Trinity and San Jacinto and Galveston Bay Basin and Bay Expert Science Team

Environmental Flows Recommendations Report

Final Submission to the Trinity and San Jacinto Rivers and Galveston Bay Basin and Bay Area Stakeholder Committee, Environmental Flows Advisory Group, and Texas Commission on Environmental Quality

November 30, 2009

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November 2009

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

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

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

Danny Vance, Chairman,
Trinity and San Jacinto Rivers and Galveston Bay
Basin and Bay Stakeholder Committee

Dear Senator Averitt, Representative Ritter, Mr. Vickery, and Mr. Vance:

For your consideration, the Trinity and San Jacinto and Galveston Bay Basin and Bay Expert Science Team (Trinity-San Jacinto BBEST) hereby submits its final report pursuant to its charge under Senate Bill 3 (80th R, 2007), including environmental flow recommendations with rationales. The Trinity-San Jacinto BBEST members have reached consensus on the presentation of the recommendations submitted in this document.

Respectfully submitted,

_____

William H. Espey, Jr., Chairman

Environmental Flows Recommendation Report

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1. PREAMBLE

The Trinity-San Jacinto Basin and Bay Expert Science Team (Trinity-San Jacinto BBEST) presents the following *Environmental Flows Recommendation Report* to the Trinity and San Jacinto Rivers and Galveston Bay Basin and Bay Area Stakeholder Committee (Trinity-San Jacinto BBASC), Texas Environmental Flows Advisory Group (EFAG), and the Texas Commission on Environmental Quality (TCEQ). This document is the culmination of twelve months of effort on the part of the Trinity-San Jacinto BBEST to meet its legislative mandate to develop environmental flow analyses to determine recommendations for environmental flows in the Trinity and San Jacinto River Basins and the Trinity-San Jacinto Estuary, acknowledging the limitations on making such a determination.

The efforts documented within this report represent a significant step forward in the Texas environmental flows process, addressing the charge to the BBEST by attempting to utilize the best science available within the limited schedule allotted. The Trinity-San Jacinto BBEST members have dedicated themselves to providing this document with recommendations and supporting rationale that will lay the necessary groundwork for the Trinity-San Jacinto BBASC to exercise its collective judgment on the recommendations and available science proffered herein to balance environmental flows with the needs of the people of Texas in the Trinity and San Jacinto River Basins and the Galveston Bay area (Trinity-San Jacinto Estuary).

1.1. Senate Bill 3

With its passage in the 80th Regular Session of the Texas Legislature in 2007, Senate Bill 3 (SB 3) became the third in a series of omnibus water bills related to State of Texas endeavors to address future water demands. Previously, Senate Bill 1 (SB 1) established a stakeholder driven approach to planning for water resources, while the later Senate Bill 2 (SB 2) Texas Instream Flow Program (TIFP) was established in recognition of the lack of available data for the determination of how much water is necessary for environmental purposes.

The TCEQ is required by the Texas Water Code (TWC) to consider and provide for freshwater inflows necessary to maintain the viability of Texas bay and estuary systems in TCEQ's regular granting of permits for the use of state waters, all while balancing other demands for water. Unfortunately, although Texas has long been the leading state at documenting existing and historical flows, the information needed to determine the instream flows and freshwater inflows necessary to support ecologically sound riverine and estuarine systems is limited.

Historically, within the Texas water rights permitting process, balancing man’s needs for water with environmental needs has been done on a case-by-case basis. In order to expedite this process, and recognizing the unique nature of Texas river basins, SB 3 has

established a basin-by-basin course of action for the development of recommendations to meet the instream flow needs of rivers as well as freshwater inflow needs of affected bays and estuaries. This process requires TCEQ to consider the recommendations of the BBESTs, along with those from the associated stakeholder groups, throughout the formulation of environmental flow standards. Such standards will be utilized in the decision-making process for new water right applications and in establishing an amount of unappropriated water to be set aside for the environment. (Texas Legislature 2007).

1.2. Trinity-San Jacinto BBEST

In accordance with SB 3, the Trinity-San Jacinto BBASC (Texas Commission on Environmental Quality 2008a) appointed members to serve on the Trinity-San Jacinto BBEST (see Table 1). The Trinity-San Jacinto BBEST has held twelve monthly meetings, as well as many subcommittee meetings, beginning with its initial meeting on December 18, 2008. During the course of this time, the Trinity-San Jacinto BBEST established subcommittees for Instream Hydrology/Biology and Bay Salinity-Biology.

These subcommittees' efforts have included numerous meetings and conference calls, in addition to the monthly meetings, as the Trinity-San Jacinto BBEST has strived to determine the available science in the study area shown in Figure 1 on page 5. The Trinity-San Jacinto BBEST meetings have been an open process benefitting from the resource agencies -- TCEQ, Texas Water Development Board (TWDB) and Texas Parks and Wildlife Department (TPWD), environmental groups such as the National Wildlife Federation (NWF), Galveston Bay Foundation, and the public. All contributions of these groups have been constructive to the process and have been carefully considered.

Table 1
Trinity-San Jacinto BBEST Membership

Name	Affiliation
Richard Browning, Ph.D.	Trinity River Authority
David Buzan	PBS&J
William H. Espey Jr., Ph.D., P.E., D. WRE	Espey Consultants, Inc.
Woody Frossard	Tarrant Regional Water District
George Guillen, Ph.D.	Environmental Institute of Houston, University of Houston Clear Lake
L. James Lester, Ph.D.	Houston Advanced Research Center
Robert McFarlane, Ph.D.	McFarlane & Associates
Alan Plummer, P.E.	Alan Plummer Associates, Inc.
Antoniettea Quigg, Ph.D.	Texas A&M University at Galveston
Sammy Ray, Ph.D.	Texas A&M University at Galveston
Mike Reedy, P.E.	Freese & Nichols, Inc.
Tony L. Smith, P.E.	Espey Consultants, Inc.
Joe Trungale, P.E.	Trungale Engineering & Science
Mike Turco	USGS
Woody Woodrow	USFWS Coastal Program

1.2.1. Legislative Mandate

Senate Bill 3, passed in 2007 by the 80th Texas Legislature, established a stakeholder-based process for including consideration of environmental flow needs in new water rights permits. Stakeholders for the Trinity and San Jacinto basins created a multidisciplinary team of scientists (i.e. the Trinity-San Jacinto BBEST) to recommend environmental flow regimes for the Trinity River, the San Jacinto River, and Galveston Bay. The responsibility of the BBEST is described in Article 1 of SB 3.

> "(m) Each basin and bay expert science team shall develop environmental flow analyses and a recommended environmental flow regime for the river basin and bay system for which the team is established through a collaborative process designed to achieve a consensus. In developing the analyses and recommendations, the science team must consider all reasonably available science, without regard to the need for the water for other uses, and the science team's recommendations must be based solely on the best science available."

SB 3 defines environmental flow analysis and environmental flow regime as:

> "(15) 'Environmental flow analysis' means the application of a scientifically derived process for predicting the response of an ecosystem to changes in instream flows or freshwater inflows."
>
> "(16) 'Environmental flow regime' means a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies."

Article 1 of SB 3 also outlines how the environmental flow regime will be considered by the TCEQ in establishment of environmental flow standards. This clearly indicates the environmental flow regime described here is one of several considerations that will form the basis of environmental flow standards to be developed by the TCEQ.

> "(b) In adopting environmental flow standards for a river basin and bay system under Subsection (a)(1), the commission shall consider:
>
> > (1) the definition of the geographical extent of the river basin and bay system adopted by the advisory group under Section 11.02362(a) and the definition and designation of the river basin by the board under Section 16.051(c);

(2) the schedule established by the advisory group under Section 11.02362(d) or (e) for the adoption of environmental flow standards for the river basin and bay system, if applicable;
(3) the environmental flow analyses and the recommended environmental flow regime developed by the applicable basin and bay expert science team under Section 11.02362(m);
(4) the recommendations developed by the applicable basin and bay area stakeholders committee under Section 11.02362(o) regarding environmental flow standards and strategies to meet the flow standards;
(5) any comments submitted by the advisory group to the commission under Section 11.02362(q);
(6) the specific characteristics of the river basin and bay system;
(7) economic factors;
(8) the human and other competing water needs in the river basin and bay system;
(9) all reasonably available scientific information, including any scientific information provided by the science advisory committee; and
(10) any other appropriate information."

SB 3 recognizes there is a degree of uncertainty in the environmental flow regime that will be described and environmental flow standards that will be created. The legislation addresses that uncertainty by containing provisions for a continuing adaptive management process, a key component of SB 3, that can be applied to refine initially identified flow regimes as information (science) that confirms ecological – flow relationships required to support a sound ecological condition becomes available.

1.3. Sound Ecological Environment

The Trinity-San Jacinto BBEST has reached consensus that the current status of the systems under analysis within this effort are healthy and sound ecological environments, within the context of, and for the purpose of these analyses. This is reflective of historic and current water demands placed upon the system. As such, the Trinity-San Jacinto BBEST has adopted the definition proposed by the Texas Environmental Flows Science Advisory Committee (SAC) in its "Methodologies for Establishing a Freshwater Inflow Regime for Texas Estuaries Within the Context of the Senate Bill 3 Environmental Flows Process" (SAC 2009a):

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.

Consistent with the above definition is the definition from the TIFP Technical Overview document which defines a sound ecological environment as:

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

1.4. Overview of Trinity, San Jacinto, and Galveston Bay Watersheds

Galveston Bay and its entire watershed comprise approximately 24,000 square miles. As evidenced in Figure 1, it extends from North Central Texas near Oklahoma to the Gulf of Mexico, a straight distance of 360 miles. Elevations in the headwaters are around 1,000 feet MSL. Relief consists of various prairies and low rolling hills. Natural vegetative cover includes grasslands at the coast and in the upper watershed, separated by woodlands. Rainfall ranges from approximately 55 inches per year near the coast to about 25 inches per year in the headwaters.

It includes the two largest metropolitan areas in Texas, Houston near the coast and the Dallas – Fort Worth area in the north. The total combined population of these areas is over 6,000,000 and together they total over half of the state's population.

Both Houston and Dallas-Fort Worth obtain the great majority of their water supplies – municipal, industrial, and agricultural – from surface waters of the Galveston Bay watershed. Within the 24,000 square miles of the total watershed, the Bay itself is about 600 square miles, the San Jacinto River basin is approximately 4,000 square miles, the Trinity River basin is about 18,000 square miles, and the balance of about 2,600 square miles are in the various coastal bayou watersheds draining directly to the Bay.

1.4.1. Galveston Bay

The Bay itself covers about 600 square miles, with several sub-bays. The Trinity River enters the north end of Trinity Bay. The San Jacinto River, including Buffalo Bayou and its tributaries, enters the northwest corner of Galveston Bay. Numerous other bayous enter the Bay directly.

The Bay, some few thousand years ago during the last ice age, was well inland and was mostly the bottomland of the San Jacinto and Trinity Rivers where they and other tributaries confluenced and flowed on southeastward. Subsequent melting of the polar caps and rise in sea level inundated those bottomlands. Siltation covered the original

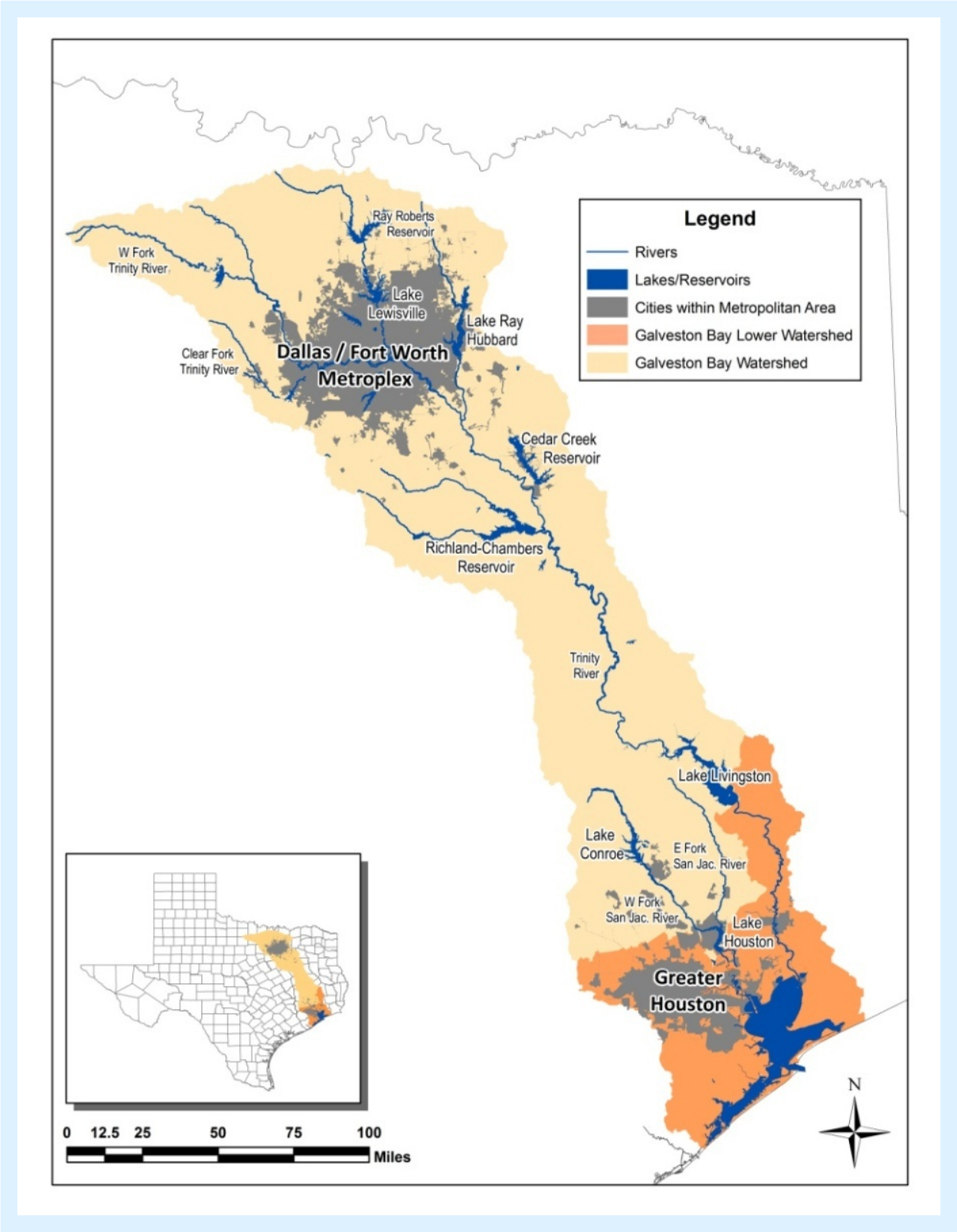

Figure 1 Study Area

channels, Gulf currents shaped Galveston Island and Bolivar Peninsula, and the present Bay took shape. The open Bay is mostly 8-10 feet deep. Many local modifications have been made since the late 1800's. The biggest is the Houston Ship Channel and adjacent side navigation channels, and the Intracoastal Waterway. Bridges, bulkheads, dredged and filled areas, and industrial plants are numerous along the western shore of the Bay. The eastern shore of Trinity Bay and the northern shore of East Bay are much less disturbed.

