species require periodic flooding for successful germination, seedling recruitment, and elimination of upland plant species that are competitively superior on well-drained soils (Sharitz and Mitsch 1993). When viewed over longer time scales, overbanking flows are critical for the sediment dynamics and geomorphic changes of the landscape needed to maintain riparian forest diversity (Shankman 1993, Meitzen 2009).

In addition to supporting major geomorphic processes (SAC-2009-05, Appendix I), overbank flows provide lateral connectivity for aquatic organisms to floodplain areas and maintain the balance and diversity of riparian zones. Assessments of lateral connectivity include reviewing available life history information of aquatic and riparian species, constructing conceptual models depicting flow-ecology relationships and needs, and evaluating the performance of overbank flow estimates in meeting those needs. Studies of fish assemblages using floodplain habitat such as oxbow lakes for different life stages are available for some Texas rivers (e.g., Winemiller et al. 2004, and see discussion below). Information on the hydraulic conditions needed to spill onto the floodplain can be derived from field based or desktop hydraulic assessments or by using flood stages identified by the National Weather Service, for example. Desktop approaches using digital elevation models have been used to relatively quickly develop relationships between magnitude and inundated floodplain area. Hydraulic information coupled with life history information for riparian species and their inundation characteristics (timing, duration, frequency, etc.) can be used to check and refine hydrology-derived characteristics of overbank flows.

Overbanking flows are a natural but relatively infrequent occurrence in east Texas. Unusual weather patterns, such as extended periods of high precipitation or hurricanes and tropical storms, can produce floods of variable magnitude and duration with greater frequency. Most “overbanking flows” do not result in extensive inundation of floodplain terrains, but instead water moves into bottomland wetlands, first in the lowest areas, such as oxbows and sloughs, and moving into wetlands with slightly higher elevations as flows inch upward. This pattern of variable flooding with variable flows is a natural consequence of landscape heterogeneity in floodplains.

Among alligator gars and other gar species (longnose and spotted gars), both adults but especially juveniles commonly move onto flooded plains to feed opportunistically on insects, amphibians, and other fish species that also exploit temporarily abundant food resources (Robertson et al. 2008). Many small fishes also use temporarily flooded riparian habitats to feed in terrestrial and soil invertebrates (Kwack 1988). In some cases, fishes may become stranded and perish when floodwater recede. However, it is assumed that most of the fish species that exploit flooded habitats find their way back to the main channel or permanent water bodies in the floodplain, and thus there is a net gain in fish biomass in response to the flood pulse.

The overbanking flow components of a flow matrix (as derived from our HEFR analysis) thus have important functions for the ecological system, and for some species this component is critical for completion of the life cycle (i.e., bottomland hardwood tree species) and/or support of significant population abundance (e.g., white and black crappies, gizzard shad). 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.

BBEST Subsistence Flow Recommendations –

As explained in the *Hydrological Analysis Section* of this report, HEFR outputs were used to estimate subsistence flows based historical streamflow data and manipulation of the MBFIT option. For our 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 (Tables 4 and 5, Freese and Nichols, HEFR analysis memo, Sept. 17, 2009), and Werner's (1982a, 1982b) drought flow recommendations based on PHABSIM/IFIM analysis (the latter only available for the lower Neches and Sabine segments).

Initially, the 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 BBEST discussed problems with this reasoning. First, it is important to consider the frequency of occurrence and 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, included crowding that leads to increased predation mortality, for unusually long periods with excessive frequency. In most cases, adoption of the lowest seasonal subsistence flow from HEFR (usually summer) for the entire year resulted in seasonal flows well below levels ever recorded for the segment. This was especially true for winter, the season when flows tend to be higher naturally. Second, adoption of the lowest seasonal subsistence flow level for all seasons resulted in many seasonal values that were significantly below 7Q2, 7Q10, and values recommended by Werner for the two lower river segments. 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, unforseen ecological factors (e.g., those related to metabolism of ecothermic 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 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, Acreman et al. (2006) established the Q_{95} (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. Acreman et al. (2006) concluded that the "Q_{95} 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 et al. (2006) used the monthly Q_{95} 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).

Next, our 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, our BBEST ultimately decided to make subsistence flow recommendations on a seasonal basis. This also allowed our BBEST to avoid making untenable recommendations for flows intended for environmental protection during the most stressful periods that would be less than levels ever recorded for a gage/segment. The major hydrological evidence considered and our BBEST's final biological overlay adjustments for subsistence flows are described below for each stream/river segment.

As a result of deliberations by the BBEST biological overlays subcommittee (Oct. 15-25, 2009) and by the full membership of the BBEST (Oct. 27-28, 2009), a series of adjustments were made to the subsistence flow estimates from the MBFIT/HEFR hydrological analysis. ***Our 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.***

Big Sandy Creek near Big Sandy –

- The minimum value for subsistence flow derived from HEFR/MBFIT was 8 cfs, which corresponded with the Summer period.
- For all flows, 8 cfs represents the 1.9 percentile – an extremely low value.
- Flows during Summer months were greater than 7 cfs 95% of the days.
- Flows during Fall months were greater than 7 cfs 99% of the days.
- Flows during Winter months were greater than 20 cfs 99% of the days.
- Flows during Spring months were greater than 11 cfs 99% of the days
- 12 cfs is the 5th percentile for all flows; 12.4 cfs is the 7Q2

<u>Biological Recommendation</u>: For Big Sandy Creek***, subsistence flows of 9 cfs during Spring and 8 cfs during Summer and Fall*** are recommended for maintenance of minimal habitat and environmental conditions for aquatic life during infrequent periods of severe and prolonged drought. ***For the Winter season, 20 cfs*** should be considered the subsistence benchmark, because the ecosystem has never experienced flows less than this during Winter.

Sabine River near Gladewater –

- The minimum value for subsistence flow derived from HEFR/MBFIT was 14 cfs, which corresponded with the Summer period.
- Recorded flows during the Winter and Spring months have never been as low as 14 cfs; the lowest flow ever recorded during the Winter was 45 cfs and for Spring 22 cfs.
- Summer flows have been greater than 14 cfs 96% of the days.
- Fall flows have been greater than 14 cfs 99 % of the days.
- For all flows, 14 cfs represents the 1.0 percentile; 32 cfs is the 5th percentile of all flows; the 7Q2 flow is 46.4 cfs.

<u>Biological Recommendation</u>: For the Sabine River reach near Gladwater, ***subsistence flows of 32 cfs during Spring, 14 cfs during Summer and 17 cfs during Fall*** are recommended for maintenance of minimal habitat and environmental conditions for aquatic life during infrequent periods of severe and prolonged drought. ***For the Winter season, 45 cfs*** should be considered the subsistence benchmark, because the ecosystem has never experienced flows less than this during Winter.

Sabine River near Beckville –

- The minimum value for subsistence flow derived from HEFR/MBFIT was 22 cfs, which corresponded with the Summer period.
- Recorded flows in the Winter and Spring months have never been as low as 22 cfs; the lowest flow ever recorded during the Winter was 66 cfs and for Spring 27 cfs.
- Summer flows have been greater than 22 cfs 96% of the days; Fall flows have been greater than 22 cfs more than 98% of the days.
- For all flows, 22 cfs represents the 1.3 percentile; 52 cfs is the 5th percentile of all flows; the 7Q2 flow is 75.9 cfs.
- 51 cfs is the Summer dry base flow value derived from MBFIT

<u>Biological Recommendation</u>: For the Sabine River near Beckville, ***subsistence flows of 28 cfs for Spring and 22 cfs for Summer and Fall*** are recommended for maintenance of minimal habitat and environmental conditions for aquatic life during infrequent periods of severe and prolonged drought. ***For the Winter season, 66 cfs*** should be considered should be considered the subsistence benchmark, because the ecosystem has never experienced flows less than this during Winter.

Sabine River near Bon Wier –

- The minimum value for subsistence flow derived from HEFR/MBFIT was 241 cfs, which corresponded with the Summer period.
- Recorded flows in the Winter and Spring months have never been as low as 241 cfs; the lowest flow ever recorded during the Winter was 479 cfs and for Spring 251 cfs.
- Summer flows have been greater than 241 cfs more than 97% of the days; Fall flows have been greater than 241 cfs more than 98% of the days.
- For all flows, 241 cfs represents the 1.1 percentile; 415 cfs is the 5th percentile of all flows; the 7Q2 flow is 703 cfs (this value is highly influenced by hydropower operations); the 7Q10 flow is 371 cfs.
- The lowest Summer flow recorded during the modern period (1971-2008) is 350 cfs.

<u>Biological Recommendation</u>: For the Sabine River near Bon Wier, ***subsistence flows of 279 cfs for Spring, 241 cfs for Summer and Fall*** are recommended for maintenance of minimal habitat and environmental conditions for aquatic life during infrequent periods of severe and prolonged drought. ***For the Winter season, 479 cfs*** should be considered the subsistence benchmark, because the ecosystem has never experienced flows less than this during Winter.

Big Cow Creek near Newton –

- The minimum value for subsistence flow derived from HEFR/MBFIT was 20 cfs, which corresponded with the Summer period.
- Recorded flows in the Winter months have never been as low as 20 cfs; the lowest flow ever recorded during the Winter was 28 cfs.
- Summer flows have been greater than 20 cfs about 96% of the days; Fall flows have been greater than 20 cfs about 97.5% of the days; Spring flows have been greater than 20 cfs more than 98% of the days.
- For all flows, 20 cfs represents the 2.2 percentile; 24 cfs is the 5th percentile of all flows; the 7Q2 flow is 30 cfs.

<u>Biological Recommendation</u>: For Big Cow Creek, ***subsistence flows of 20 cfs*** for Spring, Summer and Fall are recommended for maintenance of minimal habitat and environmental conditions for aquatic life during infrequent periods of severe and prolonged drought. ***For the Winter season, 28 cfs*** should be considered the subsistence benchmark, because the ecosystem has never experienced flows less than this during Winter.

Sabine River near Ruliff –

- The minimum value for subsistence flow derived from HEFR/MBFIT was 396 cfs, which corresponded with the Summer period.

- Recorded flows in the Winter and Spring months have never been as low as 396 cfs; the lowest flow ever recorded during the Winter was 949 cfs and for Spring 431 cfs.
- Summer and Fall flows have been greater than 396 cfs more than 97% of the days.
- For all flows, 396 cfs represents the 1.2 percentile; 662 cfs is the 5th percentile of all flows; the 7Q2 flow is 1121.3 cfs (although this value is likely influenced by hydropower operations); the 7Q10 flow is 584 cfs.
- The lowest Summer flow recorded during the modern period (1971-2008) is 456 cfs.

<u>Biological Recommendation</u>: For the Sabine River near Ruliff, ***subsistence flows of 436 cfs for Spring and 396 for Summer and Fall*** are recommended for maintenance of minimal habitat and environmental conditions for aquatic life during infrequent periods of severe and prolonged drought. ***For the Winter season, 949 cfs*** should be considered the subsistence benchmark, because the ecosystem has never experienced flows less than this during Winter.

Neches River at Neches – The minimum value for subsistence flow derived from HEFR/MBFIT was 12 cfs, which corresponded with the Summer period.

- Recorded flows in the Winter and Spring months have never been 12 cfs; the lowest flow ever recorded during the Winter was 51 cfs and for Spring 15 cfs.
- Summer flows have been greater than 12 cfs about 95% of the days; Fall flows have been greater than 12 cfs more than 98% of the time.
- For all flows, 12 cfs represents the 1.8 percentile; 26 cfs is the 5th percentile of all flows; the 7Q2 flow is 70.7 cfs.

<u>Biological Recommendation</u>: For the Neches River near Neches, ***subsistence flows of 21 cfs for Spring, 12 cfs for Summer, and 13 cfs for Fall*** are recommended for maintenance of minimal habitat and environmental conditions for aquatic life during infrequent periods of severe and prolonged drought. ***For the Winter season, 51 cfs*** should be considered the subsistence benchmark, because the ecosystem has never experienced flows less than this during Winter.

Neches River at Rockland – The minimum value for subsistence flow derived from HEFR/MBFIT was 21 cfs, which corresponded with the Summer period.

- Recorded flows in the Winter months have never been as low as 21 cfs; the lowest flow ever recorded during the Winter was 67 cfs.
- Summer flows have been greater than 21 cfs 97% of the days; Spring flows have been greater than 21 cfs about 99.9% of the days; Fall flows have been greater than 21 cfs about 98% of the days.
- For all flows, 21 cfs represents the 1.2 percentile; 58 cfs is the 5th percentile of all flows; 111.7 cfs is the 7Q2 flow.

<u>Biological Recommendation</u>: For the Neches River near Rockland, ***subsistence flows of 29 cfs for Spring and 21 cfs for Summer and Fall*** are recommended for maintenance of minimal habitat and environmental conditions for aquatic life during infrequent periods of severe and prolonged drought. ***For the Winter season, 67 cfs*** should be considered the subsistence benchmark, because the ecosystem has never experienced flows less than this during Winter.