Salinities in the Bay vary between freshwater inflows that approach 0 psu and open Gulf water at about 35 psu. Generally, there is a north-south spatial salinity gradient across the Bay between the two extremes. The exact location of the gradient varies with rate of freshwater inflow, tide, wind, and other factors.

1.4.2. San Jacinto River Watershed

The San Jacinto River watershed (Figure 2) enters Galveston Bay from the northwest and includes Buffalo Bayou and its tributaries with a total area of about 5,600 square miles. The southern part of the Buffalo Bayou watershed is in the coastal prairies region. The rest of the San Jacinto watershed is in the Piney Woods region. The northern watershed is sandy and rivers and streams have sandy banks and bottoms. The southern part of the watershed in the coastal prairie has a heavy clayey soil, and the bed and banks of waterways are variably clay, sand, or silt. All but the far northern part of the watershed is extensively urbanized. The northern edge is in national forest.

The East Fork of the San Jacinto River flows from its headwaters near Huntsville, through Lake Conroe and Lake Houston. Lake Houston and Lake Conroe were developed as water supply reservoirs and, therefore, do not provide significant storage during flood events. Lake Houston is near the mouth and has a storage capacity of about 128,000 acre-feet. Lake Conroe is on the West Fort San Jacinto River and has a storage capacity of about 416,000 acre-feet. There are two flood control-only impoundments in the headwaters of Buffalo Bayou, Addicks and Barkers Reservoirs, with a flood retention capacity of about 200,000 acre-feet each.

The East and West Forks of the San Jacinto River merge in the headwaters of Lake Houston. Total basin drainage area is 5,600 square miles. The San Jacinto River flows approximately 20 miles from Lake Houston to its confluence with the Houston Ship Channel. The river flows another 10 miles to Galveston Bay. This basin includes a portion of the Houston Ship Channel and associated tributaries. The Port of Houston Authority operates the Houston Ship Channel, which originates at the Turning Basin and follows the original alignment of Buffalo Bayou to the San Jacinto River. The Ship Channel continues through the San Jacinto River and San Jacinto Bay to Galveston Bay, which is the ultimate outfall for all drainage in Harris County. There are approximately 1,750 square miles in the West Fork drainage area, and 1,050 square miles in the East Fork drainage area. Buffalo Bayou, a major tributary to the Houston Ship Channel, has a

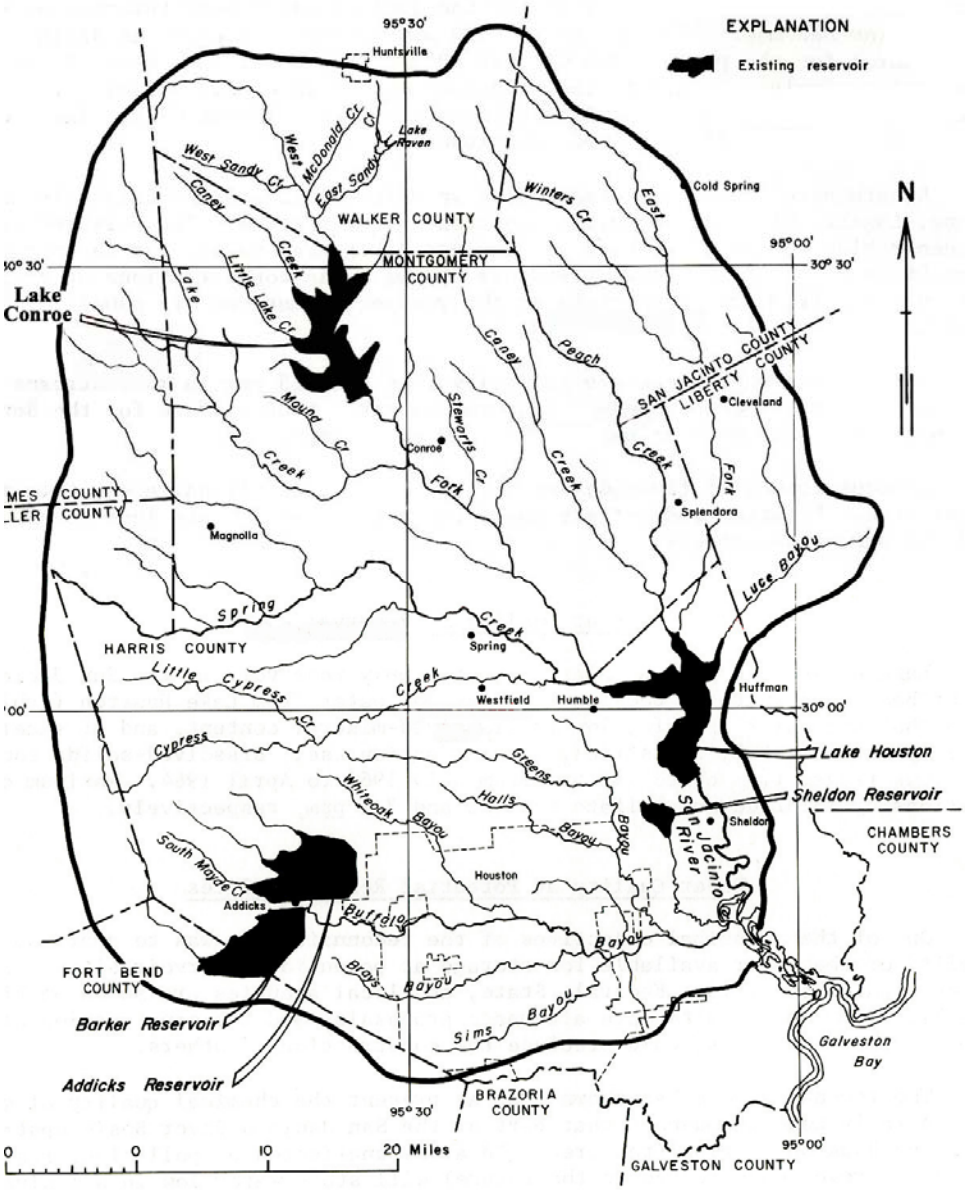

Figure 2 San Jacinto Watershed (courtesy of USGS in cooperation with TWDB)

drainage area of 1,034 square miles. There are about 310 miles of open streams within the watershed, including the primary streams and tributary channels. Associated bay and estuary segments include Upper Galveston Bay, San Jacinto Bay, Scott Bay, Burnett Bay, and Barbours Cut.

The lower portion of Buffalo Bayou and the San Jacinto River were channelized in 1915, which opened the Houston area to ship traffic. Today, the Port of Houston is the third leading shipping terminal in the United States. Oil and petrochemical industries along the channel make it one of the most highly industrialized areas of the world. Over the past several years, water quality in the Houston Ship Channel has improved due to

advanced wastewater treatment and reduced waste loads. Aquatic and/or marine organisms inhabit areas where few had previously been found.

The basin population is over 1.5 million (2000 Census) with the majority residing in Harris County. The City of Houston is the largest city in the basin. Other principal cities in the basin include Pasadena and Bellaire in Harris County and Conroe in Montgomery County. In addition to the numerous towns and cities, hundreds of wastewater treatment plants discharge into basin water bodies. This basin includes the most highly-urbanized and industrialized portions of the Houston metropolitan area. All major economic categories are represented including industrial/manufacturing, petrochemical, commercial, transportation, agriculture, recreation, and government.

The basin has been divided into 17 classified segments consisting of approximately 517 stream miles and two reservoirs (Lakes Houston and Conroe) covering 51.9 square miles surface area. Monitoring coverage in the basin has improved through the coordinated efforts of the TCEQ, Houston-Galveston Area Council, City of Houston, Galveston County Health District, San Jacinto River Authority, and Harris County Pollution Control. The San Jacinto River Basin exhibits wide variations in water quality. As the Houston metroplex expands to the north, numerous wastewater treatment plants and urban runoff increase the organic and nutrient loading and fecal coliform bacteria levels in all major tributaries to Lake Houston. Major tributaries to Lake Houston in northwestern Harris County are Cypress Creek, the West Fork of the San Jacinto River, and Spring Creek. Dissolved oxygen deficiencies can also occur in these streams.

Lake Houston tributaries draining the less populated areas of northeastern Harris County and Montgomery County, include Caney Creek, the East Fork of the San Jacinto River, and Peach Creek tend to have better water quality. In the future, the quality of these water bodies may be affected by urban expansion.

The Houston metropolitan area is drained almost entirely by Buffalo Bayou, which has been channelized to form the Houston Ship Channel in its lower reach. Major tributaries draining to Buffalo Bayou/Houston Ship Channel are Brays, Greens, Sims, and White Oak Bayous. In addition to a large number of municipal and industrial wastewater discharges, Houston bayous receive significant amounts of urban stormwater runoff. Very high fecal coliform levels are common. Depressed dissolved oxygen occurs during warm summer months, especially in smaller tributary streams.

In 1990, TDH issued a restricted consumption (one meal per month) and a sub-population no-consumption (women of child bearing age, pregnant women, and children) advisory for dioxin (ADV-3). The advisory includes all species of catfish and blue crabs in the Houston Ship Channel and all contiguous waters. In the San Jacinto River Basin this encompasses the tidal portions of Houston Ship Channel tributaries including Brays, Greens, Patrick, Sims, and Vince Bayous and the San Jacinto River Tidal.

In 2001, TDH issued a second advisory restricted consumption (one meal per month) and a sub-population no-consumption (women of child bearing age, pregnant women, and children) advisory for PCBs and Organochlorine Pesticides (ADV-20). The advisory includes all species of fish in the Houston Ship Channel upstream of the Lynchburg Ferry crossing and from the San Jacinto River downstream of the U.S. Highway 90 bridge.

1.4.3. Coastal Bayous and Watersheds

There are Bayous that directly enter all around Galveston Bay. The larger ones include Chocolate Bayou, Highland Bayou, Dickinson Bayou, Clear Creek, Cedar Bayou, Double Bayou, and Oyster Bayou. These watersheds together total about 2,600 square miles.

Some of these watersheds, especially in Harris and Galveston Counties, are extensively urbanized. Those in Chambers County are very lightly populated and developed, except for rice farming. There are several large wildlife and natural preserves in Chambers County adjacent to East Bay.

1.4.4. Trinity River Watershed

The Trinity River watershed covers about 18,000 square miles and extends over 350 miles inland from the Gulf of Mexico. It extends through the Coastal Prairies and Piney Woods, across the Post Oak Savannah, the Blackland Prairies, the East Cross Timbers, the Grand Prairies, the West Cross Timbers, and the Red River Prairies. The rainfall ranges from 55 inches near the coast to about 25 inches in the headwaters. It contains the entire Dallas-Fort Worth metropolitan area of over 6,000,000 people.

Groundwater is generally limited in the Trinity Basin, and for over a hundred years surface water impoundments have been built to supply water for human use. There are 31 impoundments of over 5,000 acre-feet with a total water supply storage capacity of over 7,000,000 acre-feet. These and some additional impoundments in other river basins are necessary to supply the large population through hot, dry summers and occasional droughts in the mid- and upper-basin.

Wastewater treatment in the Dallas-Fort Worth area is regionalized mostly into large wastewater treatment plants. Wastewater treatment over the past forty years has improved greatly to the extent that it is itself a valuable source of water supply.

The quality of the Trinity River has improved dramatically with the improvement in treatment, as shown in the plot of historical water quality in Figure 3 for the Trinity River near Rosser, just downstream of Dallas–Fort Worth.

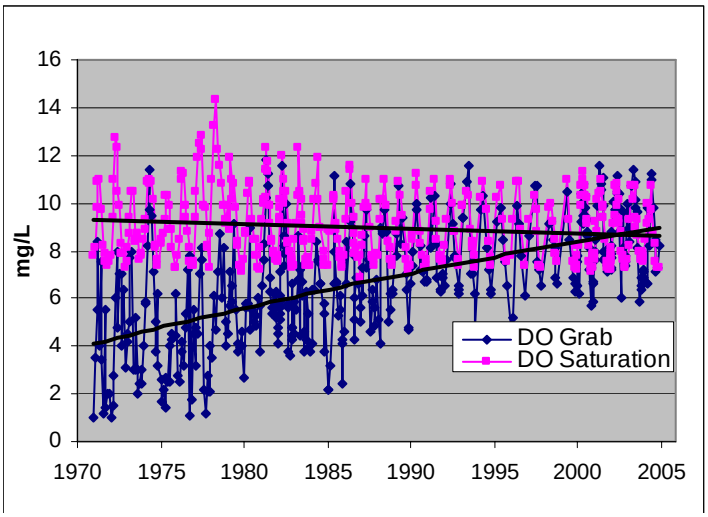

Figure 3 Historical Water Quality at Trinity River near Rosser

The low flows of the river have been increasing with the volume of treated wastewater for a hundred years, as indicated in Figure 4 below. These return flows have been reserved and permitted over the last sixty years for water supply, either for the Houston area and lower Trinity basin in Lake Livingston or by reuse in the Dallas-Fort Worth area. The construction of reservoirs has resulted in the creation of the most fragmented basin (number of reservoirs per river mile) in Texas, presenting a real limit on what can be accomplished with hydrology alone.

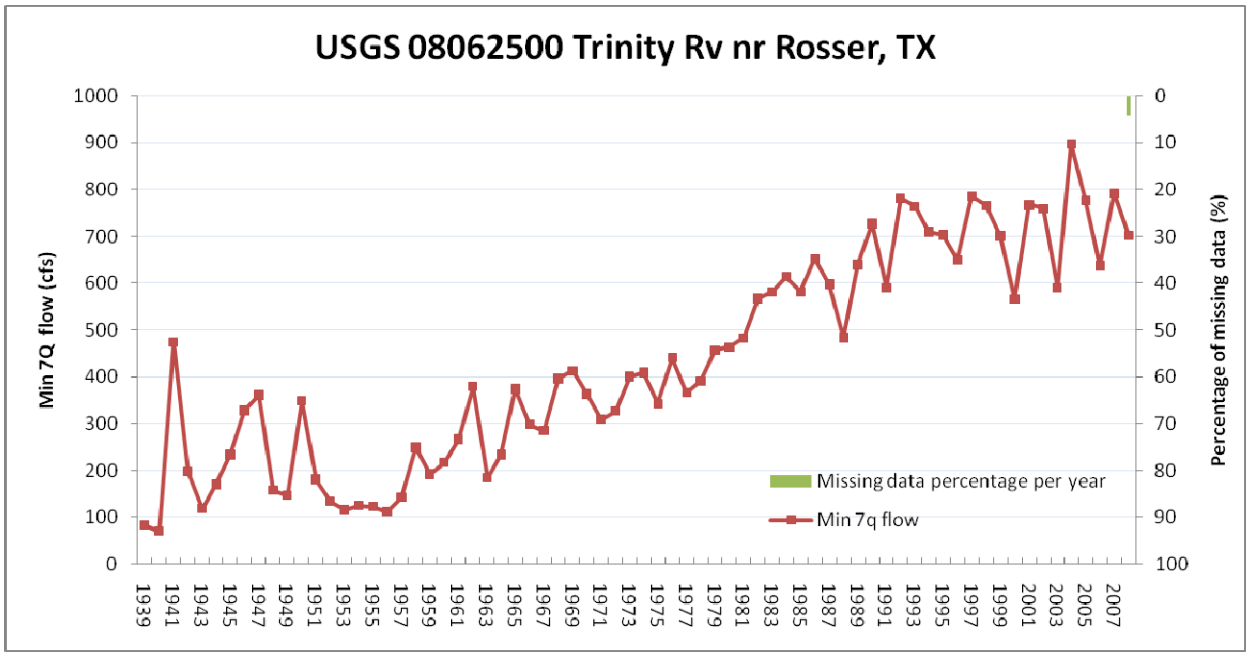

Figure 4 Historical Min7Q Flows at Trinity River near Rosser USGS Gage Site

1.5. Recommendation Report Evolution

The Trinity-San Jacinto BBEST Recommendations Report is composed of a main body which is a summary of the BBEST process, the study area, the work that was performed in the development of recommendations, and comments aggregated from members of the BBEST. The appendices provided include full texts of agendas for meetings held, minutes, and reports that were assembled through the process. Work reflected in the appendices was performed throughout the twelve months the Trinity-San Jacinto BBEST had to finish its charge. Opinions and recommendations by the report authors were not always agreed upon by consensus of the Trinity-San Jacinto BBEST. ***The body of this report is intended to be an assemblage of information reflecting recommendations as supported by various members of the Trinity-San Jacinto BBEST, as noted by their endorsement of the proposed recommendations in the denoted portions of the document.***

1.5.1. Alternative Instream Flow Approaches

Fundamental to the differences in perspectives held by advocates of two alternative approaches taken to proposing instream flow recommendations for monitoring stations and flow regimes is the level of confidence regarding:

- dependence upon hydrology, without applying other overlays, and the theoretical relationships between changing flow conditions and biological and ecological conditions developed by studies and research developed in other areas without calibrating or testing them in the Trinity and San Jacinto basins; and
- the importance and the extent that data and relevant information is specifically available for the Trinity River and San Jacinto River Basins (e.g. riffle areas, river cross section characteristics, velocities, topography required to determine conductivity, etc.).

Specific instream flow studies have not been completed in the two basins and the evaluations of biological/ecological responses to flow variation were significantly dependent upon data collected for other systems (e.g. studies summarized in Bio-West 2009a). There is recognition that a large body of scientific information has been developed relative to the relationships between flow and biological/ecological conditions. Such information is certainly of value in understanding the general concepts of importance.

1.5.1.1. Science Based Conditional Phased Approach

One approach for providing instream flow regime recommendations involves a science based conditional phased approach which acknowledges the level of uncertainty surrounding the available ecological science supporting potential recommended flow amounts by initially recommending a limited number of monitoring stations, limited

flow regime values, and identifies additional conditional monitoring stations and flow regime values. This approach also involves recommending a plan to establish a more comprehensive coverage of monitoring stations and flow regime values if needed, which would be more complex, as scientific data is developed that supports Trinity and San Jacinto River basin flow and biological/ecological relationships.

Monitoring Stations

BBEST advocates of this phased approach, in considering the lack of Trinity and San Jacinto river basin specific data concluded that it would be prudent to initially select a limited number of monitoring stations with an objective of increasing the number of stations as information is developed. The primary considerations for the monitoring station selection process included providing an initial coverage that would aid the TCEQ in the permitting process and selecting stations based on the availability of scientific information. Also of importance was identifying a process that TCEQ could use for permitting actions that require a more comprehensive coverage before additional stations are selected based on improved science.

In this regard, four monitoring stations were selected as recommended locations and two additional monitoring stations were selected to serve as Conditional Recommended locations. For the Trinity basin, it was decided that identifying flow regimes having direct applicability to the mid-Trinity is of great importance. The Oakwood monitoring station was selected as the recommended location for initially representing the mid-Trinity segment. This gage has the longest hydrological period of record and water quality information including a TCEQ mathematical model available to aid the selection of flow regimes. The other three Recommended Stations were selected on the basis of there being adequate hydrological periods of record and the need to provide coverage for aiding the TCEQ in the permitting process.

As indicated above, this phased approach involves the future identification of additional monitoring stations if needed and as scientific information is developed that supports their selection. Of major benefit to determining whether additional stations are needed will be the results of the SB 2 studies. "As mandated by SB 2 through the TIFP, studies are in progress to identify the biological, geomorphic, and hydrologic processes in priority river systems. These SB 2 studies will develop additional information on the interrelationship among these processes and their influence on attributes such as conductivity and water quality"(SAC 2009b). However, if TCEQ encounters permitting that involves segments not addressed by the Recommended Stations, the following are presented for consideration:

1. Consider the Conditional Recommended Stations and associated Conditional Recommended flow regimes in the performance of a permit specific analysis.

2. Consider that a water availability analysis at any location upstream of a recommended site can evaluate the potential impacts on instream flows at the recommended site.
3. Apply a drainage area adjustment based on the size of the drainage area above the proposed permit site.
4. "It should be noted that for any future large water development projects, such as reservoirs, a site specific study may be required as part of the permitting process." (SAC -Geographic Scope of Instream Flow Recommendations, April 3, 2009)

Flow Regimes

Advocates of the phased approach also concluded that a limited number of flow components should be included in the Recommended Flow Regimes. Recommended Flow Regimes components include values for subsistence flow, base dry flow, and an overbank flow. A collaborative approach was taken to develop the proposed values by integrating flows generated by the advocates with the flow values generated by the advocates of the approach described below. The Recommended Flow Regimes also recognize the importance of pulse flows but defer identifying specific magnitudes, frequencies, or durations until specific information is developed for the Trinity and San Jacinto River basins that support defined pulse flow characteristics necessary for a sound ecological environment.

In addition to the Recommended Flow Regimes, Conditional Flows are also included. The intent is for the Recommended Monitoring Stations and Recommended Flow Regimes to be used in the rule making process and in the permitting process. The Conditional Monitoring Stations and Conditional Flows should be considered in designing studies and research efforts to develop river basin specific scientific information. Such information would facilitate determining whether the conditional stations and flows should be recognized as being recommended. The Conditional Monitoring Stations and flows could be considered by TCEQ and others as a starting position to address permitting issues not covered by the recommended stations and flow regimes. However, the Conditional Flows are not intended to be integrated into the rule making process as there is currently no science to support that their specific flow magnitudes, durations, or frequencies are necessary for a sound ecological environment.

Path Forward Action Plan

-Define available science and assumptions that served as basis for SB3 analysis
-Develop and/or gather relatively easy to obtain information of value to adapting theoretical science to the Trinity and San Jacinto basins
    -cross sections and their characteristics
    -velocity information
    -wetted perimeters associated with various flow regimes

-sediment grain size
-topography information to assess lateral conductivity
-Monitor to develop information of value to the Adaptive Management process
-short term (physical and water quality information)
-long term (species diversity and other ecological information)
-Perform focused research and studies for developing science needed for the Trinity and San Jacinto basins
-short term (physical (velocities, water depth at different flows, numbers and extent of riffle areas, etc.) and water quality information)
-long term (species diversity and other ecological information)
-Provide input into refining initial decisions based on improved science

1.5.1.2. Science Based Environmental Flow Regime for the Trinity River, San Jacinto River, and Galveston Bay

The "Science-Based Environmental Flow Regime for the Trinity River, San Jacinto River, and Galveston Bay" describes environmental flow regimes for six reaches of the Trinity River and five streams in the San Jacinto River basin. These environmental flow regimes meet the legislative charge of identifying flows that will protect sound environments in those streams. These determinations did not consider how these regimes would be implemented in future water management. However these regimes are a starting point for the implementation process and will be one of several factors considered in the development of environmental flow standards and future water supply management.

Determination of these regimes is based on the following assumptions: 1) the aquatic communities of these streams should be maintained, and 2) a flow regime based on flows that occurred prior to development of most major reservoirs and substantial increases in wastewater discharges will create conditions that support aquatic communities with similar structures and functions to those existing now. These regimes are also based on a considerable body of research from the U.S. and Texas that has found that flow variability is necessary to maintain a healthy stream environment.

Environmental flow regimes are comprised of six different flow conditions that will support healthy aquatic communities both in the rivers and the flood plains of those rivers. These flow conditions vary between seasons and years and will support fish, non-fish vertebrates, and plants dependent on the rivers.

Subsistence flows would be expected to occur relatively rarely and for relatively short periods of time during droughts. Water quality and water quantity would be adequate for fish; however, predation, parasitism, disease, and susceptibility to extreme high and low temperatures would increase as fish densities increase. Although conditions would be stressful, no species of fish would be expected to be lost from the river.

Ecologically-based dry, average, and wet flows represent flows higher than subsistence flows but which are not substantially impacted by rainfall event-caused pulse flows.

These ecologically-derived base flows affect availability of different stream habitats during dry, normal, and wet years. Riffle habitats may be more accessible during normal dry years and fish that utilize those habitats may thrive under those conditions. Conversely, during normal wet years riffles may be relatively rare and deep pools may be relatively common, favoring species that rely on the protection of deep pools for survival. The variation provided by these three ecologically based, normal flows during periods or years that are relatively dry, average, or wet allows fish, plants and other animals to persist over several years even though their preferred habitats may not always be abundant.

High pulse flows result from rainfall events and play important roles in stimulating spawning for some fish, transporting sediment, maintaining a wet soil regime for riparian plants, and increasing access for fish to backwaters, sloughs and tributaries. The frequency, magnitude, duration, and volume of flow provided by high pulse flows are important in supporting ecosystem health.

As with high pulse flows, the frequency, magnitude, duration, and volume of overbank flows support different ecosystem functions. Overbank flows transport nutrients and sediments to the floodplain. Several species of fish spawn under these conditions and juvenile fish are transported to oxbows, swamps, and other water features in the floodplain. Later overbank flows transport the mature fish back to the river.

Fish communities in these streams and plant and non-fish communities in the floodplains were identified from a variety of data and literature. Relationships between flows and the aquatic communities were explored to understand how flow is related to spawning habits and mesohabitat preferences of different species. Flow data were analyzed using approaches described and approved by the statewide Environmental Flows Science Advisory Committee. These analyses involved the use of Indicators of Hydrologic Alteration (IHA) and Hydrology-based Environmental Flow Regime (HEFR). IHA utilizes flow gage data to calculate over 60 different ecologically relevant statistics from the flow data. A small proportion of those statistics is utilized in HEFR to create the values in the different flow categories in the environmental flow regimes. These analyses also describe the frequency of occurrence of the different flows in these flow regimes. Because these analyses are based on a period of flow records that does not include the most recent 30 years, values in these flow regimes are substantially lower than the flows that have occurred in these streams over the past three decades.

These flow regimes provide a sound basis, given the time and resources available to meet the BBEST's charge, for the development of future water management strategies. These flow regimes provide a reasonable starting point for future modifications of water rights allowed by SB 3 based on research and investigations recommended in the adaptive management portion of the BBEST's report.

1.5.2. Freshwater Inflow Process

The recommendations provided within this document ascribe to the mandates as set forth by the Texas Legislature contained in SB 3 and guidance provided by the SAC. In its guidance document, entitled "Methodologies for Establishing a Freshwater Inflow Regime for Texas Estuaries within the Context of the Senate Bill 3 Environmental Flows Process," the SAC provides a set of recommended procedures. One recommendation is that limited deterministic models and data from the estuary be used to infer responses of the system to freshwater inflows. A second recommendation is to use a simple conceptual model that retains only the most salient inflow effects. The BBEST determined to heed this advice through the modeling of the flow-salinity-biology relationships, extracted from available data, to develop freshwater inflow recommendations for the Galveston Bay ecosystem that can be shown to support a sound ecological environment.