Angelina River near Alto –

- The minimum value for subsistence flow derived from HEFR/MBFIT was 11 cfs, which corresponded with the Summer period.
- Recorded flows in the Winter and Spring months have never been as low as 11 cfs; the lowest flow ever recorded during the Winter was 55 cfs; the lowest flow recorded during the Spring is 12 cfs.
- Summer flows have been greater than 11 cfs more than 95% of the days; Fall flows have been greater than 11 cfs more than 99% of the days.
- For all flows, 11 cfs represents the 1.2 percentile; 29 cfs is the 5th percentile of all flows; 37.7 cfs is the 7Q2 flow.

<u>Biological Recommendation</u>: For the Angelina River near Alto, ***subsistence flows of 18 cfs for Spring, 11 cfs for Summer, and 16 cfs for Fall*** are recommended for maintenance of minimal habitat and environmental conditions for aquatic life during infrequent periods of severe and prolonged drought. ***For the Winter season, 55 cfs*** should be considered the subsistence benchmark, because the ecosystem has never experienced flows less than this during Winter.

Attoyac Bayou near Chireno – The minimum value for subsistence flow derived from HEFR/MBFIT was 10 cfs, which corresponded with the Summer period.

- Recorded flows in the Winter and Spring months have never been as low as 10 cfs; the lowest flow ever recorded during the Winter was 29 cfs and the lowest flow recorded during the Spring is 13 cfs.
- Summer flows have been greater than 10 cfs more than 95% of the days; Fall flows have been greater than 10 cfs more than 99% of the days.
- For all flows, 10 cfs represents the 2.0 percentile; 17 cfs is the 5th percentile of all flows; 25.6 cfs is the 7Q2 flow.

<u>Biological Recommendation</u>: For the Attoyac Bayou near Chireno, ***subsistence flows of 10 cfs for Spring, Summer, and Fall*** are recommended for maintenance of minimal habitat and environmental conditions for aquatic life during infrequent periods of severe and prolonged drought. ***For the Winter season, 29 cfs*** should be considered the subsistence benchmark, because the ecosystem has never experienced flows less than this during Winter.

Neches River at Evadale –

- The minimum value for subsistence flow derived from HEFR/MBFIT was 228 cfs, which corresponded with the Summer period.
- Recorded flows in the Spring months have never been as low as 228 cfs; the lowest flow ever recorded during the Spring was 266 cfs.
- Summer flows have been greater than 228 cfs more than 97% of the days, more than 95% of the days in the Fall, and more than 99% of the days in the Winter months.
- For all flows, 228 cfs represents the 1.7 percentile; 370 cfs is the 5th percentile of all flows; the 7Q2 flow is 1838.6 cfs (although this value is likely influenced by hydropower operations); the 7Q10 flow is 361 cfs.

Biological Recommendation: For the Neches River near Evadale, ***subsistence flows of 266 cfs for Spring and 228 cfs for Winter, Summer, and Fall*** are recommended for maintenance of minimal habitat and environmental conditions for aquatic life during infrequent periods of severe and prolonged drought.

Village Creek near Kountze –

- The minimum value for subsistence flow derived from HEFR/MBFIT was 41 cfs, which corresponded with the Summer/Fall period.
- Recorded flows in the Winter and Spring months have never been as low as 41 cfs; the lowest flow ever recorded during the Winter was 83 cfs and the lowest flow recorded during the Spring is 44 cfs.
- Summer flows have been greater than 41 cfs more than 96% of the days; Fall flows have been greater than 41cfs more than 97% of the days.
- For all flows, 41 cfs represents the 1.6 percentile; 61 cfs is the 5th percentile of all flows; 78.9 cfs is the 7Q2 flow.

Biological Recommendation: For the Village Creek near Kountze, ***subsistence flows of 49 cfs for Spring and 41 cfs for Summer and Fall*** are recommended for maintenance of minimal habitat and environmental conditions for aquatic life during infrequent periods of severe and prolonged drought. ***For the Winter season, 83 cfs*** should be considered the subsistence benchmark, because the ecosystem has never experienced flows less than this during Winter.

BBEST Base Flow Recommendations –

For our ecological analysis, the HEFR base flows for dry-year, average-year, and wet-year estimates from each gage were compared with our information on the ecology of focal species (BIO-WEST 2009a) and, when appropriate, findings from the BIO-WEST instream flow study of fishes in the lower Colorado River (BIO-WEST 2008a). With only one minor exception (Sabine River near Beckville), base flow estimates from the HEFR analysis were deemed ecologically suitable. 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. It is important to note that base flow benchmarks represent a lower threshold (floor) which flows should not fall below unless it has been determined from independent data sources that the region has entered into a prolonged, severe drought.

Big Sandy Creek near Big Sandy – The following base flows derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- Base flow, Winter, Dry year: 66 cfs
- Base flow, Winter, Average year: 106 cfs
- Base flow, Winter, Wet year: 163 cfs
- Base flow, Spring, Dry year: 30 cfs
- Base flow, Spring, Average year: 51 cfs
- Base flow, Spring, Wet year: 111 cfs
- Base flow, Summer, Dry year: 14 cfs
- Base flow, Summer, Average year: 18 cfs
- Base flow, Summer, Wet year: 26 cfs
- Base flow, Fall, Dry year: 20 cfs
- Base flow, Fall, Average year: 36 cfs
- Base flow, Fall, Wet year: 63 cfs

Sabine River near Gladewater – The following base flows derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- Base flow, Winter, Dry year: 277 cfs
- Base flow, Winter, Average year: 472 cfs
- Base flow, Winter, Wet year: 836 cfs
- Base flow, Spring, Dry year: 119 cfs
- Base flow, Spring, Average year: 283 cfs
- Base flow, Spring, Wet year: 664 cfs
- Base flow, Summer, Dry year: 34 cfs
- Base flow, Summer, Average year: 46 cfs
- Base flow, Summer, Wet year: 78 cfs
- Base flow, Fall, Dry year: 49 cfs
- Base flow, Fall, Average year: 105 cfs
- Base flow, Fall, Wet year: 232 cfs

Sabine River near Beckville – The following base flows derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- Base flow, Winter, Dry year: 438 cfs
- Base flow, Winter, Average year: 807 cfs
- Base flow, Winter, Wet year: 1580 cfs

- Base flow, Spring, Dry year: 232 cfs
- Base flow, Spring, Average year: 526 cfs*
- Base flow, Spring, Wet year: 1260 cfs
- Base flow, Summer, Dry year: 52 cfs
- Base flow, Summer, Average year: 74 cfs
- Base flow, Summer, Wet year: 122 cfs
- Base flow, Fall, Dry year: 75 cfs
- Base flow, Fall, Average year: 141 cfs
- Base flow, Fall, Wet year: 356 cfs

*Note: In this instance, the base flow for dry periods will be 52 cfs (the 5^{th} percentile of all days), the only instance in our gage analysis in which the base flow estimate equals subsistence flow estimate.

Sabine River near Bon Wier – The following base flows derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- Base flow, Winter, Dry year: 1460 cfs
- Base flow, Winter, Average year: 5870 cfs
- Base flow, Winter, Wet year: 15400 cfs
- Base flow, Spring, Dry year: 857 cfs
- Base flow, Spring, Average year: 1590 cfs
- Base flow, Spring, Wet year: 6680 cfs
- Base flow, Summer, Dry year: 478 cfs
- Base flow, Summer, Average year: 656 cfs
- Base flow, Summer, Wet year: 1120 cfs
- Base flow, Fall, Dry year: 478 cfs
- Base flow, Fall, Average year: 615 cfs
- Base flow, Fall, Wet year: 1110 cfs

Big Cow Creek near Newton – The following base flows derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- Base flow, Winter, Dry year: 56 cfs
- Base flow, Winter, Average year: 78 cfs
- Base flow, Winter, Wet year: 106 cfs
- Base flow, Spring, Dry year: 38 cfs
- Base flow, Spring, Average year: 52 cfs
- Base flow, Spring, Wet year: 74 cfs
- Base flow, Summer, Dry year: 28 cfs
- Base flow, Summer, Average year: 36 cfs
- Base flow, Summer, Wet year: 48 cfs
- Base flow, Fall, Dry year: 36 cfs
- Base flow, Fall, Average year: 46 cfs

- Base flow, Fall, Wet year: 64 cfs

Sabine River near Ruliff – The following base flows derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- Base flow, Winter, Dry year: 1520 cfs
- Base flow, Winter, Average year: 2565 cfs
- Base flow, Winter, Wet year: 5063 cfs
- Base flow, Spring, Dry year: 1208 cfs
- Base flow, Spring, Average year: 1795 cfs
- Base flow, Spring, Wet year: 3035 cfs
- Base flow, Summer, Dry year: 670 cfs
- Base flow, Summer, Average year: 870 cfs
- Base flow, Summer, Wet year: 1430 cfs
- Base flow, Fall, Dry year: 735 cfs
- Base flow, Fall, Average year: 970 cfs
- Base flow, Fall, Wet year: 1400 cfs

Neches River at Neches – The following base flows derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- Base flow, Winter, Dry year: 178 cfs
- Base flow, Winter, Average year: 408 cfs
- Base flow, Winter, Wet year: 814 cfs
- Base flow, Spring, Dry year: 87 cfs
- Base flow, Spring, Average year: 194 cfs
- Base flow, Spring, Wet year: 524 cfs
- Base flow, Summer, Dry year: 42 cfs
- Base flow, Summer, Average year: 73 cfs
- Base flow, Summer, Wet year: 108 cfs
- Base flow, Fall, Dry year: 73 cfs
- Base flow, Fall, Average year: 104 cfs
- Base flow, Fall, Wet year: 172 cfs

Neches River at Rockland – The following base flows derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- Base flow, Winter, Dry year: 548 cfs
- Base flow, Winter, Average year: 1390 cfs
- Base flow, Winter, Wet year: 2500 cfs
- Base flow, Spring, Dry year: 382 cfs
- Base flow, Spring, Average year: 1020 cfs
- Base flow, Spring, Wet year: 2160 cfs
- Base flow, Summer, Dry year: 61 cfs

- Base flow, Summer, Average year: 88 cfs
- Base flow, Summer, Wet year: 151 cfs
- Base flow, Fall, Dry year: 82 cfs
- Base flow, Fall, Average year: 168 cfs
- Base flow, Fall, Wet year: 381 cfs

Angelina River near Alto – The following base flows derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- Base flow, Winter, Dry year: 252 cfs
- Base flow, Winter, Average year: 581 cfs
- Base flow, Winter, Wet year: 971 cfs
- Base flow, Spring, Dry year: 82 cfs
- Base flow, Spring, Average year: 206 cfs
- Base flow, Spring, Wet year: 518 cfs
- Base flow, Summer, Dry year: 36 cfs
- Base flow, Summer, Average year: 48 cfs
- Base flow, Summer, Wet year: 69 cfs
- Base flow, Fall, Dry year: 47 cfs
- Base flow, Fall, Average year: 92 cfs
- Base flow, Fall, Wet year: 176 cfs

Attoyac Bayou near Chireno – The following base flows derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- Base flow, Winter, Dry year: 107 cfs
- Base flow, Winter, Average year: 188 cfs
- Base flow, Winter, Wet year: 339 cfs
- Base flow, Spring, Dry year: 49 cfs
- Base flow, Spring, Average year: 96 cfs
- Base flow, Spring, Wet year: 178 cfs
- Base flow, Summer, Dry year: 20 cfs
- Base flow, Summer, Average year: 28 cfs
- Base flow, Summer, Wet year: 48 cfs
- Base flow, Fall, Dry year: 34 cfs
- Base flow, Fall, Average year: 65 cfs
- Base flow, Fall, Wet year: 122 cfs

Neches River at Evadale – The following base flows derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- Base flow, Winter, Dry year: 1760 cfs
- Base flow, Winter, Average year: 2590 cfs
- Base flow, Winter, Wet year: 4980 cfs

- Base flow, Spring, Dry year: 1553 cfs
- Base flow, Spring, Average year: 3070 cfs
- Base flow, Spring, Wet year: 3868 cfs
- Base flow, Summer, Dry year: 471 cfs
- Base flow, Summer, Average year: 2140 cfs
- Base flow, Summer, Wet year: 3210 cfs
- Base flow, Fall, Dry year: 438 cfs
- Base flow, Fall, Average year: 1280 cfs
- Base flow, Fall, Wet year: 2630 cfs

Village Creek near Kountze – The following base flows derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- Base flow, Winter, Dry year: 240 cfs
- Base flow, Winter, Average year: 424 cfs
- Base flow, Winter, Wet year: 672 cfs
- Base flow, Spring, Dry year: 106 cfs
- Base flow, Spring, Average year: 189 cfs
- Base flow, Spring, Wet year: 335 cfs
- Base flow, Summer, Dry year: 70 cfs
- Base flow, Summer, Average year: 91 cfs
- Base flow, Summer, Wet year: 135 cfs
- Base flow, Fall, Dry year: 89 cfs
- Base flow, Fall, Average year: 138 cfs
- Base flow, Fall, Wet year: 236 cfs

BBEST High Flow Pulses and Overbank Flow Recommendations –

For our ecological analysis, the HEFR pulse flows were evaluated in the context of ecological information compiled for our focal species (BIO-WEST 2009a 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 2000, Zeug et al. 2005, 2009, Zeug and Winemiller 2007, 2008, Robertson et al. 2008). 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, we also examined the percent flooding of wetland and bottomland hardwood vegetation zones in several of our reaches (this information was provided by the National Wildlife

Federation (NWF) and the Greater Edwards Aquifer Alliance (GEAA); Reference Appendix XVII). High flow pulse 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 meet, 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 gages 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. Only four gages had sufficient data to develop models (Big Sandy, Ruliff, Neches, Evadale) and the R^2 values for all four models were 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 pineywoods wetland/riparian zones inundated (Table 1). Results of this analysis are shown in each of the gages HEFR version 2 outputs (Figures 3 – 6).

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 gages 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 gages are not sufficient to inundate riparian areas on an annual basis in both the lower Sabine River and lower Neches River. Given this trend, we recommend 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.

	Overbank		**High Flow Pulse**					
	1 per 2 years		**1 per year**		**2 per 3 years**		**2 per year**	
	Flow (cfs)	Predicted % Area Inundated	Flow (cfs)	Predicted % Area Inundated	Flow (cfs)	Predicted % Area Inundated	Flow (cfs)	Predicted % Area Inundated
Big Sandy	2930	83.38%	1920	65.50%	1420	56.65%	1170	52.23%
Ruliff	41300	100%	29000	100%	22700	82.46%	16800	55.91%
Neches	7280	61.49%	4880	56.25%	3430	51.64%	2440	47.18%
Evadale	26800	100%	19500	70.69%	15800	49.39%	13000	29.64%

Table 1. 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.

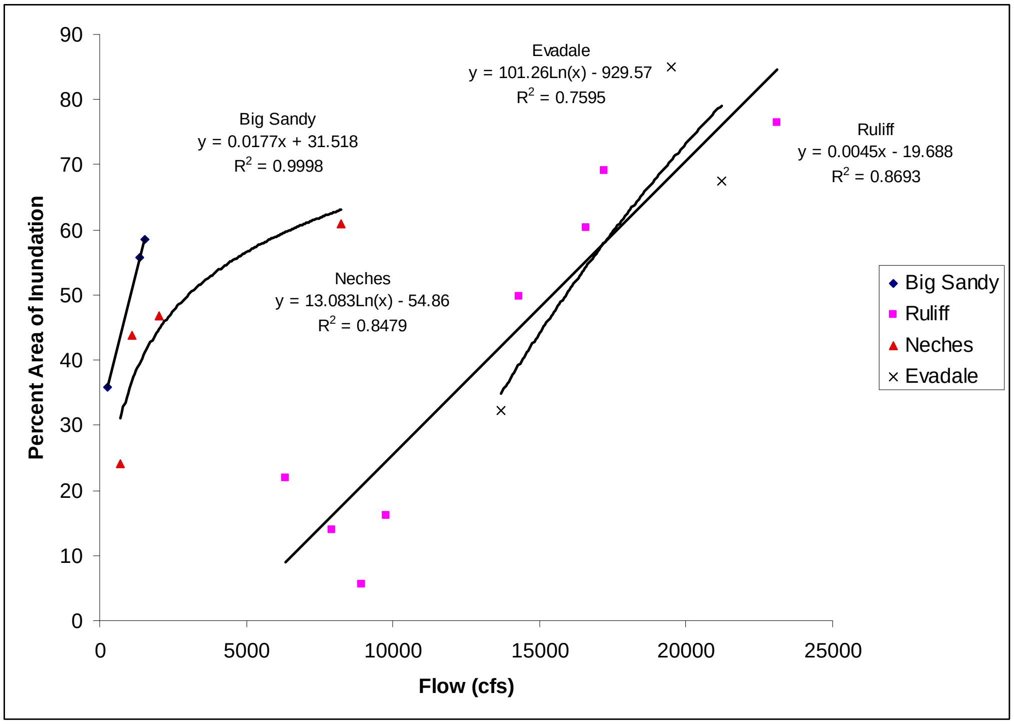


Figure 2. Relationship between observed flow and percent total area of Pineywoods Riparian Ecotones (wetlands and bottomland hardwood vegetation communities) inundated using NWF/GEAA overbanking flows analysis for the maintenance of bottomland hardwoods.

Overbank Flows	Qp: 2,930 cfs with Frequency 1 per 2 years Percent Area of Inundation = 83.38%			
High Flow Pulses	Qp: 942 cfs with Frequency 1 per season Percent Area of Inundation = 48.19%	Qp: 950 cfs with Frequency 1 per season Percent Area of Inundation = 48.33%	Qp: 132 cfs with Frequency 1 per season Percent Area of Inundation = 33.85%	Qp: 367 cfs with Frequency 1 per season Percent Area of Inundation = 38.01%
	Qp: 358 cfs with Frequency 2 per season Percent Area of Inundation = 37.85%	Qp: 313 cfs with Frequency 2 per season Percent Area of Inundation = 37.06%	Qp: 50 cfs with Frequency 2 per season Percent Area of Inundation = 32.40%	Qp: 130 cfs with Frequency 2 per season Percent Area of Inundation = 33.82%

Figure 3. Percent area of inundation predicted for HEFR v2 overbank and high flow pulses for Big Sandy.

Overbank Flows	Qp:41,300 cfs with Frequency 1 per 2 years Percent Area of Inundation =100%			
High Flow Pulses	Qp: 9,880 cfs with Frequency 1 per season Percent Area of Inundation = 24.77%	Qp: 9,880 cfs with Frequency 1 per season Percent Area of Inundation = 24.77%	Qp: 6,600 cfs with Frequency 1 per season Percent Area of Inundation = 10.01%	Qp: 6,030 cfs with Frequency 1 per season Percent Area of Inundation = 7.45%
	Qp: 1,600 cfs with Frequency 2 per season Percent Area of Inundation = 0%	Qp: 3,250 cfs with Frequency 2 per season Percent Area of Inundation = 0%	Qp: 3,380 cfs with Frequency 2 per season Percent Area of Inundation = 0%	Qp: 2,020 cfs with Frequency 2 per season Percent Area of Inundation = 0%

Figure 4. Percent area of inundation predicted for HEFR v2 overbank and high flow pulses for Ruliff.

Overbank Flows	Qp: 7,280 cfs with Frequency 1 per 2 years Percent Area of Inundation = 61.49%			
High Flow Pulses	Qp: 1,370 cfs with Frequency 1 per season Percent Area of Inundation = 39.63%	Qp: 1,370 cfs with Frequency 1 per season Percent Area of Inundation = 39.63%	Qp: 248 cfs with Frequency 1 per season Percent Area of Inundation = 17.27%	Qp: 782 cfs with Frequency 1 per season Percent Area of Inundation = 32.30%
	Qp: 833 cfs with Frequency 2 per season Percent Area of Inundation = 33.12%	Qp: 820 cfs with Frequency 2 per season Percent Area of Inundation = 32.92%	Qp: 113 cfs with Frequency 2 per season Percent Area of Inundation = 6.99%	Qp: 345 cfs with Frequency 2 per season Percent Area of Inundation = 21.59%

Figure 5. Percent area of inundation predicted for HEFR v2 overbank and high flow pulses for Neches.

Overbank Flows	Qp: 26,800 cfs with Frequency 1 per 2 years Percent Area of Inundation = 100%			
High Flow Pulses	Qp:8,700 cfs with Frequency 1 per season Percent Area of Inundation = 0%	Qp: 8,700 cfs with Frequency 1 per season Percent Area of Inundation = 0%	Qp: 3,390 cfs with Frequency 1 per season Percent Area of Inundation = 0%	Qp: 3,820 cfs with Frequency 1 per season Percent Area of Inundation = 0%
	Qp: 2,000 cfs with Frequency 2 per season Percent Area of Inundation = 0%	Qp: 3,440 cfs with Frequency 2 per season Percent Area of Inundation = 0%	Qp: 1,190 cfs with Frequency 2 per season Percent Area of Inundation = 0%	Qp: 1,150 cfs with Frequency 2 per season Percent Area of Inundation = 0%

Figure 6. Percent area of inundation predicted for HEFR v2 overbank and high flow pulses for Evadale.

Based on our analysis of these multiple sources of information, it was concluded that the following categories of flood pulses in our 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 our 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. *For this reason, our BBEST recognizes the ecological functions and benefits of these higher flow pulse categories, but we do not recommend actions be taken to produce such flows.* Normally, climatic conditions and events produce these levels of flow despite the best efforts to control and limit them.

Big Sandy Creek near Big Sandy – The following high flow pulses derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes (volumes and durations are average values):

- 2-per-season, Winter: 358 cfs, volume 5,932, duration 10 days
- 2-per-season, Spring: 313 cfs, volume 5,062, duration 13 days
- 2-per-season, Summer: 50 cfs, volume 671, duration 6 days
- 2-per-season, Fall: 130 cfs, volume 2,189, duration 9 days
- 1-per-season, Winter: 942 cfs, volume 14,544, duration 16 days
- 1-per-season, Spring: 950 cfs, volume 12,852, duration 19 days
- 1-per-season, Summer: 132 cfs, volume 2,054, duration 11 days
- 1-per-season, Fall: 367 cfs, volume 6,055, duration 14 days
- *1-per-2 years: 2,930 cfs, volume 35,703, duration 30 days (not recommended, but ecological functions and benefits have been identified)*

Sabine River near Gladewater – The following high flow pulses derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- 2-per-season, Winter: 1,880 cfs, volume 48,599, duration 15 days
- 2-per-season, Spring: 1,580 cfs, volume 51,150, duration 16 days
- 2-per-season, Summer: 168 cfs, volume 2,752, duration 7 days
- 2-per-season, Fall: 380 cfs, volume 1,098, duration 11 days
- 1-per-season, Winter: 5,570 cfs, volume 194,743, duration 24 days

- 1-per-season, Spring: 5,070 cfs, volume 140,612, duration 25 days
- 1-per-season, Summer: 730 cfs, volume 13,480, duration 17 days
- 1-per-season, Fall: 2,240 cfs, volume 66,875, duration 21 days
- *1-per-2 years: 18,100 cfs, volume 483,275, duration 44 day (not recommended, but ecological functions and benefits have been identified)*

Sabine River near Beckville – The following high flow pulses derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- 2-per-season, Winter: 2,900 cfs, volume 84,998, duration 15 days
- 2-per-season, Spring: 2,160 cfs, volume 72,092, duration 15 days
- 2-per-season, Summer: 285 cfs, volume 5,436, duration 6 days
- 2-per-season, Fall: 628 cfs, volume 7,245, duration 9 days
- 1-per-season, Winter: 7,200 cfs, volume 302,174, duration 24 days
- 1-per-season, Spring: 7,030 cfs, volume 220,513, duration 27 days
- 1-per-season, Summer: 1,120 cfs, volume 19,863, duration 16 days
- 1-per-season, Fall: 3,250 cfs, volume 100,717, duration 21 days
- *1-per-2 years: 16,100 cfs, volume 541,644, duration 45 days (not recommended, but ecological functions and benefits have been identified)*

Sabine River near Bon Wier – The following high flow pulses derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- 2-per-season, Winter: 13,800 cfs, volume 421,966, duration 14 days
- 2-per-season, Spring: 6,700 cfs, volume 151,163, duration 12 days
- 2-per-season, Summer: 5,880 cfs, volume 132,571, duration 13 days
- 2-per-season, Fall: 2,590 cfs, volume 40,957, duration 7 days
- 1-per-season, Winter: 20,600 cfs, volume 690,800, duration 17 days
- 1-per-season, Spring: 16,500 cfs, volume 483,992, duration 21 days
- 1-per-season, Summer: 7,360 cfs, volume 175,009, duration 14 days
- 1-per-season, Fall: 8,960 cfs, volume 249,617, duration 17 days
- *1-per-year: 28,700 cfs, volume 931,140, duration 28 days (not recommended, but ecological functions and benefits have been identified)*