The Trinity-San Jacinto BBEST solicited proposals from its members for projects needed to fill information gaps on the issue of freshwater inflow regimes for Galveston Bay. These proposals were considered and voted upon by the BBEST, ultimately selecting two similar approaches by Tony Smith and Joe Trungale, to evaluate salinity zonation and its historic relation to freshwater inflows within Galveston Bay. The Trinity-San Jacinto BBEST organized a subcommittee to work on the freshwater inflow recommendations for Galveston Bay. The subcommittee invited experts on estuarine ecology from multiple agencies and Texas universities. This Bay and Estuary (B&E) subcommittee met four times. During that process, Espey Consultants, Inc. and Trungale Engineering & Science were contracted to prosecute a salinity zonation analysis for the Galveston Bay system.

Biological indicators were identified by the B&E Subcommittee and their salinity niches decided upon. Areas of the bay in which these conditions were to be targeted were determined by the subcommittee based upon their expertise and knowledge of the system. Each species demonstrated a record of spatial distribution either in the TPWD monitoring database or in other monitoring studies. Once the biological indicators and their areas had been established, there was a discussion about the relationship between flow and the establishment of suitable salinity conditions in those areas, whereupon the subcommittee decided to base recommended flow rates on achievement of the targeted salinity niches of all or nearly all of the designated areas.

Using the methods described in the chapter below on Freshwater Inflows, the BBEST has arrived at a set of recommended freshwater inflow values. The tables therein present flow recommendations stated in acre-feet per month for three flow sources: Trinity River, San Jacinto River and coastal streams. Each flow source has recommendations for three seasons: Spring, Summer, and Fall.

2. INSTREAM FLOWS

2.1. Science Based Conditional Phased Approach

Endorsed by:

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Science-Based Conditional Phased Approach

2.1.1. Introduction

For the determination of instream flow recommendations for the Trinity and San Jacinto river basins, the Trinity and San Jacinto and Galveston Bay Basin and Bay Expert Science Team (BBEST) has crafted a recommendation designed to adhere to the mandate put forward to the BBEST by Senate Bill 3. Namely:

1) Finalize environmental flow regime recommendations and submit them to the basin and bay area stakeholders committee, the advisory group, and the commission not later than November 1, 2009, except that at the request of the basin and bay area stakeholders committee for good cause shown, the advisory group may extend the deadline provided by this subdivision [§Sec. 11.02362(c-3)].

2) Develop environmental flow analyses and a recommended environmental flow regime for the river basin and bay system for which the team is established through a collaborative process designed to achieve a consensus. In developing the analyses and recommendations, the science team must consider all reasonably available science, without regard to the need for the water for other uses, and the science team's recommendations must be based solely on the best science available [§Sec. 11.02362(m)].

An "environmental flow regime" is defined by SB3 as:

> "a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies."

Senate Bill 3 defines an "environmental flow analysis" as the:

> "application of a scientifically derived process for predicting the response of an ecosystem to changes in instream flows or freshwater inflows."

Senate Bill 3 contains provisions for:

> a continuing adaptive management process that can be applied to refine initially identified flow regimes as information (science) that confirms ecological – flow

> relationships required to support a sound ecological condition becomes available.

Essential to the formulation of a recommendation based upon the "best science available" is the scientific justification for inferences made, and data supporting such conclusions. The Trinity-San Jacinto BBEST has attempted to ascribe to this logic through rigorous research of available biological, geomorphologic, water quality, and hydrologic data sources and information for the system, utilizing input from the state's Environmental Flows Science Advisory Committee (SAC) where appropriate. A conditional phased approach is proffered herein as a process whereupon recommended results would be advanced in phases, acknowledging the uncertainty residing within the results of this effort. The BBEST's recommendation comprises two phases, in which the first is a set of flows at certain sites recommended for consideration as a standard under SB 3, and the second is a set of flows at certain sites recommended for further refinement under the adaptive management phase of SB 3.

Fundamental to the analyses employed in deriving a flow regime recommendation is the acknowledgment that the Trinity and San Jacinto rivers, at the locations considered by the BBEST, are currently a sound ecological environment. This reflects the current water demand structures in place, and is the culmination of achieving required dissolved oxygen conditions in the Trinity River and of the historical flow regimes that have been visited upon the systems over time. Implicit in the analyses of such historical flow regimes is the knowledge that while these flows may be statistically characterized, there are legally appropriated waters making up a significant component of these historical flows. The impact of historical human activities and their correlation with ecological effects is a significant component of uncertainty in the analyses of watershed hydrology. Recognizing these uncertainties, the BBEST has identified flow components on the basis of historical seasonal frequency, but recognizes and accepts that the ultimate attainment frequency associated with each flow component within the flow regime may be less than that based on the historical frequency of occurrence and still yield a sound ecological environment. The SAC acknowledges this issue, as well as the current lack of sufficient site-specific scientific data and analyses describing essential relationships between environmental flows and actual needs of aquatic organisms. A thorough discussion on this subject is provided within the SAC Discussion Paper: Moving from Instream Flow Regime Matrix to Environmental Flow Standard Recommendations (SAC 2009c), wherein it is stated:

> "As a surrogate for such information, statistical flow parameters based on historical hydrologic conditions are being examined as a default for establishing environmental flow requirements in those stream systems considered to currently reflect a sound ecological environment. The premise is that if a sufficiently close representation of key elements of the historical hydrology is maintained, then a reasonable approximation of the historical sound ecological environment is likely to also be maintained, while at the same time making

> available water for development. In this regard, any recommendations for environmental flow requirements replicating these historical flow parameters (and their historical frequencies of occurrence) logically might be considered an approximation (arguably the *maximum*) of the flow conditions needed to continue to support a sound ecological environment as available water resources are being developed. The presumption is that different quantities of flow, different frequencies of occurrence, or different seasonal distribution patterns of recommended flows may also be adequate. Depending on how the parameters are chosen and calculated, various components of the overall environmental flow matrix could be altered, perhaps significantly, from the historical period of record and still yield a sound ecological environment. In addition, it is important to recognize that, because conditions in some watersheds have changed over the historical period, there is no guarantee that the biological response to a repeat of historical hydrologic conditions (say the drought of record, for example) would be essentially the same as it was many decades ago. Even acknowledging these qualifications, the presumption is that some less quantities of flow or some lesser frequency of occurrence than were experienced historically may still be adequate to sustain a sound ecological environment." (SAC 2009c)

The hydrology of the Trinity and San Jacinto Rivers and their tributaries must be thoroughly examined before generating environmental flow regimes in order to understand their natural characteristics and how the historic measured hydrology has and has not been modified. An understanding of the sources of flow in the naturalized and historical record must be documented and used to inform the other layers – geomorphologic, biologic, and water quality – of environmental flow regimes. Time series changes, naturalized flows, flow frequencies, and others must be considered. Three independent naturalized flow studies have been performed for many sites in the Trinity basin. Different sources of flow in the historic record must be identified and quantified as far as possible – runoff, springs, return flows, regulated releases from impoundments, flood releases from impoundments, etc. It is necessary to know to what extent the historic hydrology has and has not been changed. The BBEST does not attempt to satisfy competing uses, but it does consider the makeup and nature of historic flows in order to interpret their natural ecological functions.

The clearest human induced change in the historic record is a significant and continuous increase in the level of low flows in the Trinity River from Fort Worth and Dallas on downstream due to return flows beginning with the start of wastewater collection and treatment in those cities in the early 1900's. It began about 1910 and is now approximately 500 mgd. Starting about the same time, impoundments began to be built to supply water for those cities and others, and that has increased throughout the 1900's. The impoundments have the dual effect of decreasing some higher flows downstream and increasing the low flows when the supplies are used and returned. The San Jacinto River and tributaries have experienced the same kind of changes, with

the general difference of having depended much more on groundwater for water supplies until the 1980's, and since then converting gradually to a predominant dependence on surface water impoundments and supplies.

Most sites for major water supply impoundments have now been used, and starting about 1960 supplies began to be obtained from out-of-basin impoundments for both basins. The use of out-of-basin sources began to increase very significantly in the 1990's and will continue. These imported supplies produce further increases in low flows via return flows without reducing higher flows in the Trinity basin. Simultaneously, reuse of return flows has become a significant factor in the Trinity basin, at least at base flows. The first sizeable reuse began in the basin in the 1980's and has increased rapidly since 2000. Water rights permits and plans are in place to continue to increase reuse significantly.

2.1.2. Best Available Science for Support of Recommendations

Little specific data currently exist for the support of flow recommendations within the Trinity or San Jacinto basins. As noted within the "Ecological Overlay for the Trinity River for support of Development of Instream Flow Recommendations for Environmental Flows", the only instream recommendations that can be made "are either going to be generic or specific depending on the availability of HEP and previous IFIM/PHABSIM guidance" (Guillen, et. al., 2009). Unfortunately, there is an insufficient amount of information regarding the geomorphology of the system, as well as the behavior of flows within the Trinity related to habitat at varying flow levels, at locations within the system to establish biological-flow relationships.

A significant finding of the Guillen et. al. 2009 report is the recommendation to maintain flows to promote water quality (specifically dissolved oxygen levels). There is a significant amount of dissolved oxygen data available, and a limited amount of data available for other water quality parameters (i.e. phosphorous, nitrogen, suspended solids, bacteria, etc.). Also noted is the importance of maintaining floodplain connectivity with floodplain lakes and oxbows.

The "San Jacinto River Basin SB3 Ecological Overlay" report indicates generic information regarding flow components and their potential for impacts on focal instream biological components. Ultimately the report concludes "no site-specific analysis has been discovered to support identification of quantitative flow values for priority locations" (Espey 2009).

A significant amount of discussion focused upon the utility of information from studies external to the Trinity watershed, particularly the utility of information from the findings of the BIO-WEST instream flow study of fishes in the lower Colorado River (BIO-WEST 2008). As can be seen from the findings in that report, the variations in habitat areas are significantly diverse at different locations within the Colorado watershed. While this study may provide a conceptual framework, the theorization of a shift in habitat types

under various dry and wet year conditions cannot be inferred for Trinity and SJ watersheds, as no information exists within these basins to ascribe varying flow magnitudes to different habitat areas at specific locations within the watersheds. Thereby no reliable means exist to meaningfully relate such findings to specific flow magnitudes within the Trinity and San Jacinto basins.

Table 2 below presents a broad characterization of some basic biological assessment methodologies developed by the National Research Council of the National Academies (NRC 2005). Given the limited data sources and information available on the Trinity and San Jacinto River basins, it is readily apparent that any approach that may be utilized by the Trinity-San Jacinto BBEST will likely fall on the far left of Table 2, as there is great uncertainty given the lack of available data. That is to say, the level of sophistication of a flow recommendation relating to the biology within the basins under analysis in this effort can only be holistic in nature, and cannot presently be shown to support a fine spatial resolution with a series of simulated values at variable flows.

Table 2
Ordination of Some Basic Biological Assessment Methodologies from Holistic to Specific (NRC 2005)

	Holistic Higher Uncertainty	←			→	Specific Lower Uncertainty
	Ecosystem Indicator	←			→	Metrics with Direct Response to Flow
Approach	Course Ecological Indicators	Assemblage Structure	Habitat Guilds	Species HSC	Population Models	Individual-based Models
Key Characteristics	Integrates many components/ processes; correlational	Integrates many components; correlational	Integrates many components; correlational	Individual or species; correlational	Dynamic simulation of aggregate response variable	Dynamic simulation of ecological mechanisms
Strengths (Benefits)	Rapid, cheap, Repeatable	←			→	Predictive with high resolution
Weaknesses (Limitations)	Ecological responses and mechanisms not specified	←			→	System site specific; expensive; time consuming
Settings where appropriate	Any	←			→	Those for which much information is available
Appropriate spatial scales	Intermediate to large	Intermediate to large	Intermediate	Small	Large	Small to large
Outputs	A single target value and correlations with flow	A set of values and correlation with flow	A set of values and correlation with flow	A series of values and correlation with flow	A series of simulated values at variable flows	A series of simulated values at variable flows
Examples/Applications	Multiple applications: water quality, watersheds, etc.	Channel-floodplain connectivity	Leonard and Orth, 1988	Many ISF programs	Long history but few formal applications to ISF	Jager et al., 1997, 2001; Railsback et al., 1999, 2002, others

While estimates based upon professional judgment could be proffered for any number of hydrologic components, the BBEST's intent is to again ascribe to the mandate of utilizing the "best available science" to provide flow recommendations that can be "shown to be adequate to support a sound ecological environment and to maintain the

productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies."

The definition of the "Scientific Method" from the Merriam-Webster dictionary is a useful, though simplistic, reminder of the level of sophistication of what evaluations must be brought to bear to develop a "scientific" flow recommendation, and is as follows:

> "principles and procedures for the systematic pursuit of knowledge involving the recognition and formulation of a problem, the collection of data through observation and experiment, and the formulation and testing of hypotheses."

An estimate based upon professional judgment is merely a single step in the formulation of "science", i.e. the formulation of a hypothesis. The scientific method also requires reproducible results. When results are quantified, the uncertainty or variability must also be quantified. As noted in Guillen et. al. 2009 and Espey 2009, no collection of data is available within the Trinity nor San Jacinto basins; thus, no basis currently exists for observation and experimentation to validate such an estimate to arrive at a scientifically sound conclusion. While it is feasible that flow recommendations developed by the BBEST as hypotheses could be experimentally tested through adaptive management, the BBEST maintains that such recommendations should be used solely as a means of validation through comparison with scientifically derived data that can be shown to support a sound ecological environment in the future.

Ultimately, there is a preponderance of hydrological data available to investigate. As noted within the Use of Hydrologic Data in the Development of Instream Flow Recommendations for the Environmental Flows Allocation Process and the Hydrology-Based Environmental Flow Regime (HEFR) Methodology guidance document, the "hydrologic analyses discussed [therein] constitute the first, and perhaps the easiest, step in the process of developing instream flow recommendations" (SAC, 2009d). While the Trinity-San Jacinto BBEST concurs with this statement, it is further necessary to note that hydrologic analyses are merely a "step in the process" (only one overlay), and without any additional supporting ecological analyses are insufficient to develop an instream flow recommendation. Further, it must be noted that the HEFR software is merely a convenient statistical processing package of hydrologic data, and the level of precision ascribed through its application is too great when no other ecological information is available to support the output. Unless additional information is available to help establish the percentiles for each flow component, there is no environmental connection with the resulting flow regime. The BBEST recommends that more than one overlay (Hydrology, Water Quality, Environmental, etc.) is necessary to define a reliable Instream Flow recommendation. These data sets need to be developed by site location or by similar reaches in order to be relevant to the recommendation.