Big Cow Creek near Newton – The following high flow pulses derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- 2-per-season, Winter: 693 cfs, volume 4,911, duration 8 days
- 2-per-season, Spring: 350 cfs, volume 2,545, duration 7 days
- 2-per-season, Summer: 109 cfs, volume 873, duration 13 days
- 2-per-season, Fall: 322 cfs, volume 2,232, duration 7 days
- 1-per-season, Winter: 1,080 cfs, volume 7,387, duration 10 days
- 1-per-season, Spring: 862 cfs, volume 6,075, duration 10 days
- 1-per-season, Summer: 191 cfs, volume 1,447, duration 7 days
- 1-per-season, Fall: 790 cfs, volume 5,038, duration 9 days

- *1-per-2 years: 3,180 cfs, volume 18,325, duration 17 days (not recommended, but ecological functions and benefits have been identified)*

Sabine River near Ruliff – The following high flow pulses derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- 2-per-season, Winter: 1,600 cfs, volume 10,202, duration 3 days
- 2-per-season, Spring: 3,250 cfs, volume 42,883, duration 8 days
- 2-per-season, Summer: 3,380 cfs, volume 54,321, duration 11 days
- 2-per-season, Fall: 2,020 cfs, volume 17,662, duration 5 days
- 1-per-season, Winter: 9,880 cfs, volume 261,464, duration 22 days
- 1-per-season, Spring: 9,880 cfs, volume 253,851, duration 21 days
- 1-per-season, Summer: 6,600 cfs, volume 157,936, duration 19 days
- 1-per-season, Fall: 6,030 cfs, volume 110,471, duration 15 days
- *1-per-year: 29,000 cfs, volume 1,760,073, duration 60 days (not recommended, but ecological functions and benefits have been identified)*

Neches River at Neches – The following high flow pulses derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- 2-per-season, Winter: 833 cfs, volume 19,104, duration 10 days
- 2-per-season, Spring: 820 cfs, volume 20,405, duration 12 days
- 2-per-season, Summer: 113 cfs, volume 1,339, duration 4 days
- 2-per-season, Fall: 345 cfs, volume 5,391, duration 8 days
- 1-per-season, Winter: 1,370 cfs, volume 39,549, duration 13 days
- 1-per-season, Spring: 1,370 cfs, volume 31,846, duration 15 days
- 1-per-season, Summer: 248 cfs, volume 4,029, duration 7 days
- 1-per-season, Fall: 782 cfs, volume 19,996, duration 12 days
- *1-per-2 years: 7,280 cfs, volume 172,590, duration 38 days (not recommended, but ecological functions and benefits have been identified)*

Neches River at Rockland – The following high flow pulses derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- 2-per-season, Winter: 3,080 cfs, volume 82,195, duration 14 days
- 2-per-season, Spring: 1,720 cfs, volume 39,935, duration 12 days
- 2-per-season, Summer: 195 cfs, volume 1,548, duration 5 days
- 2-per-season, Fall: 515 cfs, volume 649, duration 8 days
- 1-per-season, Winter: 6,910 cfs, volume 256,523, duration 22 days
- 1-per-season, Spring: 5,600 cfs, volume 167,866, duration 23 days
- 1-per-season, Summer: 615 cfs, volume 13,365, duration 11 days
- 1-per-season, Fall: 2,240 cfs, volume 72,600, duration 17 days
- *1-per-2 years: 18,500 cfs, volume 661,717, duration 41 days (not recommended, but ecological functions and benefits have been identified)*

Angelina River near Alto – The following high flow pulses derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- 2-per-season, Winter: 1,620 cfs, volume 37,114, duration 13 days
- 2-per-season, Spring: 1,100 cfs, volume 24,117, duration 14 days
- 2-per-season, Summer: 146 cfs, volume 2,632, duration 8 days
- 2-per-season, Fall: 588 cfs, volume 12,038, duration 12 days
- 1-per-season, Winter: 3,530 cfs, volume 89,332, duration 18 days
- 1-per-season, Spring: 52,760 cfs, volume 59,278, duration 20 days
- 1-per-season, Summer: 397 cfs, volume 7,129, duration 13 days
- 1-per-season, Fall: 1,500 cfs, volume 34,291, duration 16 days
- *1-per-2 years: 9,690 cfs, volume 204,931, duration 29 days (not recommended, but ecological functions and benefits have been identified)*

Attoyac Bayou near Chireno – The following high flow pulses derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- 2-per-season, Winter: 837 cfs, volume 13,871, duration 10 days
- 2-per-season, Spring: 690 cfs, volume 10,618, duration 13 days
- 2-per-season, Summer: 146 cfs, volume 1,888, duration 7 days
- 2-per-season, Fall: 405 cfs, volume 6,353, duration 9 days
- 1-per-season, Winter: 1,200 cfs, volume 19,704, duration 12 days
- 1-per-season, Spring: 1,200 cfs, volume 18,062, duration 15 days
- 1-per-season, Summer: 390 cfs, volume 5,384, duration 12 days
- 1-per-season, Fall: 898 cfs, volume 16,133, duration 12 days
- *1-per-2 years: 7,520 cfs, volume 91,536, duration 27 days (not recommended, but ecological functions and benefits have been identified)*

Neches River at Evadale – The following high flow pulses derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- 2-per-season, Winter: 2,000 cfs, volume 21,702, duration 6 days
- 2-per-season, Spring: 3,440 cfs, volume 64,381, duration 12 days
- 2-per-season, Summer: 1,190 cfs, volume 15,630, duration 8 days
- 2-per-season, Fall: 1,150 cfs, volume 12,160, duration 6 days
- 1-per-season, Winter: 8,700 cfs, volume 255,138, duration 22 days
- 1-per-season, Spring: 8,700 cfs, volume 250,330, duration 23 days
- 1-per-season, Summer: 3,390 cfs, volume 64,197, duration 13 days
- 1-per-season, Fall: 3,820 cfs, volume 68,248, duration 13 days
- *1-per-year: 19,500 cfs, volume 1,242,210, duration 38 days (not recommended, but ecological functions and benefits have been identified)*

Village Creek near Kountze – The following high flow pulses derived from HEFR analysis are recommended for maintenance of native biota and its associated ecological processes:

- 2-per-season, Winter: 2,010 cfs, volume 36,927, duration 13 days
- 2-per-season, Spring: 1,380 cfs, volume 23,093, duration 13 days
- 2-per-season, Summer: 341 cfs, volume 6,159, duration 8 days
- 2-per-season, Fall: 712 cfs, volume 11,426, duration 9 days
- 1-per-season, Winter: 2,070 cfs, volume 38,134, duration 13 days
- 1-per-season, Spring: 2,070 cfs, volume 31,650, duration 15 days
- 1-per-season, Summer: 814 cfs, volume 11,418, duration 13 days
- 1-per-season, Fall: 2,070 cfs, volume 31,143, duration 13 days
- *1-per-2 years: 12,400 cfs, volume 170,313, duration 29 days (not recommended, but ecological functions and benefits have been identified)*

Estuarine Ecosystem Realm –

According to the SAC Guidance document for Estuarine Ecosystems (SAC 2009-04, 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 2009-04, 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 our BBEST was that the Sabine Lake estuary would receive the freshwater inflows that result from our HEFR-hydrological analysis and preliminary 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, our BBEST contracted BIO-WEST to provide a literature review and summary of focal species for the Sabine Lake ecosystem (BIO-WEST 2009b). Several plant, invertebrate, and fish species were selected to cover a range of population responses to salinity levels in Upper Gulf Coast estuaries. Second, our BBEST enlisted the help of the National Wildlife Federation (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, our 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 the State Methodology for Estuarine (Kuhn and Chen 2005). We considered these two different approaches to be the best available science available for evaluating the suitability of freshwater inflows derived from our 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 us with the most feasible and robust means for independent assessment of environmental flows for the estuary. Both analyses supported the view that our 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.

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

The recent SB 3 Science Advisory Committee report on methods for establishing an estuarine inflow regime (SAC, 2009-04, 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 specific 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, Olney bulrush (adults and seedlings), Intermediate Marsh, and Brackish Marsh. The bivalve mollusk *Rangia cuneata* (*Rangia* hereafter), blue crabs, oysters, and the Olney bulrush were recommended “focal species” in a previous report to the BBEST (BIO-WEST 2009b). The spatial extent and abundance of oyster and blue crabs are well known in Sabine Lake based on the Texas Parks and Wildlife Department’s long-term sampling program. The Olney bulrush was recommended by BIO-WEST (2009b, Appendix VII) due to its likely occurrence in the marsh types surrounding Sabine Lake.

The spatial extent and abundance of *Rangia* 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, *Rangia* are widespread in the majority of Sabine Lake, approximately the upper three-fourths of the estuary. Thus *Rangia* 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).

There are well-established salinity suitability relationships for their focal species (e.g. 10-20 ppt is optimal for oysters) including relationships for particular life stages (*e.g*. for *Rangia*). For the marshland communities, the salinity suitability relationships are broad levels thought to support that particular community over a long-term.

The availability of a set of existing salinity-inflow regression equations at several points in the estuary facilitated the examination of how these species and communities are likely to respond to freshwater inflows and associated salinity patterns. The primary focus of these assessments is evaluation of the potential freshwater inflows that would result from fluvial environmental flow regimes recommended by the BBEST. However, their analysis also aimed to evaluate the levels of freshwater inflow that may be necessary to support these species and communities and thus protect a "sound ecological environment."

The flows passing through gages at Ruliff (Sabine), Evadale (Neches) and near Kountze (Village Creek) do not comprise all of the potential inflow to Sabine Lake. There are also contributions from other gaged watersheds (Pine Island Bayou and Cow Bayou) as well as ungaged areas below these gages or other wholly ungaged drainages. For these areas the Texas Water Development Board (TWDB) has estimates of inflows dating back to 1941 on a monthly basis. The TWDB also has records, or estimates, of diversions, return flows, direct precipitation onto Sabine Lake, and evaporation that must also be taken into account. Although these later components are generally minor compared to the mainstem river contributions they can be important for very low portions of the environmental flow regimes.

Their 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 (TIFP 2008). 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 gages and other wholly ungaged drainages, remained unchanged.

For the creation of the synthetic flows, several steps and a few assumptions were necessary:

1) for any flow component being evaluated, it was assumed that that flow level (e.g. base flow during an average year & high-tier seasonal pulse) was occurring at all three sites (Ruliff, Evadale, and Village Creek) simultaneously;
2) HEFR components that are depicted as flow rates in cubic feet per second (cfs) were converted to a volumetric value considering the number of applicable days in the month;
3) high flow pulses, expressed as a volume, are added to the converted base flows. However, due to the mechanics of the HEFR program, to avoid double counting volume, the duration of the pulse (days) was deducted from the applicable days of base flow;
4) for the "low-tier pulses" that occur twice per season it was assumed these occur in the first and second month of the season;
5) the higher tier pulses, occurring once per season, were assumed to occur in the middle month of the season; and
6) when assembling the synthetic subsistence inflow record it was assumed that the subsistence level of flows were imposed for the period of March-June, a duration of approximately 120 days, and this flow level was occurring at all three HEFR sites. For the remainder of the year historic inflows prevailed again.

For "average" conditions and the presumed occurrence of "base average" flows at the HEFR sites, they used all years in the 1941-2005 period in which the historic total inflows were between the 40^{th} and 60^{th} percentiles on an annual basis. To analyze "subsistence" conditions, they chose all years in which the historic total inflows were less than or equal to the 5^{th} percentile on an annual basis.

After the synthetic inflow record is created with the HEFR-derived inflows, it is next necessary to predict the salinity response in the estuary. For this step we relied upon previously developed inflow – salinity regression equations as presented in Kuhn and Chen (2005). These equations were derived for three areas of Sabine Lake. Their regression equations and statistical r-squared values are:

Upper: $Sal = 41.7760 - 4.3824 \cdot \ln(Q1) - 0.9153 \cdot \ln(Q2)$ [$r^2=0.73$]
Middle: $Sal = 42.1146 - 4.6393 \cdot \ln(Q1) - 0.7225 \cdot \ln(Q2)$ [$r^2=0.71$]
Lower: $Sal = 61.2663 - 7.1793 \cdot \ln(Q1) - 0.0521 \cdot \ln(Q2)$ [$r^2=0.75$]

where Sal is predicted salinity, ppt; Q1 = cumulative inflow volume over previous 30 days, 1000 ac-ft; Q2 = cumulative inflow volume for previous 31-60 days, 1000 ac-ft.

These equations are based on inflows and salinity data for the 1977-97 period (Kuhn and Chen 2005).

Figures 7 and 8 illustrate the salinity response at the mid-estuary site for representative "average" and "very dry" years 1999 and 1996, respectively. 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.

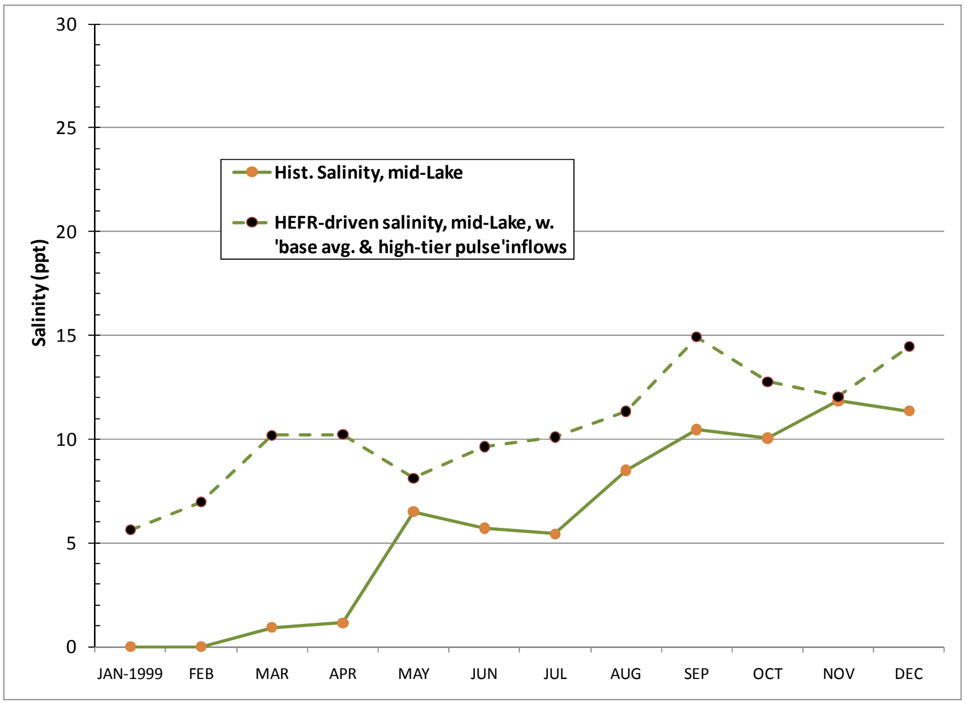


Figure 7. Predicted salinity in Sabine Lake under the original historic inflows for 1999 and with the synthetic inflow record of HEFR-derived values corresponding to "base average and high-tier seasonal pulse" for the sites at Ruliff, Evadale, and Village Creek.

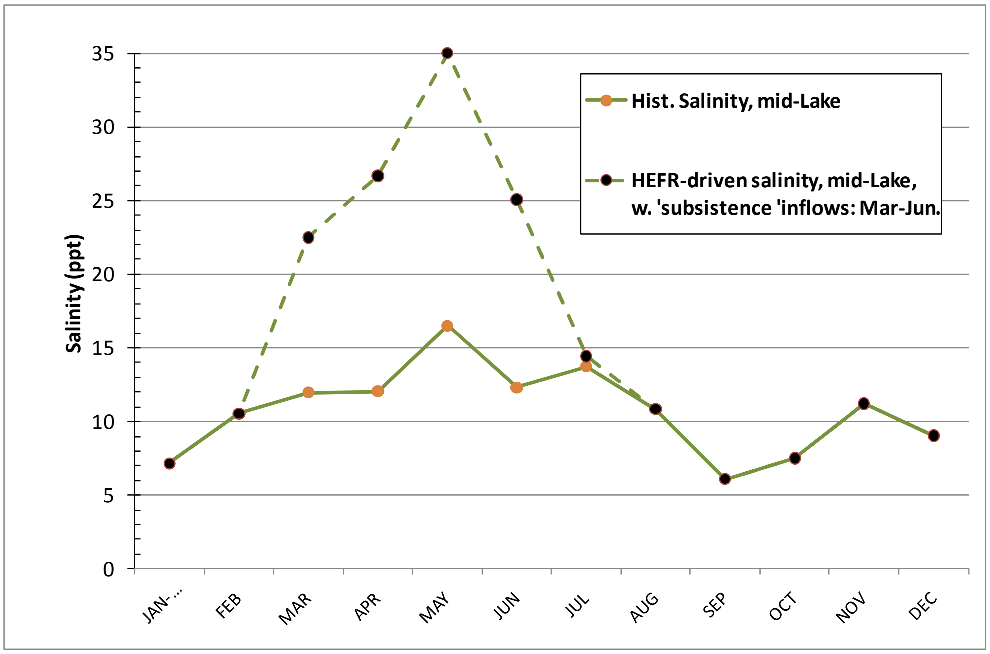


Figure 8 – Illustration of the predicted salinity in Sabine Lake under the original historic inflows for 1996 and with the synthetic inflow record of HEFR-derived values corresponding to “subsistence” levels for the March – June period at the sites at Ruliff, Evadale, and Village Creek.

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 (*Rangia cuneatea*, 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 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.

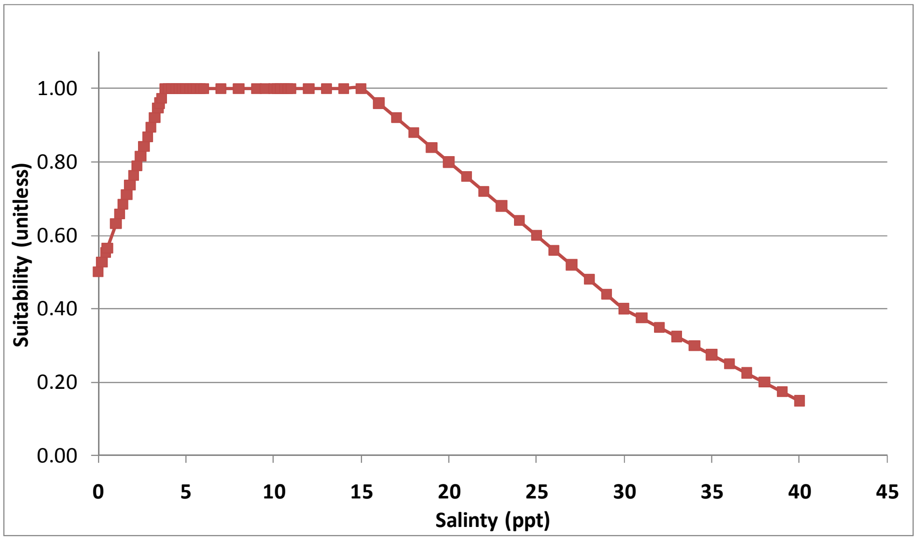


Figure 9. The salinity suitability relationship for blue crabs (based on the synthesis of literature from LCRA-SAWS (2007).

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 10 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 figure are the 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.

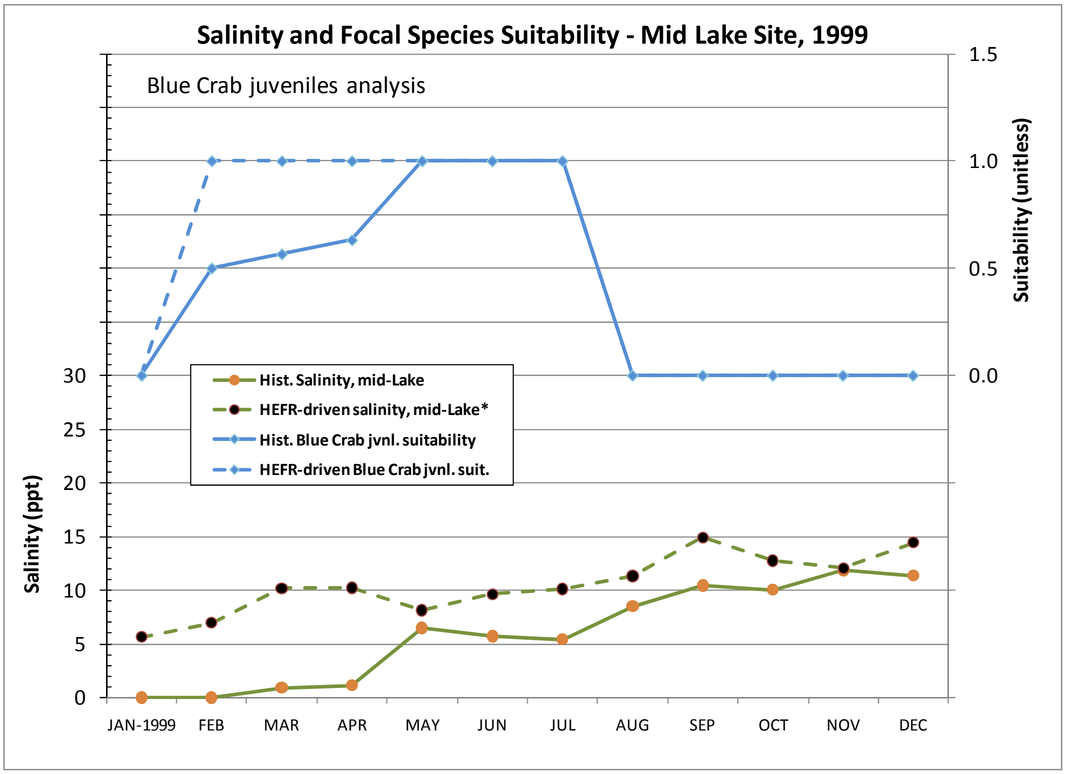
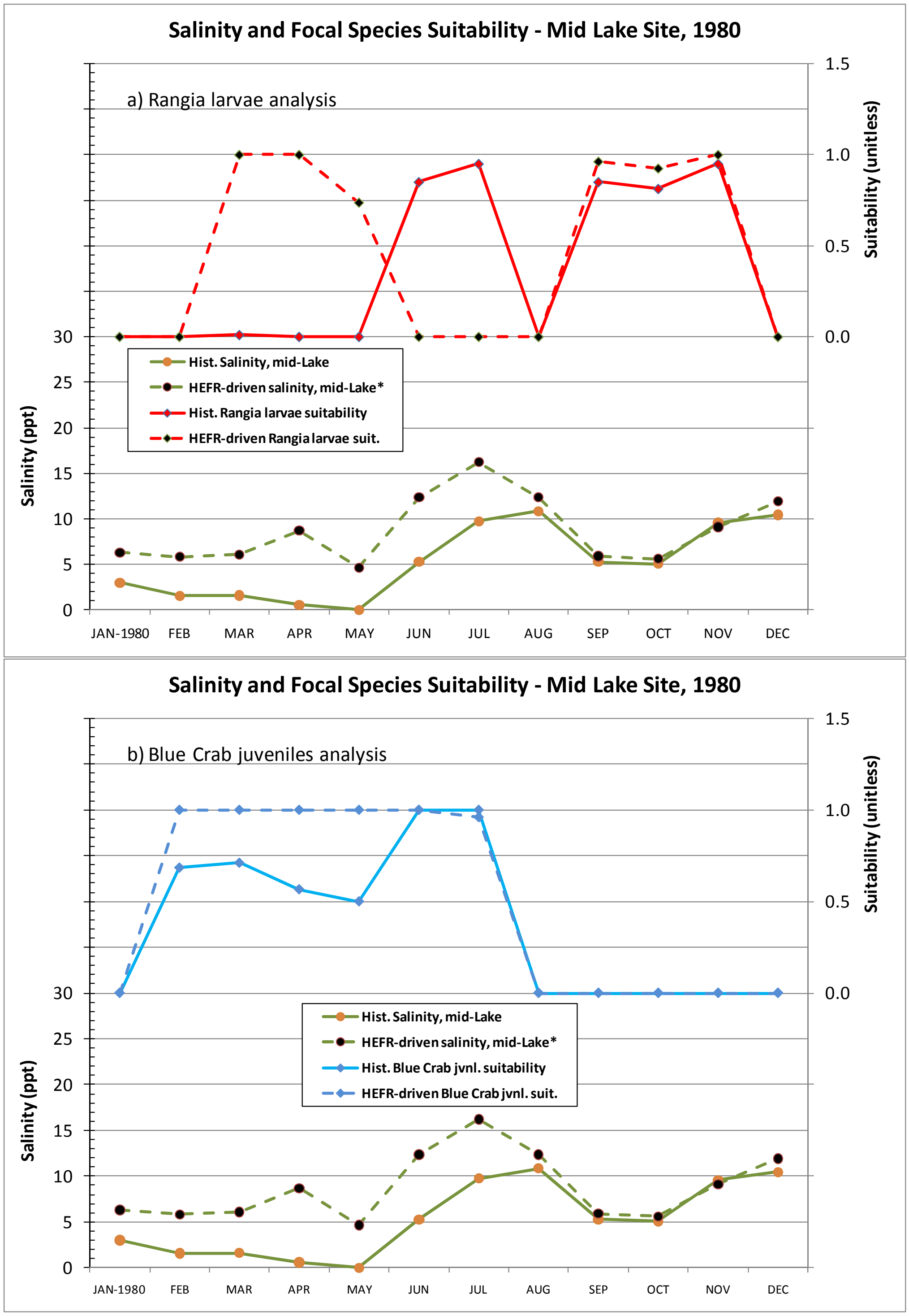


Figure 10. An illustration of how the salinity suitability relationship for blue crabs is combined with the predicted salinity values from the historic record and for HEFR-derived values. Salinities on the lower portion are for historic and HEFR-based "base average and high-tier seasonal pulse" inflows. Corresponding suitabilities for each month in the Feb-July period are in top panel.