2.1.3. Approach

There is insufficient information in the Trinity River Basin to perform a sound scientific assessment of flow regime impacts on aquatic life, fluvial geomorphology and other overlays; specifically in identifying particular flow magnitudes necessary for the support of specific ecological functions for the river at given locations. Therefore, achieving the BBEST mandate to develop a recommendation on a flow regime involves the application of a conditional phased approach utilizing what science is available to reach sound conclusions, and the identification of where more study is necessary through adaptive management. It is also the responsibility of the BBEST to convey the level of confidence associated with the decisions employed in the development of these recommendations in order to inform upon their utility to the Texas Commission on Environmental Quality and the public.

The Trinity-San Jacinto BBEST recommends that the conditional phased approach applied herein be utilized only at the locations suggested within this document, until further supporting science can be developed in the future to specifically identify flows necessary for a sound ecological environment at specific locations within the Trinity and San Jacinto river basins. Due to insufficient information being available for the two river basins, recommended flow amounts for a limited number of flow conditions at a limited number of stations (Recommended Flow Stations) are proffered. The process of selecting these stations gave consideration to the information available at the stations and to providing initial geographic coverage that would be beneficial to TCEQ in the permitting process. The process employed to select the Recommended Flow Stations also identified other stations that may be of value for establishing flow regimes at additional stations if determined to be needed. For these other stations and for additional flow conditions (i.e. base wet flow, pulse flows, etc.) at the Recommended Flow Stations, Conditional Flow Amounts have been identified as candidate flows. The additional stations and the Conditional Flow Amounts may be of utility in an adaptive management context. Locations where recommended and provisional flows have been made are identified in Table 3 below.

Table 3
Recommended and Conditional Instream Flow Locations

Basin	USGS Gage No.	Station Name	Study Period
Trinity	08065000	Trinity River near Oakwood	1924-64
	08049500	West Fork Trinity River at Grand Prairie	1926-55
	08066500	Trinity River at Romayor	1925-68
	08057000	Trinity River at Dallas	1904-53
San Jacinto	08068000	West Fork San Jacinto River near Conroe	1940-69
	08070000	East Fork San Jacinto River near Cleveland	1940-69

It is important to recognize that both realistic operations of water supply systems and the prior appropriation water rights system play very important roles in the maintenance and reliable occurrence of flows under dry hydrologic conditions to the

extent such flows are naturally available. Clearly, the bed and banks delivery of reliable water supplies from large reservoir projects to downstream points of diversion contributes to the maintenance of flow in the intervening stream segment. Under dry hydrologic conditions, such water deliveries may exceed seasonal subsistence and approach seasonal base flows within a recommended flow regime. Similarly, hydropower releases from major reservoirs may contribute at higher levels within a recommended flow regime. The prior appropriation system also functions to ensure the occurrence of instream flows upstream of a major reservoir or run-of-river water right, particularly the critical maintenance of such flows in the range between subsistence and base under dry hydrologic conditions. As major reservoirs are not full and run-of-river rights may not be fully satisfied under dry hydrologic conditions, junior water rights and future applicants for surface water appropriation located upstream would be required to pass inflows for downstream water rights. The Trinity-San Jacinto BBEST feels that it is imperative that TCEQ recognize the contributions of downstream water deliveries, hydropower releases, and inflow passage to honor downstream water rights towards maintenance of recommended flow regimes supportive of a sound ecological environment. This has been noted within the Sabine-Neches BBEST's environmental flow recommendations (S&N BBEST, 2009).

The Trinity-San Jacinto BBEST has provided flow regime recommendations at streamflow gaging stations located within the Trinity and San Jacinto River Basins. These reference locations are, among other things, representative of major streams above and below existing reservoirs as well as tributary streams in the upper and lower portions of each river basin. The Trinity-San Jacinto BBEST recommends that the TCEQ develop appropriate methods for interpolation of flow conditions applicable to future permits and amendments from reference locations for which flow regimes supporting a sound ecological environment are established. Such methods should include, at a minimum, drainage area adjustments, but may also include consideration of springflow contributions, channel losses, aquifer recharge zones, soil cover complex, and other factors as necessary and appropriate. It is the Trinity-San Jacinto BBEST's understanding that the TCEQ has initiated a research project focused on development of methods for geographic interpolation of flow regimes. A similar recommendation has been proffered by the Sabine-Neches BBEST (S&N BBEST, 2009).

2.1.4. Recommended Flows

Recommended flow amounts have been developed and are proffered for their potential use in the permitting process. These recommended flows for the Trinity and San Jacinto river basins are discussed below.

2.1.4.1. Trinity River Basin

The major return flows to the Trinity River Basin occur upstream of the mid-Trinity Basin. Therefore, this reach is of major importance in developing a flow regime recommendation, as has been acknowledged by its selection as a Senate Bill 2 detailed study site for the Trinity Basin. There are four flow monitoring stations within this

reach, and hydrologic characteristics that support a sound ecological environment are very similar at each of these sites. The hydrology of all four stations is very similar and the available geomorphologic, water quality, and biologic information also indicates no differentiation between them.

Taking into account available data and knowledge of the mid Trinity segment, the similarities of flow conditions at Rosser, Trinidad, and Crockett; and the lack of biological-flow relationships for individual monitoring stations, a recommendation for a flow regime at a single location (Trinity River at Oakwood) for representing the mid-Trinity segment has been established. (Note: As additional science is developed for the mid-Trinity through SB 2 and/or other future studies, through an adaptive management process flow values could be developed for other locations and conditions, if needed.)

The identification of a recommended hydrologic regime gives consideration to flows generated by the HEFR methodology as suggested by the SAC within the Use of Hydrologic Data in the Development of Instream Flow Recommendations for the Environmental Flows Allocation Process and the Hydrology-Based Environmental Flow Regime (HEFR) Methodology guidance document (SAC 2009d). As also recommended by the SAC, Modified Base Flow Index with Threshold method (MBFIT) analyses have been performed by Espey Consultants, Inc., as well as Indicators of Hydrologic Alteration (IHA) analyses performed by Trungale Engineering. Both techniques have been utilized in order provide a suite of investigations into the separation of the hydrograph into base flow and runoff components. A HEFR analysis has been performed on the results of both of these analyses, utilizing an early period of record in an attempt to represent as minimal a human impact as possible in order to characterize more “natural” conditions for the watershed. As site specific scientific data justifies the need for a hydrological value, a HEFR amount is generated for consideration. Peak flow rates with frequencies of two per season have been calculated using the frequency-based method in HEFR. Seasonal base flow values were calculated using HEFR application assumptions as the respective 25th percentile base flow values for each season. As the amounts resulting from the MBFIT analyses and the IHA analyses are arbitrary in nature, the results have been averaged to arrive at seasonal base flow and subsistence flow values in order to facilitate collaboration on a set of values. Subsistence flows were initially calculated as the median of the lowest 10 percent of historical base flows by season using HEFR. Resulting subsistence flow values were then compared to available water quality information, as discussed below.

The TCEQ developed a QUALTX model for the upper and mid-Trinity River. TCEQ applies the upper Trinity calibrated model to develop wasteload allocations and TPDES discharge permit criteria to assure compliance with Texas Surface Water Quality Standards (TSWQS). Upper and mid-Trinity River flows are dominated by the discharges from a number of wastewater treatment plants (river flow is greater than 90 percent wastewater discharges during low flow conditions). As low flows (as measured by 7Q2) have continuously increased as wastewater treatment plant discharges to the basin

have grown, the quality of the wastewater discharges has continuously improved since the 1970's. As a result, dissolved oxygen conditions within the upper- and mid-Trinity basin have been maintained at higher levels due to the improvements in discharge quality. As reflected in the information gathered within Guillen et. al. 2009, fish species diversity has increased as a result of the improvements in the dissolved oxygen conditions for the reach of the Trinity River just downstream of Dallas:

- Period 1972-1974	4 species
- Period 1987	11 species
- Period 93-95	25 species

Guillen et. al. 2009 indicates that maintenance of appropriate flows and sufficient dissolved oxygen is important for supporting fisheries, which should also support other biological communities, including most mussel populations. As indicated above, information is available for performing a dissolved oxygen overlay assessment. An assessment has been performed on subsistence flow levels established through a HEFR analysis at the Oakwood gage (Recommended Flows). This assessment utilizing the QUALTX model provides a reasonable level of confidence that the selected flow regime should be supportive of a sound ecological condition represented by achieving stream standards for dissolved oxygen that support fishery conditions. Minimum baseflows are recommended to prevent dewatering to support most mussel populations, as identified within Guillen et. al. 2009. The possibility of having separate flow recommendations for "wet," "dry," and "average" conditions has been considered. While such conditions may exist, there has been no practical definition of these conditions other than some arbitrary statistical percentiles. There is no data relating the concept to actual ecological functions and specific flows in the Trinity basin. The BBEST thus selected to utilize the 25th percentile of baseflows to characterize the baseflow condition.

It is recognized that overbank pulses (e.g. 1 per year, 1 per-2 years) are essential for the long-term maintenance of biota and ecosystem productivity. While these flows may provide ecological functions in the Trinity and San Jacinto basins, they are also the cause of significant movement of bed materials, a process that creates both instream and floodplain aquatic habitat structure. To maintain seasonal connectivity with floodplain lakes and oxbows in order to provide necessary velocity refuge areas for spawning, nesting, and rearing, historical overbank flow values have been identified. Similar to the approach adopted by the Sabine-Neches BBEST, it is recognized that the frequency and duration of such flow events are naturally driven by rainfall runoff events, and there could be variable degrees of risk to certain economic activities in the floodplains, property, and public safety (S&N BBEST 2009). For this reason, the BBEST recognizes the ecological functions and benefits of these higher flow pulse categories, but does not recommend actions be taken to produce such flows, nor should overbank flows be included as an environmental flow standard or future permit condition. In addition, these resulting flows with frequency and duration are based upon the identified period

of record and with changing watershed landuse; these flows may not represent the existing or future conditions.

Based on application of the best available science (i.e., extensive flow data, a significant amount of dissolved oxygen data, fishery conditions relative to dissolved oxygen conditions, and a calibrated QUALTX water quality model for the assessment of dissolved oxygen), the recommendation for the Trinity River near Oakwood gage is as shown in Table 4 below:

Table 4
Flow Recommendation for Trinity River near Oakwood

Overbank Flows	Historic Qp: 24,600 cfs Historic Duration is 18 to 61 (Average: 33) DEFINITION: Overbank flows are naturally driven, infrequent, high magnitude flow events that produce water levels that exceed channel banks and result in water entering the floodplain. BBEST does not recommend action be taken to produce such flows											
High Flow Pulses	DEFINITION: High flow pulses are short duration, high magnitude (but still within channel) flow events that occur during or immediately following rainfall events. PURPOSE: The BBEST recognizes that high flow pulses provide an important ecological function to riverine habitat. Lacking specific ecological data, conditional flow magnitudes identified are an arbitrary representation of high flow pulses, and not a representation of the flow necessary to support a sound ecological environment until such supporting specific ecological data are developed.											
Base Flows (cfs)	265 at (91% over 41 yrs)			322 at (95% over 41 yrs)			186 at (85% over 41 yrs)			162 at (82% over 41 yrs)		
	DEFINITION: Base flows represent the range of "average" or "normal" flow conditions in the absence of significant precipitation or runoff events. PURPOSE: Maintain typical occurrence and persistence of consecutive base flow days											
Subsistence Flows (cfs)	98 at (100% over 41 yrs)			80 at (100% over 41 yrs)			75 at (97% over 41 yrs)			85 at (96% over 41 yrs)		
	DEFINITION: An atypical, short-duration (days to weeks) low flow event PURPOSE: Maintain historical occurrence and persistence, prevent development of poor water quality conditions											
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
	Winter			Spring			Summer			Fall		

High flow pulses are short duration, high magnitude (but still within channel) flow events that occur during or immediately following rainfall events. The BBEST recognizes that high flow pulses, as a component of a natural flow regime, can provide an important ecological function to riverine habitat. However, lacking specific ecological data, only conditional flow amounts can be arbitrarily identified as a likely representation of high flow pulses. These amounts cannot be suggested as a representation of the flow (or flows) necessary to support a sound ecological environment, as no such ecological information exists to support their identification. Noting this, flow magnitudes for high flow pulses are included within the discussion on conditional flows later in this document.

No information can be brought to bear to identify what specific magnitudes of flow are necessary to support a sound ecological environment within the lower portion of the Trinity watershed. However, in recognition of the importance of the lower Trinity basin,

a characterization of similar flow components are provided as an instream flow recommendation for the Trinity River at Romayor gage location, as seen in Table 5.

Table 5
Flow Recommendation for Trinity River at Romayor

Overbank Flows	Historic Qp: 44,600 cfs Historic Duration is 34 DEFINITION: Overbank flows are naturally driven, infrequent, high magnitude flow events that produce water levels that exceed channel banks and result in water entering the floodplain. BBEST does not recommend action be taken to produce such flows.			
High Flow Pulses	DEFINITION: High flow pulses are short duration, high magnitude (but still within channel) flow events that occur during or immediately following rainfall events. PURPOSE: The BBEST recognizes that high flow pulses provide an important ecological function to riverine habitat. Lacking specific ecological data, conditional flow magnitudes identified are an arbitrary representation of high flow pulses, and not a representation of the flow necessary to support a sound ecological environment until such supporting specific ecological data are developed.			
Base Flows (cfs)	744 at (91% over 44 yrs)	923 at (93% over 44 yrs)	510 at (83% over 44 yrs)	515 at (74% over 44 yrs)
	DEFINITION: Base flows represent the range of "average" or "normal" flow conditions in the absence of significant precipitation or runoff events. PURPOSE: Maintain typical occurrence and persistence of consecutive base flow days			
Subsistence Flows (cfs)	295 at (100% over 44 yrs)	290 at (100% over 44 yrs)	223 at (97% over 44 yrs)	240 at (95% over 44 yrs)
	DEFINITION: An atypical, short-duration (days to weeks) low flow event PURPOSE: Maintain historical occurrence and persistence, prevent development of poor water quality conditions			
	Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
	Winter	Spring	Summer	Fall

2.1.4.2. San Jacinto River Basin

Similarly to the Trinity basin, little ecological data exist to identify specific flow magnitudes necessary to maintain the health of the fluvial system. Further, no water quality relationships are of utility in identifying necessary maintenance flow conditions. Thus, in order for the BBEST to meet its mandate of providing a recommended flow regime for the Trinity and San Jacinto river basins, a flow regime based solely on historical hydrology is proffered for two gages in the watershed.

The East Fork San Jacinto River at Cleveland and the West Fork San Jacinto River at Conroe gage sites have been selected as sites for flow recommendations. The Cleveland gage site is downstream of a relatively less-impacted stream reach within the watershed. A flow recommendation at this location could prove useful for further investigation in subsequent phases of adaptive management, particularly in comparison to a developed stream reach such as the West Fork San Jacinto upstream of the Conroe gage. Should development occur within the East Fork watershed in the future, monitoring and analyses could assess the validity and utility of the flow recommendations suggested herein. Even if no development occurs, an assessment could be made on the impacts of future changes in the hydroclimatology and their effects with respect to the flow recommendations. More explicitly, such an assessment may offer an opportunity to evaluate basin-wide changes in hydrologic conditions.

In order to arrive at a flow recommendation, again the MBFIT method was employed to parse an early period (1940-1969) hydrograph utilizing USGS gage data for this site. A HEFR analysis has been performed to identify minimum flows and overbank flow amounts to characterize a flow regime for the location. As indicated previously, this flow regime is based solely on hydrologic data, and is provided as a means of investigation of a less-impacted stream in the future through adaptive management. The recommended flow regimes developed through the analysis of historical data for the East Fork San Jacinto near Cleveland and West Fork San Jacinto near Conroe are presented in Tables 6 and 7 below.

Table 6
Flow Recommendation for East Fork San Jacinto River near Cleveland

Overbank Flows	Historic Qp: 16,000 cfs Historic Duration is 20 to 64 (Average: 36) DEFINITION: Overbank flows are naturally driven, infrequent, high magnitude flow events that produce water levels that exceed channel banks and result in water entering the floodplain. BBEST does not recommend action be taken to produce such flows.			
High Flow Pulses	DEFINITION: High flow pulses are short duration, high magnitude (but still within channel) flow events that occur during or immediately following rainfall events. PURPOSE: The BBEST recognizes that high flow pulses provide an important ecological function to riverine habitat. Lacking specific ecological data, conditional flow magnitudes identified are an arbitrary representation of high flow pulses, and not a representation of the flow necessary to support a sound ecological environment until such supporting specific ecological data are developed.			
Base Flows (cfs)	27 at (86% over 30 yrs)	28 at (90% over 30 yrs)	16 at (69% over 30 yrs)	16 at (66% over 30 yrs)
	DEFINITION: Base flows represent the range of "average" or "normal" flow conditions in the absence of significant precipitation or runoff events. PURPOSE: Maintain typical occurrence and persistence of consecutive base flow days			
Subsistence Flows (cfs)	10 at (100% over 30 yrs)	10 at (100% over 30 yrs)	9 at (91% over 30 yrs)	9 at (89% over 30 yrs)
	DEFINITION: An atypical, short-duration (days to weeks) low flow event PURPOSE: Maintain historical occurrence and persistence, prevent development of poor water quality conditions			
	Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
	Winter	Spring	Summer	Fall

Table 7
Flow Recommendation for West Fork San Jacinto River near Conroe

Overbank Flows	Historic Qp: 16,800 cfs Historic Duration is 18 to 61 (Average: 33) DEFINITION: Overbank flows are naturally driven, infrequent, high magnitude flow events that produce water levels that exceed channel banks and result in water entering the floodplain. BBEST does not recommend action be taken to produce such flows.											
High Flow Pulses	DEFINITION: High flow pulses are short duration, high magnitude (but still within channel) flow events that occur during or immediately following rainfall events. PURPOSE: The BBEST recognizes that high flow pulses provide an important ecological function to riverine habitat. Lacking specific ecological data, conditional flow magnitudes identified are an arbitrary representation of high flow pulses, and not a representation of the flow necessary to support a sound ecological environment until such supporting specific ecological data are developed.											
Base Flows (cfs)	38 at (90% over 30 yrs)			47 at (90% over 30 yrs)			17 at (81% over 30 yrs)			16 at (77% over 30 yrs)		
	DEFINITION: Base flows represent the range of "average" or "normal" flow conditions in the absence of significant precipitation or runoff events. PURPOSE: Maintain typical occurrence and persistence of consecutive base flow days											
Subsistence Flows (cfs)	10 at (100% over 30 yrs)			12 at (100% over 30 yrs)			10 at (95% over 30 yrs)			10 at (92% over 30 yrs)		
	DEFINITION: An atypical, short-duration (days to weeks) low flow event PURPOSE: Maintain historical occurrence and persistence, prevent development of poor water quality conditions											
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
	Winter			Spring			Summer			Fall		

2.1.5. Conditional Flows (Not Recommended until Further Science is Developed)

Conditional flow amounts have been developed and are provided for their potential use in an adaptive management context. These provisional flows are **not provided as recommendations for instream flow targets**, but are rather provided as potential future additions to the recommended amounts as scientific refinements are developed. While it has been found that there is insufficient science to specifically identify a flow magnitude, frequency, or duration, these conditional flows are provisional in the sense that they may be utilized as a means of contributing to the development of monitoring or analyses to scientifically justify the inclusion of such flow components.

2.1.5.1. Adaptive Management

Adaptive management has been acknowledged as a highly useful means to handle complex and dynamic situations (NRC, 2004). The validation of the aforementioned flow recommendations for the Trinity River at Oakwood, Trinity at Romayor, East Fork San Jacinto near Cleveland, and West Fork San Jacinto at Conroe sites, as well as establishment and refinement of other flow regime components (i.e. a naturally driven base wet flow condition from rainfall-runoff influenced events, etc.) may be investigated through further scientific study. Investigations of scientific evidence developed from other water bodies need to be confirmed as to their transferability to the Trinity and San Jacinto River basins, through appropriate studies. Investigations should also be performed within the watersheds themselves. This will be initiated through the activities associated with SB 2 and other investigations.

Such future refinements to the BBEST recommendations should include guidance on how a recommendation might be employed that is coincident with the level of confidence in the supporting science upon which the recommendation was derived. Components of a recommendation with a greater degree of uncertainty (i.e. a low level of confidence) might include associated monitoring and analysis to develop the information required to justify their inclusion in a future permit amendment through the adaptive management process.

As there is currently not enough data to support a more refined flow recommendation, future flow regimes should be used to establish guidance for gathering additional data to support their potential for inclusion as part of a flow recommendation. If justified scientifically (i.e. with data that can demonstrate a justifiable need for a magnitude, frequency, and/or duration of flow to support the ecology of the system), these conditions could be incorporated into a future permit in accordance with the adaptive management process.

Proposed flow regime quantities should be revisited on a periodic basis, as provided for by SB-3. As additional science and data are developed, assessments should be performed to determine whether flows should be adjusted upward or downward through the adaptive management process. Due to the constraints on available data, scientific understanding, confidence level, and time, water right permits issued based on the proposed flow regimes should be subject to adjustment in accordance with the 12.5-percent adjustment approach, as set forth in SB 3. The Trinity-San Jacinto BBEST has identified 13 USGS gage sites (see Table 8) as potentially useful "priority" gage locations for subsequent study and analyses.

Submitted for consideration below (Tables 9-14) are characterizations of specific conditional flow components of the flow regime for various locations within the Trinity and San Jacinto watersheds. It is the understanding of the Trinity-San Jacinto BBEST that translation of seasonal pulse flows of specified frequencies into environmental flow standards may result in less frequent occurrence of high flow pulses as a result of the full application of existing permits as well as issuance of new surface water appropriations or amendments. Furthermore, it has been identified by the Trinity-San Jacinto BBEST that available hydrologic, biologic, geomorphologic, and water quality data are insufficient to conclude that future high flow pulse frequencies representative

Table 8
Priority Gage Locations for the Trinity and San Jacinto River Basins

Basin	USGS Gage No.	Station Name
Trinity	08062500	Trinity River near Rosser
	08065000	Trinity River near Oakwood
	08062700	Trinity River at Trinidad
	08065350	Trinity River near Crockett
	08049500	West Fork Trinity River at Grand Prairie
	08055500	Elm Fork Trinity River near Carrollton
	08066500	Trinity River at Romayor
	08057000	Trinity River at Dallas
San Jacinto	08068000	West Fork San Jacinto River near Conroe
	08068500	Spring Creek near Spring
	08070000	East Fork San Jacinto River near Cleveland
	08075000	Brays Bayou at Houston
	08073700	Buffalo Bayou at Piney Point

of infrastructure consistent with meeting water needs for human uses in the foreseeable future would result in loss of a sound ecological environment. Hence, the BBEST has derived recommended high flow pulses on the basis of historical seasonal frequency as assessed by the application of the frequency-based method in HEFR utilizing a 2 per season magnitude, but recognizes and accepts that the ultimate attainment frequency associated with each seasonal pulse event within the flow regime will certainly be less than that based on the historical frequency of occurrence derived by HEFR and shown in Tables 9 through 14. A similar approach has been adopted by the Sabine-Neches BBEST (S&N BBEST, 2009).

All identified peak flow rates are limited to the overbank threshold identified within the flow recommendations, unless National Weather Service (NWS) data indicate bankfull or flooding conditions at a lower flow.

2.1.5.2. *Candidate Flows*

Initial Stations

Table 9

Conditional Flows for Adaptive Management for Trinity near Oakwood Site

High Flow Pulses	Qp: 3,200 cfs at (34% over 41 yrs) Volume is 18,931 Duration is 5			Qp: 7,840 cfs at (31% over 41 yrs) Volume is 141,705 Duration is 11			Qp: 1,180 cfs at (40% over 41 yrs) Volume is #N/A Duration is 2			No recommendation			These are a reasonable representation of the hydrology, but the relationship between the ecological health of the system and these magnitudes and frequencies of flow has not yet been defined. Defer to adaptive management to identify what is necessary for future science to support the utilization of these amounts in developing an instream flow recommendation or in a water permitting context.
Base Flows - Wet (cfs)	980			1080			470			370			
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	
	Winter			Spring			Summer			Fall			

Table 10

Conditional Flows for Adaptive Management for Trinity at Romayor Site

High Flow Pulses	Qp: 10,100 cfs at (28% over 44 yrs) Volume is 83,087 to 281,058 (152,814) Duration is 7 to 25 (13)			Qp: 10,900 cfs at (36% over 44 yrs) Volume is 106,220 to 319,381 (184,186) Duration is 8 to 29 (15)			Qp: 1,870 cfs at (46% over 44 yrs) Volume is 9,538 to 35,559 (18,417) Duration is 3 to 13 (7)			Qp: 2,560 cfs at (26% over 44 yrs) Volume is 15,903 to 51,774 (28,695) Duration is 4 to 15 (8)			These are a reasonable representation of the hydrology, but the relationship between the ecological health of the system and these magnitudes and frequencies of flow has not yet been defined. Defer to adaptive management to identify what is necessary for future science to support the utilization of these amounts in developing an instream flow recommendation or in a water permitting context.
Base Flows - Wet (cfs)	1753			1900			910			720			
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	
	Winter			Spring			Summer			Fall			

Table 11

Conditional Flows for Adaptive Management for East Fork San Jacinto near Cleveland Site

High Flow Pulses	Qp: 475 cfs at (14% over 30 yrs) Volume is 5,055 Duration is 8			Qp: 687 cfs at (9% over 30 yrs) Volume is 6,769 Duration is 8				Qp: 94 cfs at (12% over 30 yrs) Volume is 288 Duration is 2			Qp: 56 cfs at (17% over 30 yrs) Volume is #N/A Duration is 2	
Base Flows - Wet (cfs)	80			64				34			38	
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
	Winter			Spring			Summer			Fall		

These are a reasonable representation of the hydrology, but the relationship between the ecological health of the system and these magnitudes and frequencies of flow has not yet been defined.
Defer to adaptive management to identify what is necessary for future science to support the utilization of these amounts in developing an instream flow recommendation or in a water permitting context.

Table 12

Conditional Flows for Adaptive Management for West Fork San Jacinto near Conroe Site

High Flow Pulses	Qp: 420 cfs at (30% over 30 yrs) Volume is 3,679 Duration is 7			Qp: 1,100 cfs at (13% over 30 yrs) Volume is 12,377 Duration is 9				Qp: 74 cfs at (25% over 30 yrs) Volume is 380 Duration is 2			No recommendation	
Base Flows - Wet (cfs)	111			88				38			47	
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
	Winter			Spring			Summer			Fall		

These are a reasonable representation of the hydrology, but the relationship between the ecological health of the system and these magnitudes and frequencies of flow has not yet been defined.
Defer to adaptive management to identify what is necessary for future science to support the utilization of these amounts in developing an instream flow recommendation or in a water permitting context.