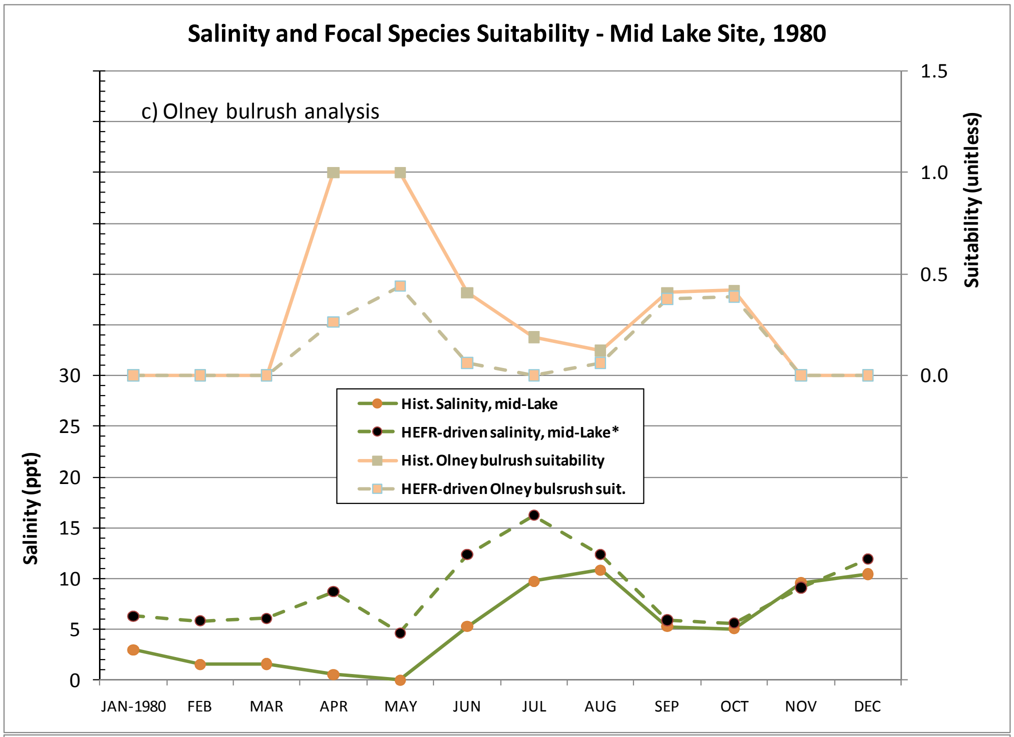
Findings: Salinity Suitablilty Analysis of HEFR-derived Inflows

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.



Salinity and Focal Species Suitability - Mid Lake Site, 1980
a) Rangia larvae analysis
Hist. Salinity, mid-Lake
HEFR-driven salinity, mid-Lake*
Hist. Rangia larvae suitability
HEFR-driven Rangia larvae suit.
Salinity (ppt)
Suitability (unitless)
JAN-1980
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Salinity and Focal Species Suitability - Mid Lake Site, 1980
b) Blue Crab juveniles analysis
Hist. Salinity, mid-Lake
HEFR-driven salinity, mid-Lake*
Hist. Blue Crab jvnl. suitability
HEFR-driven Blue Crab jvnl. suit.
Salinity (ppt)
Suitability (unitless)

Fig. 11 a, b


Salinity and Focal Species Suitability - Mid Lake Site, 1980
c) Olney bulrush analysis
Hist. Salinity, mid-Lake
HEFR-driven salinity, mid-Lake*
Hist. Olney bulrush suitability
HEFR-driven Olney bulsrush suit.
Salinity (ppt)
Suitability (unitless)
0
5
10
15
20
25
30
0.0
0.5
1.0
1.5
JAN-1980
FEB
MAR
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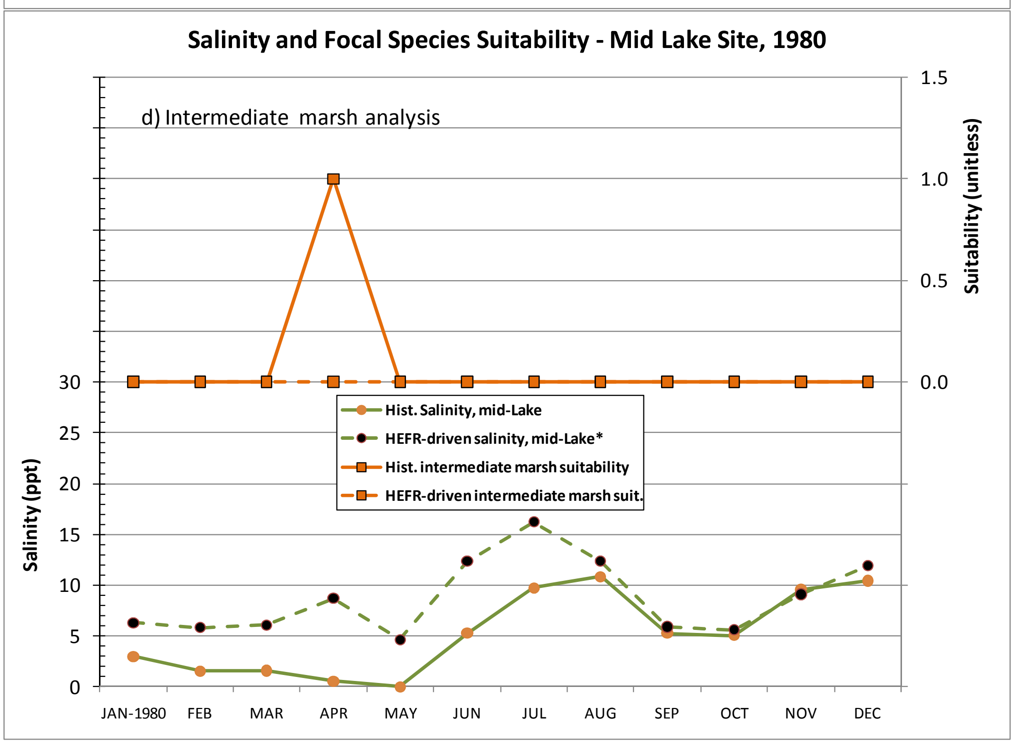
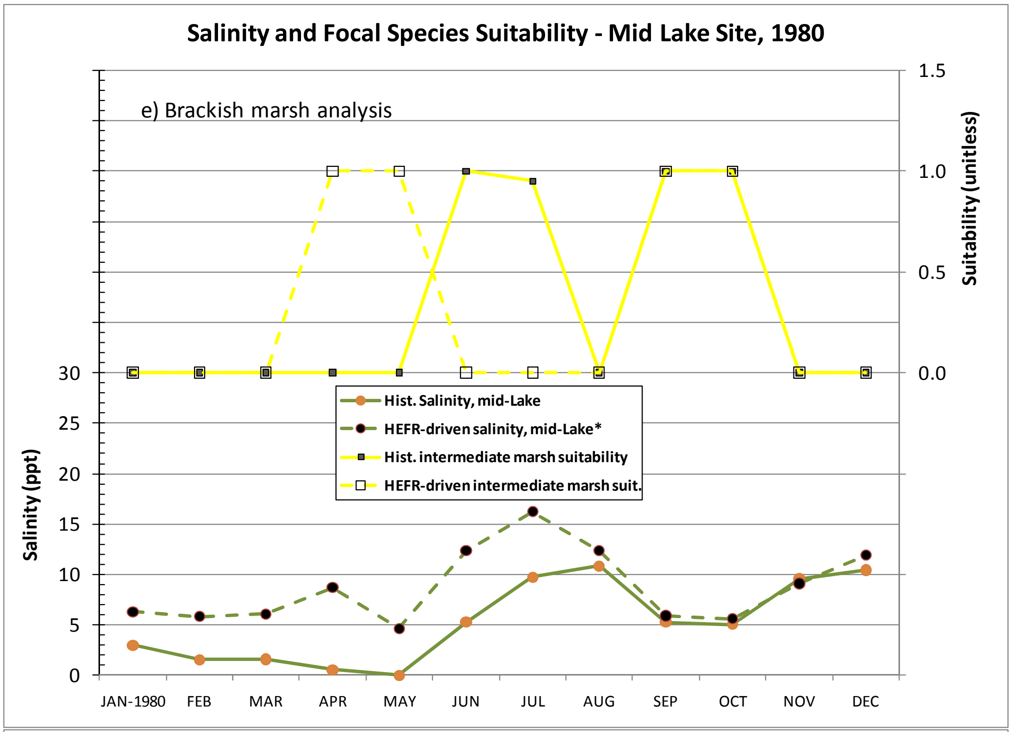

Salinity and Focal Species Suitability - Mid Lake Site, 1980
d) Intermediate marsh analysis
Hist. Salinity, mid-Lake
HEFR-driven salinity, mid-Lake*
Hist. intermediate marsh suitability
HEFR-driven intermediate marsh suit.
Salinity (ppt)
Suitability (unitless)
0
5
10
15
20
25
30
0.0
0.5
1.0
1.5
JAN-1980
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Fig 11 c, d



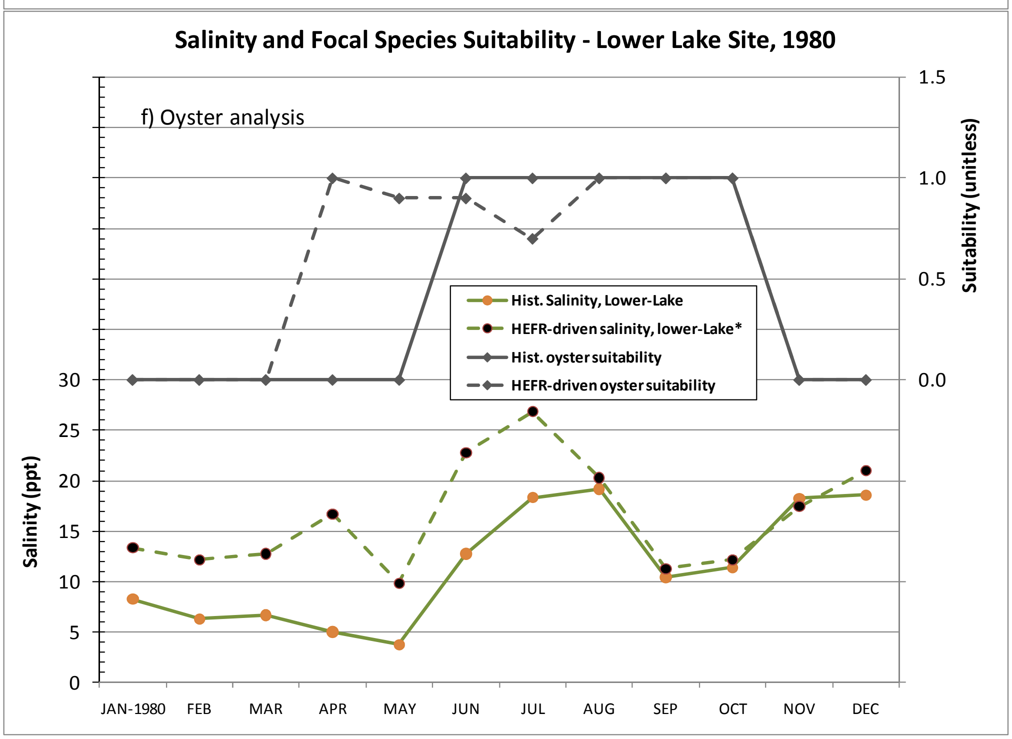


Fig. 11 e, f

Figure 11 (panels a-f). The predicted salinity and salinity suitability results of several key species and communities after substitution of the HEFR-derived instream flow "base average and high-tier seasonal pulse" values for the three BBEST sites (Sabine River at Ruliff, Neches River at Evadale, and Village Creek near Kountze) for 1980.

<u>Inflows at the "subsistence" level</u> – Figure 12a-e illustrates the results of inflows to Sabine Lake when the three BBEST sites Sabine River at Ruliff, Neches River at Evadale, and Village Creek near Kountze have flows at the "subsistence" level for the March-June period. 1967 was used as an example year since historic total inflows were at their lowest in the historic record for 1941-2005. During March-June, and for the remainder of the year, all other inflow contributions are maintained at their historic level. Each figure shows both the salinity response and individual key species and community salinity suitability for the year.