Additional Stations

Table 13

Conditional Flows for Adaptive Management for West Fork Trinity River at Grand Prairie Site

Overbank Flows	10,700 cfs Duration is 13 to 49 (25) DEFINITION: Overbank flows are naturally driven, infrequent, high magnitude flow events that produce water levels that exceed channel banks and result in water entering the floodplain. BBEST does not recommend action be taken to produce such flows.												These are a reasonable representation of the hydrology, but the relationship between the ecological health of the system and these magnitudes and frequencies of flow has not yet been defined. Defer to adaptive management to identify what is necessary for future science to support the utilization of these amounts in developing an instream flow recommendation or in a water permitting context.
High Flow Pulses	Qp: 392 cfs at (89% over 30 yrs) Volume is 3,830 Duration is 4			Qp: 1,280 cfs at (19% over 30 yrs) Volume is 8,345 Duration is 8			Qp: 293 cfs at (32% over 30 yrs) Volume is 1,899 Duration is 3				No recommendation		
Base Flows - Wet (cfs)	118			138			82				79		
Base Flows (cfs)	45 at (85% over 30 yrs)			45 at (89% over 30 yrs)			35 at (82% over 30 yrs)			35 at (75% over 30 yrs)			
	DEFINITION: Base flows represent the range of "average" or "normal" flow conditions in the absense of significant precipitation or runoff events. PURPOSE: Maintain typical occurrence and persistence of consecutive base flow days												
Subsistence Flows (cfs)	19 at (99% over 30 yrs)			17 at (99% over 30 yrs)			16 at (97% over 30 yrs)			15 at (95% over 30 yrs)			
	DEFINITION: An atypical, short-duration (days to weeks) low flow event PURPOSE: Maintain historical occurrence and persistence, prevent development of poor water quality conditions												
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	
	Winter						Spring						

Table 14
Conditional Flows for Adaptive Management for Trinity River at Dallas Site

Overbank Flows	Qp: 11,100 cfs Duration is 10 to 41 (21) DEFINITION: Overbank flows are naturally driven, infrequent, high magnitude flow events that produce water levels that exceed channel banks and result in water entering the floodplain. BBEST does not recommend action be taken to produce such flows.												These are a reasonable representation of the hydrology, but the relationship between the ecological health of the system and these magnitudes and frequencies of flow has not yet been defined. Defer to adaptive management to identify what is necessary for future science to support the utilization of these amounts in developing an instream flow recommendation or in a water permitting context.
High Flow Pulses	Qp: 758 cfs at (28% over 50 yrs) Volume is #N/A Duration is 3			Qp: 4,120 cfs at (16% over 50 yrs) Volume is 41,998 Duration is 9				Qp: 660 cfs at (29% over 50 yrs) Volume is 685 Duration is 3				No recommendation	
Base Flows - Wet (cfs)	272			304				225				198	
Base Flows (cfs)	31 at (87% over 50 yrs)			37 at (90% over 50 yrs)			32 at (86% over 50 yrs)			26 at (82% over 50 yrs)			
	DEFINITION: Base flows represent the range of "average" or "normal" flow conditions in the absense of significant precipitation or runoff events. PURPOSE: Maintain typical occurrence and persistence of consecutive base flow days												
Subsistence Flows (cfs)	15 at (93% over 50 yrs)												
	DEFINITION: An atypical, short-duration (days to weeks) low flow event PURPOSE: Maintain historical occurrence and persistence, prevent development of poor water quality conditions												
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	
	Winter						Spring						

2.2. Science Based Environmental Flow Regime for the Trinity River, San Jacinto River, and Galveston Bay

Endorsed by:

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Science-Based Environmental Flow Regime for the Trinity River, San Jacinto River, and Galveston Bay

> *"The Neches, San Jacinto, Trinity, Brazos, Colorado, Guadalupe, San Antonio, and Nueces rivers are the principal streams of Texas which lie wholly within the State….. The Trinity, Brazos,and Colorado are each about 1,000 miles long and are streams of much importance; like all the others of this State, however, they are subject to great floods and periodic droughts."*
>
> ------ *Evermann and Kendall (1892)*

2.2.1. Executive Summary

Variation in flow is a fundamental reality for all natural streams. Every Texas stream has experienced floods and droughts, and Texans understand that we live with these flood and drought conditions. In between, we can see a wide range of flow conditions. Some years or periods are wetter and others are drier than normal.

This natural variation of flow creates diverse aquatic habitats and provides ecological functions forming the foundation of environmental stream health. The Texas Legislature recognized the importance of maintaining sound environments in rivers. The Legislature passed Senate Bill 3 (SB 3) to create a science-based process for identifying the flow conditions - from drought to flood, over a range of dry to wet years - that represent environmentally healthy streams.

The report below describes the basis for identifying those flow conditions for the Trinity and San Jacinto Rivers, including the long history of data collection and analysis of flow and biological conditions in those rivers. This document then provides a flow regime for the rivers based on the available data, analysis and the judgment of the participating scientists of what flow conditions best represent environmentally sound conditions for these river systems. In SB 3 terms, this document provides:

> "a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies."

Fish have been collected from the Trinity and San Jacinto rivers since the nineteenth century. Flows have been measured for extended time periods at 45 sites including some locations for over a hundred years. Water quality has also been measured intensively for over 40 years. In addition to long-term monitoring of flow and water quality, numerous intensive studies of river biology, water quality, and flow have been conducted. Over 520 studies were reviewed and

over 33,000 unique records were generated in preparation for the Biological Overlay analysis (Guillen et al. 2009). These data and reports reveal four fundamental components of river flow in the Trinity and San Jacinto rivers based on ecological needs, each supporting environmental health in different ways:

1. Drought Flows (also referred to as subsistence flows)
    a. Rarely occur. Years may pass without drought.
    b. Water quality and quantity remain adequate for fish to survive. Oxygen and temperature levels do not reach levels that directly kill fish.
    c. Pools are connected by flowing water.
    d. Populations of fish, insects, and crustaceans eaten by other fish, water birds, and aquatic reptiles are reduced by predators.

2. Ecological Base Flows represent the flows that exist between rainfall runoff events. The three levels of ecological base flow represent periods when different habitats are more available than at other times. For example, shallow riffle habitat will be maximized and more available during relatively dry periods and lower flows than during relatively wet periods or years when flows are higher and depths are greater. Therefore the range of ecological base flows that occur during dry to wet periods provides different amounts of ideal habitat (depth, velocity, cover) that benefit some species during certain periods and others during subsequent periods. For example, a relatively dry period may promote survival and reproduction of smaller minnows and sunfish. Beneficial conditions and suitable habitat for this species assemblage, during these periods, leads to reduced stress, increased growth rates and population increases to levels that allow them to persist through wetter than normal periods when optimal habitat may be less available. Conversely, blue catfish, a large river fish will benefit from increased flows due to larger amounts of optimal habitat (deeper water, higher velocities) during average and wetter periods which allows this species to persist during relatively dry times. It is the range of these ecological base flows, rather than one flow, that allows species of fish, invertebrates, and plants with relatively different spawning and habitat requirements to persist and contribute to the health of the aquatic community. We can conclude that individual species may have different habitat needs which are “best” supported at different ecological base flows.
    a. Ecological base flows during dry periods: These flows occur during dry (not drought) years or periods. More riffle, shallow run, and shallow pool habitat is available which is preferred by blacktail shiners, juvenile flathead catfish, bluegill and longear sunfish, largemouth bass, and longnose gar. These periods allow these species to thrive but conditions are not extreme enough to eliminate other species from the fish community. For example, the shallow pools are poor habitat for freshwater drum and blue catfish but some will continue to survive.
    b. Ecological base flows during average flow years or periods: These flows occur during years or periods which are neither typically dry nor wet. The area of riffles, shallow runs and pools, decreases and is replaced by increasing areas of deeper runs and pools. Deeper runs and pools are better habitat for gizzard and threadfin shad and inland

silversides, all important forage fish for fish and other vertebrate predators. Deeper pools and runs increase habitat for adult blue, channel, and flathead catfish that tend to hide in deeper pools and runs during the day. Habitat for smallmouth buffalo that prefer moderate currents over muddy bottoms increases. Slight increases in inundated backwaters and tributaries provide habitat for red shiners, another important forage fish. During these years, some of the minnows and sunfish may have less habitat and be more exposed to larger river predators.

c. Ecological base flows during wetter than normal years or periods: The area of rapids, deep pools and runs, and access to backwaters and tributaries increases. Spotted bass, a typical riverine fish, thrives in the faster currents. Deeper habitats are enhanced for freshwater drum and smallmouth buffalo. Alligator gar, largemouth bass, and some sunfish will move into the backwaters and tributaries.

3. High Pulse Flows: Result from rainfall runoff entering the river. Important components of high pulse flows include timing and duration of the pulses. Ecological functions provided by high pulse flows include:
    a. Shaping the channel by transporting sediments, flushing silt and fine particulate matter,
    b. Cueing reproductive and spawning behavior;
    c. Connecting the mainstem of the river and its organisms with tributaries, backwaters, and other habitats off the channel; and,
    d. Contributing to germination and transport of seeds for riparian and bottomland species and maintaining composition of floodplain forests by fostering water tolerant species.

4. Overbank Flows (large floods): Naturally occurring but less common than high pulse flows. Usually result from hurricanes, tropical storms, or stalled frontal systems with high rainfall rates. Ecological functions provided by overbank flows include:
    a. Moving coarse woody debris and sediments, scouring deep pools, depositing sediments to form sandbanks;
    b. Transporting fish, aquatic invertebrates and aquatic plants to ephemeral aquatic floodplain habitats and from those floodplain aquatic habitats back to the river;
    c. Dispersing seeds of bottomland hardwood tree species and stimulating successful germination, seedling recruitment, and elimination of upland plant species that are competitively superior on well-drained soils; and
    d. Maintaining the sediment dynamics and geomorphic changes of the landscape needed to maintain riparian forest diversity.

SAC identified decision points encountered when using hydrologic data to help define environmental flow recommendations.

1. Number of Instream Flow Regime Components

   This recommendation includes the six flow regime components included in the SAC guidance document - Subsistence, Base Dry, Base Average, Base Wet, High Flow Pulse, Overbank Flows. Flow regimes can be complex. For example, dissecting a continuous yearlong hydrograph into discrete components can be arbitrary. The instream flow regime components selected by the SAC, represent a basic representation of flow regime complexity. These components also relate to different aspects of river ecological structure and function.

2. Geographic Scope of Instream Flow Recommendations and Spatial Extent of Individual Instream Flow Recommendations

   The flow recommendation should be applied to the stream segment on which the USGS gage is located. TCEQ stream segments "are streams and waterbodies that have been individually defined by the TCEQ and assigned unique identification numbers. Intended to have relatively homogeneous chemical, physical, and hydrological characteristics." Based on these relatively homogeneous characteristics, it is appropriate in the absence of data to the contrary to apply the targets derived from these gages to these segments. Consistent with the Sabine Neches BBEST recommendation, it is the recommendation of the Trinity San Jacinto BBEST that the TCEQ develop appropriate methods for interpolation of flow conditions applicable to future inter-adjacent permits and amendments from reference locations for which flow regimes supporting a sound ecological environment are established. Such methods should include, at a minimum, drainage area adjustments, but may also include consideration of springflow contributions, channel losses, aquifer recharge zones, soil cover complex, and other factors as necessary and appropriate.

3. Hydrologic Period of Record

   The pre-impact period of record was selected as the basis for the development of instream flow recommendations. Many studies (Rinne et al 2005; Giller and Malqvist 2004; Bryan and Rutherford 1993; and Locke et al. 2008; Poff et al. 1997; Brierly and Fryirs 2005; Richter et al. 1998) have demonstrated that deviations from the natural flow regime in terms of decreased volumes and variability have led to shifts in the native fish communities, local extinctions, reductions in species, and shifts in ecological base sediment transport regime. As was noted in an earlier SAC document "A varied flow regime that mimics natural historical patterns and that maintains adequate sediment loadings is the key to sustaining the fish and wildlife resources within and adjacent to Texas rivers and streams." (SAC 2004)

4. Hydrologic/Climatic Condition

   The safest and simplest approach to ensure that both natural variability and threshold conditions are maintained is to mimic the natural flow pattern as closely as possible including variability patterns (wet, dry and average years, seasonal), and associated duration and magnitude of flows. The recommendations included herein include a range of values supportive of this inter- and intra-annual variability.

5. Assignment Period

   Review of the historical hydrograph, temperature patterns, and the existing fish communities led to the selection of the following seasonal classifications.

   Spring – (March –Jun)
   Summer – (July – Sep)
   Fall – (Oct-Nov)
   Winter – (Dec-Feb)

6. Memory

   Application of these recommendations should consider long term attainment frequencies (using Water Availability Models, WAMs). Implementation has not been defined by BBEST.

7. Delineation of High Flow Pulse and Overbank Flow Components

   These recommendations include peak magnitude, duration, frequency, timing and total volume. From a strictly scientific perspective the BBEST recommends that these components mimic natural patterns as closely as possible. The BBEST recognizes that implementation of these recommendations in real time will present new challenges to the State's regulatory agencies.

8. Subsistence Flows Less Than 7Q2

   The 5th percentile flows were selected based on a finding of the lower Colorado River study which determined, based on water quality and instream habitat modeling, that 5th percentile flows were generally protective of the subsistence flow goals. It should be pointed out that these 5th percentile flow are based on pre-impact flow conditions and, in the Trinity and San Jacinto River Basins, these are very low flows. In most locations these flows have not been observed in decades, and it is unlikely that they will be observed in the near future. Given this fact, it is difficult to estimate the impact of these flows on water quality as no data exists to calibrate the models at these low levels. However, it is assumed that these estimates will be re-evaluated by more detailed studies long before flow management approaches these values.

9. Number and Location of Control Points

Eleven (6 in the Trinity, 5 in San Jacinto) sites were selected to provide wide spatial coverage of the mainstem streams in the basins. Unfortunately time and resource constraints did not permit the development of recommendations for tributary streams or for other gage locations.

10. Flow Recommendations For Waters not Specifically Included in These Environmental Flow Recommendations

The BBEST assumes that the basic methodology employed in this report will either be repeated if data exists to do so or that appropriate adjustments to the recommendations in this report will be applied appropriately.

11. Daily Average versus Instantaneous Flow Data

Daily average flows were used to develop flow recommendations although instantaneous data was used to verify the overbanks estimates which appear to be reasonable.

12. Overbank Recommendations

The overbank flow magnitudes were derived primarily from data obtained from the National Weather Service (NWS) flood stage. The BBEST recognizes mimicking the natural pattern of overbank flows is supportive of a sound ecological environment. The BBEST does not, however, recommend that any action be taken to create or enhance overbank flows rather that future projects that may alter these events carefully consider the ecological health of the river.