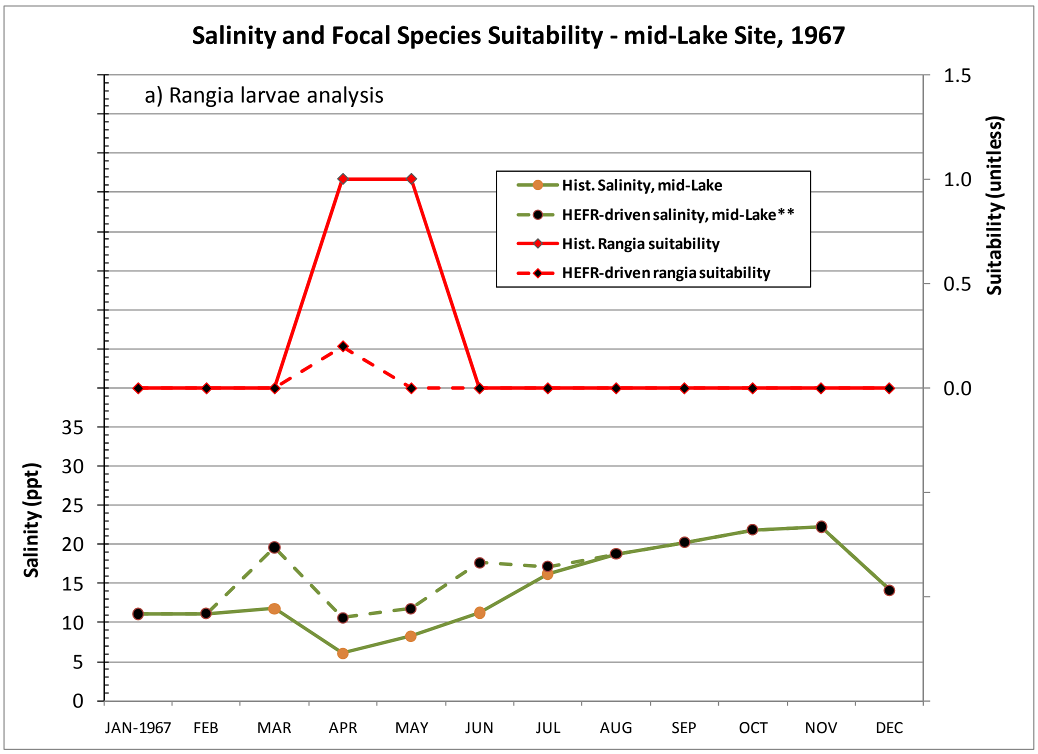
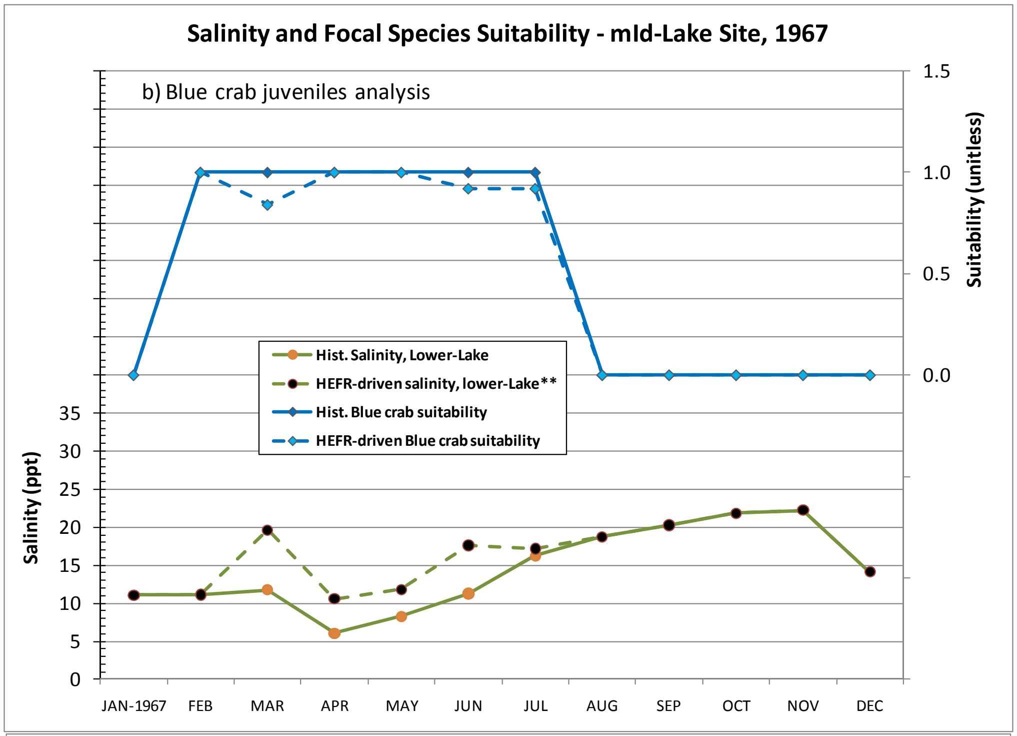
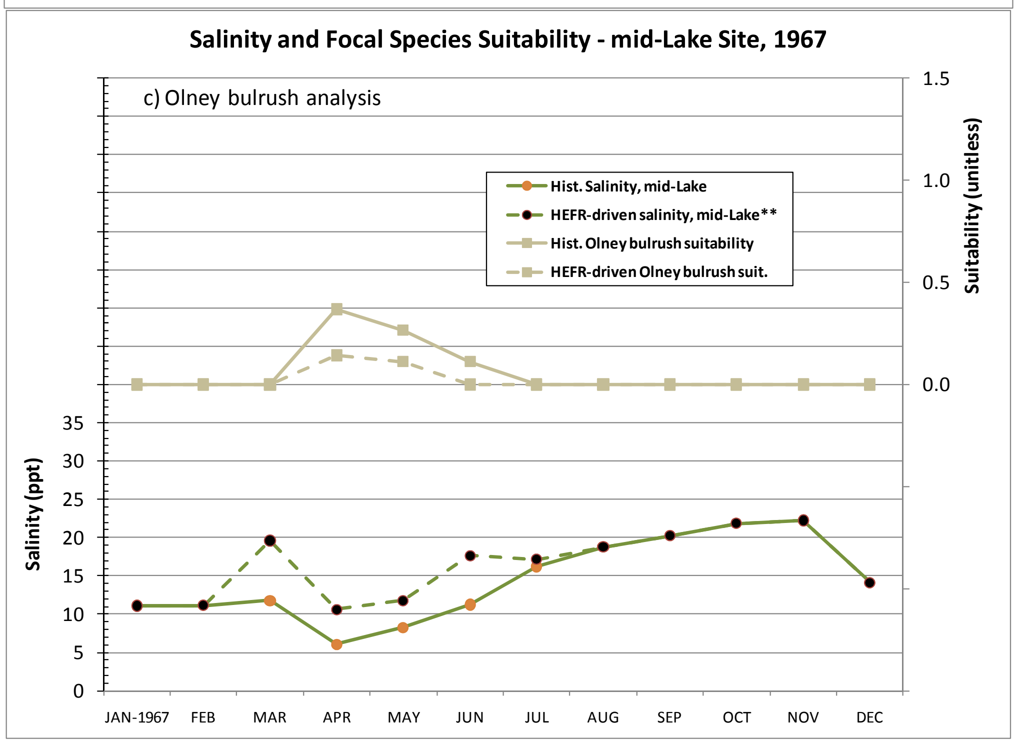


Fig. 12a



Salinity and Focal Species Suitability - mId-Lake Site, 1967
b) Blue crab juveniles analysis
Hist. Salinity, Lower-Lake
HEFR-driven salinity, lower-Lake**
Hist. Blue crab suitability
HEFR-driven Blue crab suitability
Salinity (ppt)
Suitability (unitless)
0
5
10
15
20
25
30
35
0.0
0.5
1.0
1.5
JAN-1967
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC



Salinity and Focal Species Suitability - mid-Lake Site, 1967
c) Olney bulrush analysis
Hist. Salinity, mid-Lake
HEFR-driven salinity, mid-Lake**
Hist. Olney bulrush suitability
HEFR-driven Olney bulrush suit.
Salinity (ppt)
Suitability (unitless)
0
5
10
15
20
25
30
35
0.0
0.5
1.0
1.5
JAN-1967
FEB
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Fig. 12 b, c

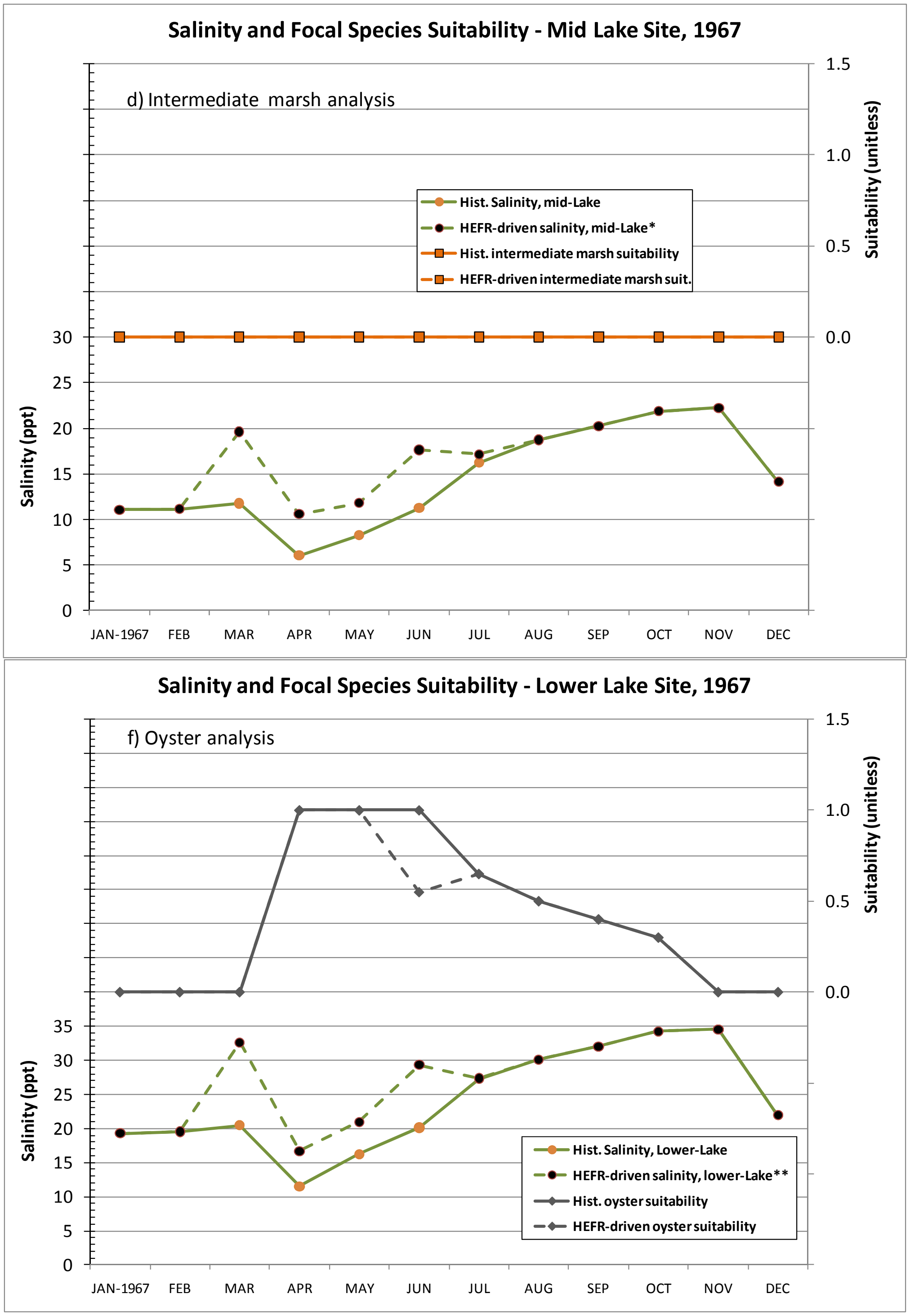

Fig. 12 d, f

Figure 12 (panels a-f). The predicted salinity and salinity suitability results of several key species and communities after substitution of the HEFR-derived instream flow "subsistence" values for the three BBEST sites Sabine River at Ruliff, Neches River at Evadale,and Village Creek near Kountze for 1967.

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 *Rangia*, 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. 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 *Rangia* 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 *Rangia* 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 *Rangia* 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.

THE STATE METHODOLOGY FOR ESTIMATING FRESHWATER INFLOW NEEDS OF BAYS AND ESTUARIES

General Procedure

The Texas Water Development Board (TWDB) and the Texas Parks and Wildlife Department (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" [Texas Water Code §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: i) salinity at selected locations in the estuary as a function of inflow, and ii) abundances of several key species as a function of inflow. Both of these are determined by a statistical fit to data. For the salinity relation, 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 Sabine Lake, fisheries abundance is based upon the TPWD Coastal Fisheries database. The last substantial step of the State Methodology process is to employ the salinity and key species regressions in a sophisticated nonlinear multivariate optimization model, called TxEMP, to determine the distribution of monthly inflows that either maximizes or minimizes some variable, defined by a specific management "goal". The most important of such goals are:

MaxC, total annual harvest/abundance is maximized, subject to constraints on inflows

MinQ, total annual inflow is minimized, subject to the constraint that total annual harvest be no lower than 70% of its period-of-record average, and subject only to constraints on salinity

MinQsal, total annual inflow is minimized and subject only to constraints on salinity

In addition, solutions are sometimes provided for MaxQ and MinQ-sal, and additional potential goal formulations are given in Longley (1994). Figure 13 presents monthly MinQsal, MaxC, and MinQ flows for Sabine Lake. Although the State Methodology does not provide attainment frequencies for MinQsal, MinQ, and MaxC, it is understood that minimum attainment frequencies are part of an environmental flow recommendation. For example, the Region H Regional Water Plan, based on input from the Galveston Bay Freshwater Inflows Group, has identified attainment frequencies of 50%, 60% and 75% for MaxH/MaxC, MinQ and MinQsal, respectively.

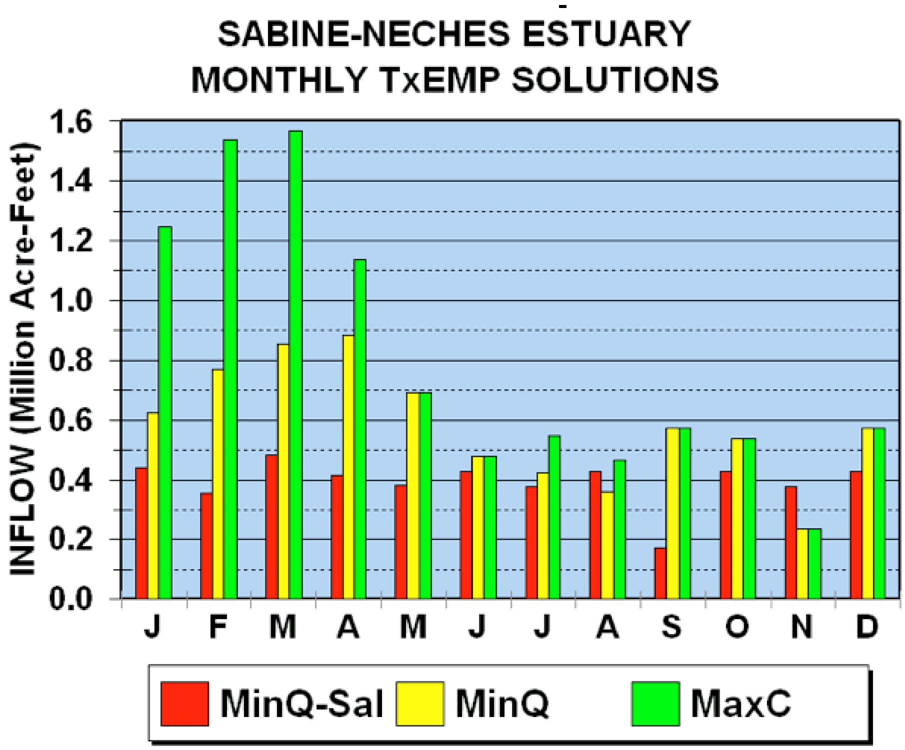

Figure 13. Comparison of monthly freshwater inflow requirements for Sabine Lake according to three different response variables from the state methodology.

Strengths of the State Methodology include:

- *Easily understood objectives* - The catch/abundance goal of maintaining a minimum abundance/catch as a fraction of the historical mean of "economically important and ecologically characteristic sport or commercial fish and shellfish" is clearly understood.
- *Sensible way to integrate disparate information* - TxEMP integrates management goals with hydrological and biological goals and constraints.
- *Attempts to make best use of flow resource* - TxEMP computes the minimum flows that meet goals and constraints.
- *Constraints keep solution "reasonable"* - Hydrological and biological constraints keep the solution "reasonable". Salinity zones are evaluated for important habitat areas as a final check. Although the optimization may be weak due to nature of catch-inflow equations, reasonableness of the solution is enforced by constraints.
- *Optimization model is objective* - Solution found after goals and constraints are set is objective.
- Solutions have been obtained for each of the major estuaries of the State and are available in an appendix to the TPWD verification reports.[2]

Weaknesses of the State Methodology include:

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[2] Texas Water Development Board, Bays & Estuaries Program, http://midgewater.twdb.state.tx.us/bays_estuaries/b_nEpage.html#studies_done, retrieved 11/30/2009

• *Commercial harvest data subject to numerous sources of error and are affected by factors having no relation to abundance* - Fishing effort, reporting of catch, and other issues affect accuracy of reported harvest can undermine the use of harvest as a representation of abundance. Moreover, harvest may not have occurred in the system where it was sold at dockside.
• *Low predictive ability of catch- inflow equations* - Predictive ability of harvest/abundance equations is low, although this is not surprising due to the complexity of the ecological relationships between flow and harvest/abundance.
• *Species may not fully represent estuarine ecology* - Initial applications of the State Methodology focused exclusively on commercial species (mainly because harvest data records provided the only sufficient record of species information). As extended periods of TPWD fisheries independent data became available, more recent applications have included one or two species of ecological, but not commercial, significance.
• *Solution implies that flows must always be met* - While the goal of determining flows to meet targets is met by the State Methodology, the solution calls for the flow to always to be met. That is, there is no attainment strategy, such as a statistical frequency of occurrence. Moreover, the *maxC* and *minQ* patterns do not occur exactly in the historical inflow record to the estuary.
• *Does not address low flow needs explicitly*. This is because low flows do not arise as optimum solutions as long as there is a biological constraint, or biology is the objective function.
• *Does not provide an inflow regime consistent with the requirements of Senate Bill 3* that reflects seasonal and yearly fluctuations, including the required frequency of various inflow amounts or inflow patterns needed during very dry periods, as well as the frequency of higher inflows during wet years that help sustain a healthy bay and estuarine ecosystem.
• *The optimized solution is dominated by the constraints*, e.g. that each monthly or bimonthly flow must lie between the 10th percentile and median values, which are specified without scientific defense. While constraints are a necessary and important aspect of the optimization problem specification because they ensure that the solution is realistic, when the majority of the resulting monthly flows are the constraint values, these constraints are, in effect, the answer, and therefore the basis for their specification becomes central.

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 our BBEST by Freese and Nichols (HEFR memo to Sabine-Neches BBEST, Sept. 17, 2009). The flow data consisted of historical daily flows from BBEST 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 Texas Water Development Board (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 the 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 2 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[3] 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. Subsistence flows have not historically occurred during the winter and spring months. In these months the fall HEFR result was used to calculated volumes.

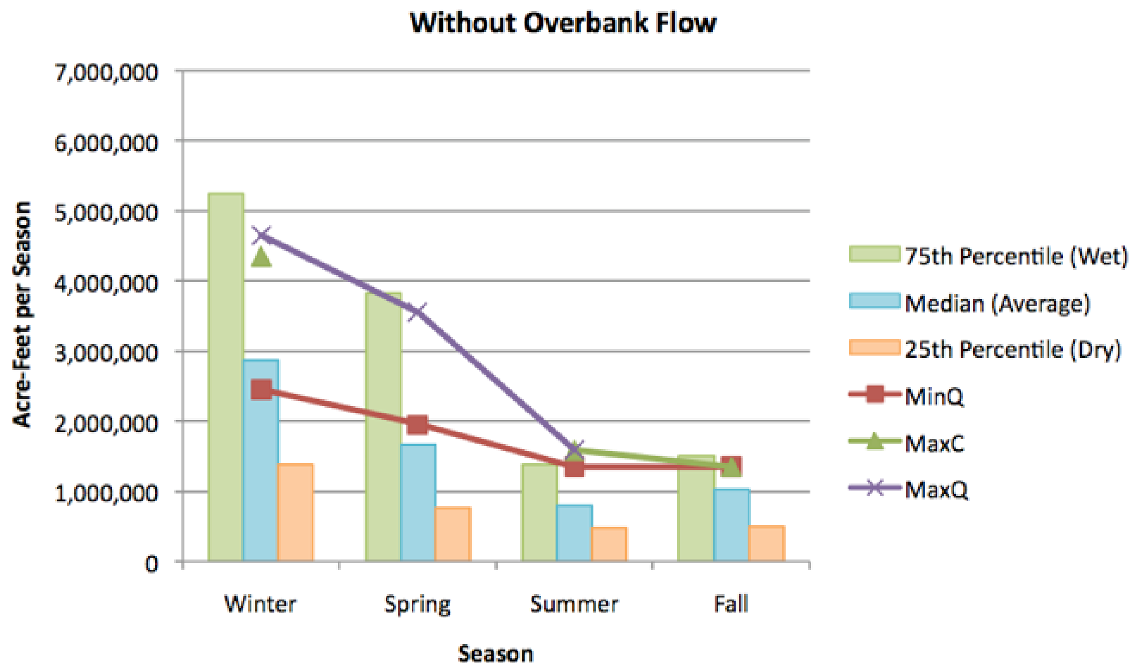
Comparing HEFR-generated flow components to the State Methodology shows that the HEFR 25th percentile (dry) conditions are less than the MinQ unless an overbank event occurs during the year. Base + pulse flows for median (average) conditions are less than MinQ for the Full Period and Pre-dam time periods, 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 14 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.

Table 2. Comparison of HEFR-generated annual freshwater inflow volumes to freshwater inflow volumes recommended for Sabine Lake according to the State Methodology (values in acre-feet per year).

HEFR Annual Volumes	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		



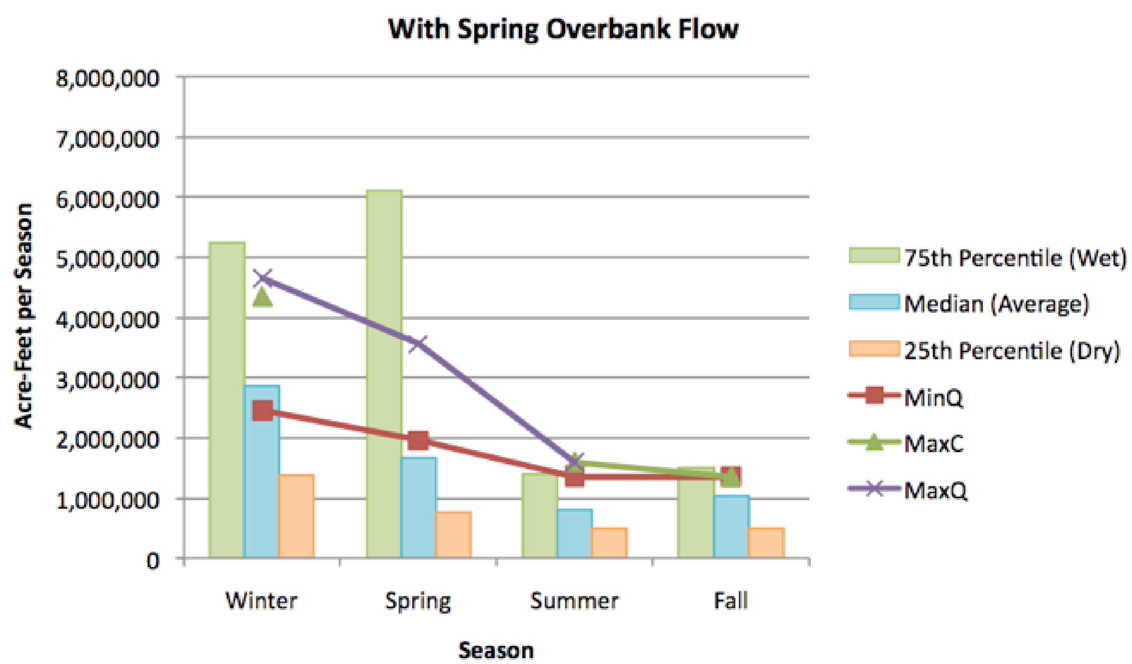


Figure 14. Comparison of seasonal flow volumes for full period HEFR and State Methodology for Sabine Lake, with and without overbank Flow (from Freese and Nichols, HEFR analysis memo to Sabine-Neches BBEST, Sept. 17, 2009).

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 Sabine-Neches ship channel 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 Gulf Intracoastal Waterway (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 (Sabine-Neches Waterway) 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 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 ends 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, 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, and resulted 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).

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 Texas Instream Flow Program (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 SB3, 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.

We have 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. We were only able to obtain data for a limited

number of our 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.

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