2.2.2. Legislative Mandate

Senate Bill 3 (SB3), passed in 2007, by the 80th Texas Legislature, established a stakeholder-based process for including consideration of environmental flow needs in new water rights permits. Stakeholders for the Trinity and San Jacinto basins created a multidisciplinary team of scientists to identify environmental flow regimes for the Trinity River, the San Jacinto River, and Galveston Bay. This multidisciplinary team is referred to as the BBEST (Basin and Bay Expert Science Team). The responsibility of the BBEST is described in Article 1 of SB 3.

> "(m) Each basin and bay expert science team shall develop environmental flow analyses and a recommended environmental flow regime for the river basin and bay system for which the team is established through a collaborative process designed to achieve a consensus. In developing the analyses and recommendations, the science team must consider all reasonably available science, without regard to the need for the water for other uses, and the science team's recommendations must be based solely on the best science available."

SB 3 defines environmental flow analysis and environmental flow regime as:

> "(15) 'Environmental flow analysis' means the application of a scientifically derived process for predicting the response of an ecosystem to changes in instream flows or freshwater inflows."
>
> "(16) 'Environmental flow regime' means a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies."

Article 1 of SB 3 also outlines how the environmental flow regime will be considered by the Texas Commission on Environmental Quality (TCEQ) in establishment of environmental flow standards. This clearly indicates the environmental flow regime described here is one of several considerations that will form the basis of environmental flow standards to be developed by the TCEQ.

> "(b) In adopting environmental flow standards for a river basin and bay system under Subsection (a)(1), the commission shall consider:
>
> > (1) the definition of the geographical extent of the river basin and bay system adopted by the advisory group under Section 11.02362(a) and the definition and designation of the river basin by the board under Section 16.051(c);
> > (2) the schedule established by the advisory group under Section 11.02362(d) or (e) for the adoption of environmental flow standards for the river basin and bay system, if applicable;

(3) the environmental flow analyses and the recommended environmental flow regime developed by the applicable basin and bay expert science team under Section 11.02362(m);
(4) the recommendations developed by the applicable basin and bay area stakeholders committee under Section 11.02362(o) regarding environmental flow standards and strategies to meet the flow standards;
(5) any comments submitted by the advisory group to the commission under Section 11.02362(q);
(6) the specific characteristics of the river basin and bay system;
(7) economic factors;
(8) the human and other competing water needs in the river basin and bay system;
(9) all reasonably available scientific information, including any scientific information provided by the science advisory committee; and
(10) any other appropriate information."

SB 3 was written with full knowledge of the ongoing Texas Instream Flow Program (established through SB 2 of the 2001 legislature). The legislature made a clear decision to move forward with environmental flow standards in part because of the lengthy time frame of the SB 2 studies. SB 3 recognizes there is a degree of uncertainty in the environmental flow regime that will be described and environmental flow standards that will be created. The legislation addresses that uncertainty by providing for adaptive management, a key component of SB 3, over a ten-year period and provisions for adjustments to flow standards as more complete information provided by SB 2 studies becomes available. It is important not to wait until results of SB 2 studies, in part, because they will only include the middle reach of the mainstem of the Trinity River between Dallas and Lake Livingston, and they will not include the San Jacinto River basin.

The environmental flow regime provided in this report is consistent with the TIFP, the National Academy of Sciences review of the TIFP, the Texas Environmental Flows Science Advisory Committee (SAC) recommendations, and the state-of-the-science of instream flows. Although impossible to know at this time how environmental flow standards will be set by the TCEQ, the BBEST is responsible for ensuring TCEQ has access to an environmental flow regime based on the best science available. This report attempts to accomplish that charge.

2.2.3. Best Available Science

Like many other complex environmental issues, instream flow studies and recommendations operate in the realm of extreme complexity where simple models and experimental manipulation are difficult to apply (Figure 5). Consequently, the availability of off-the-shelf predictive models with good fits (high r-square) is more of a rarity, than the norm due to high inter-annual variation in both hydrology and population and community interactions. Nonetheless there is a rich scientific literature on the ecology and response of riverine biota and geomorphology to altered stream hydrology (Rinne et al 2005; Giller and Malqvist 2004; Bryan and Rutherford 1993; and Locke et al. 2008; Poff et al. 1997; Brierly and Fryirs 2005; Richter et al. 1998). These various studies conducted throughout the world have yielded predictive models of responses of aquatic life and geomorphology to changes in hydrology. In almost every case, deviations from the natural flow regime in terms of decreased volumes and variability have caused shifts in the native fish communities, local extinctions, reductions in species, and shifts in ecological base sediment transport regime.

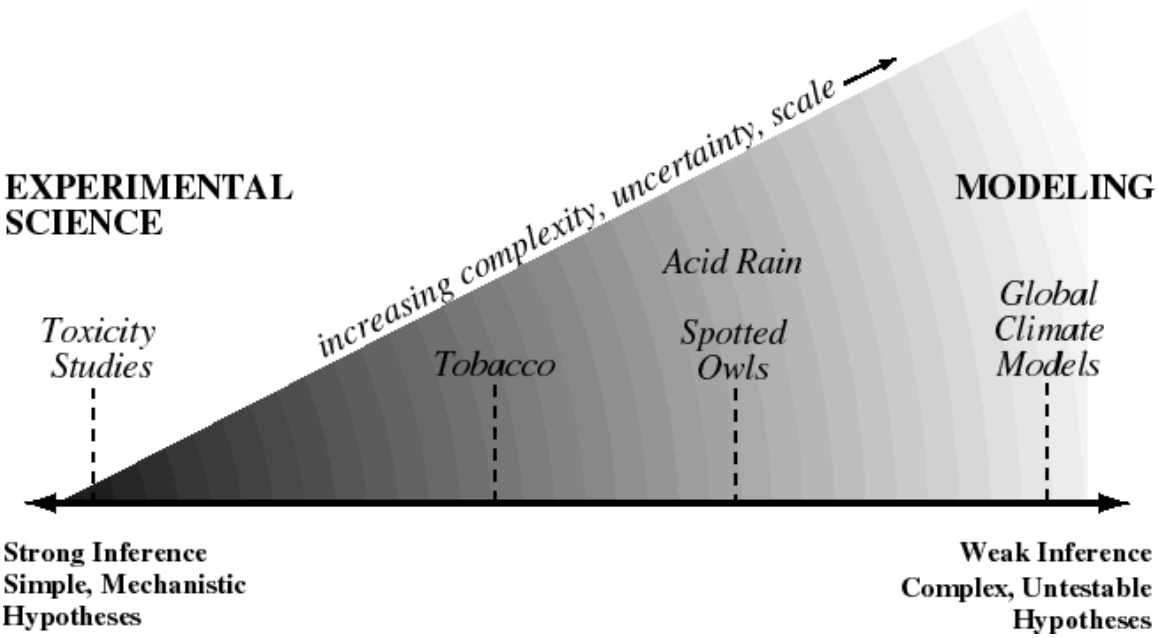

Figure 5 Relationship between traditional use of experimental science and complexity of system. Uncertainty increases with models of increasing complexity due mainly to the impossibility of testing the hypotheses upon which these models are based. Determination of instream flows for environmental purposes most likely falls in the region near Spotted Owl conservation and Acid Rain. (Source Bradshaw and Borchers. 2000).

Compared to streams that have been intensively studied specifically to support development of environmental flow regimes, there is less site specific information on the response of Trinity and San Jacinto River (TRSJR) aquatic biota to altered hydrology. In addition, the algorithm traditionally used to evaluate altered flow regimes uses some functions of habitat suitability in addition to flow including velocity, sediment type, depth, and cover. Contrast this to the simpler coastal model that primarily utilizes salinity regime and has more biological monitoring data. Unfortunately unlike estuaries and reservoirs, there is no long-term lotic community monitoring program for rivers and streams.

Evaluation of the impacts of altered hydrology on the TRSJR systems is further complicated by the fact that some historical fish collections reflect the impact of highly degraded water quality regime present in portions of each basin (e.g. hypoxia/anoxia, ammonia) for rivers and streams. Water quality has steadily improved with resulting increased numbers and species of fish in the area below Dallas. However, many sections of the Trinity River and San Jacinto River basins continue to have problems and are on the 303d list for dissolved oxygen. Another complicating factor in the case of the Trinity River is that the original river basin has become the most fragmented (# reservoirs/mile) river in Texas (Chin et al. 2008). There were no instream flow studies that occurred prior to the construction of the major dams on the river and/or period of degraded water quality. Consequently for both rivers, there is less site-specific habitat and biological data analyzed in conjunction with hydrology that illustrates organisms' responses to different flows than would be typically used in an intensive environmental flows analysis.

The environmentally sound flow regimes described in this report should be supported by future studies described in the adaptive management section of this report. However, there are sufficient scientific data to make recommendations on the flow components in these flow regimes as they relate to supporting critical aquatic communities (e.g. focal species, guilds).

Section 11.02362 of the Texas Water Code (TWC) specifies that each basin and bay expert science team (BBEST) shall develop environmental flow analyses and a recommended environmental flow regime for the river basin and bay system for which the team is established. The TCEQ also specifies that the flow analysis and flow regime be developed through a collaborative process designed to achieve a consensus. In developing the analyses and recommendations, the science teams must consider all reasonably available science, without regard to the need for the water for other uses, and the science team's recommendations must be based solely on the best science available.

SB3 provides additional guidance to the overall process of setting environmental flows. They defined environmental flow analysis and regime as such:

> "(15) 'Environmental flow analysis' means the application of a scientifically derived process for predicting the response of an ecosystem to changes in instream flows or freshwater inflows."
>
> (16) 'Environmental flow regime' means a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically, by specific location in a watershed, and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies."

The key term is "*Best Available Science"* which is different from "*Best Science",* which is more applicable to an ideal goal we should seek as new studies are commissioned through the adaptive management process. Best available science is a relatively broad term that has been used by many organizations at both the state and federal level. It has also in many cases

generated extensive discussion since to some extent it is often defined by individual disciplines (e.g. geology, biology, engineering) and their perceptions of the state of science as it relates to their scientific field. Therefore information is presented on "Best Scientific Information" as it relates primarily to aquatic and fisheries science, which are two of the major areas of expertise that relate to development of environmental flow recommendations.

In the United States, the use of "best scientific information available" and related terms originated in legislation protecting marine mammals (Marine Mammal Protection Act of 1972), in amendments to the Endangered Species Act of 1973, and in establishing management standards for marine fisheries (Fishery Conservation and Management Act of 1976; reauthorized in 1996 as the Magnuson-Stevens Act). Under the Magnuson-Stevens Act, National Standard 2 specifies that "conservation and management measures shall be based upon the best scientific information available" (Magnuson-Stevens Act, sec. 301). Similar terminology has been included in subsequent federal and state environmental statutes (NAS 2004). Much of the text that follows has been taken verbatim from that document. Dr. George Guillen's comments are in italic.

> The nature of scientific inquiry varies with the field of endeavor and the constraints imposed by the system under examination. For example, tightly controlled and replicated laboratory experiments form the basis of most research on the physiology and genetics of organisms. In contrast, this type of experimental approach often may be impractical for investigating the population biology, ecological relationships, and evolution of these same organisms because of the temporal and spatial scales and complexity of the systems. *The study of environmental flows falls into the category of population and community level investigations.* In these fields, much scientific information is derived from careful observation and analysis of empirical data. For each approach to scientific inquiry, potential sources of error or bias in either data collection or analysis may be identified through peer review. Ultimately, the quality of a given scientific analysis is revealed over time as additional information becomes available that either confirms or refutes earlier interpretations. *In the case of instream flows, an extensive peer reviewed literature on the response of organisms to altered hydrology has accumulated (Rinne et al. 2005; Gordon et al. 2004; Bovee et al. 1998; Poff et al. 1997; Yeager 1993; Locke et al. 2008; Hirji and Davis 2009; Acreman and Dunbar 2004; Dyson et al. 2004; Winemiller et al. 2008; Hersh and Maidment 2006; Poff and Zimmerman 2009; Bunn and Arthington 2002)*. Most of these studes and reviews conclude that there is a need to preserve and restore natural variability in the river hydrograph to support various life history needs of riverine biota and geomorphic functions.
>
> In practice, most disputes over scientific information used in management have arisen from the addition of the modifiers "best" and "available." The term "best" explicitly suggests that there is no better scientific information available and implicitly suggests the use of the most relevant and contemporary data and methods. Practically, best information will vary depending on the circumstances. The best information in a region where there is little scientific capacity or for a species about which little is known will

differ in quality from the best information in a region with careful stock surveys and long-term monitoring by scientific experts. The term available suggests that management action is not contingent on the acquisition of new information. Hence, "best scientific information available" acknowledges the existence of scientific uncertainty, a feature of even the most robust biological population assessments, and dictates that prudent management be consistent with the scientific information that is available even though data gaps exist.

Various definitions of best available science exist in agency and professional organization guidance and may vary by profession (e.g. engineers, chemists, hydrologists, fisheries biologists). Within the professional community of fisheries biologists, which includes individuals who study and recommend instream flow regimes there is guidance that was produced by the Best Science Committee of the American Fisheries Society and the Estuarine Research Federation (now Coastal and Estuarine Research Federation = CERF) (Sullivan et al. 2006). The American Fisheries Society is the leading professional society that represents fisheries biologists in North America and provides voluntary Professional Certification Services. They recognized that fisheries biologists often must deal with complex environmental problems with high degrees of uncertainty. They cited four common sources of ecological uncertainty including:

1. Lack of basic biological information, exemplified through natural history or demographics;
2. Lack of information on functional relationships between populations and environmental factors;
3. Unpredictable events, such as the timing of floods and hurricanes; and
4. High variability associated with key parameter estimates.

Several of these sources of uncertainty apply to the task of setting instream flow standards. The AFS/CERF Committee went on to define what is "best available science". They indicated that this could include "conventionally accepted sources for scientific information such as peer-reviewed literature, gray literature, expert opinion, and anecdotal experience. These sources are commonly viewed as reflecting different levels of innovation, quality, respectability, and accessibility depending on the source and the uses to which they have been put. However, it may not be reasonable to conclude that a single source of information—conventional or new—is the best under all circumstances." Similar definitions of best available science for guidance of fisheries management are provided in several agency guidance documents.

Within the context of the BBEST tasks, several sources of guidance have been provided including the Texas Instream Flow Program (TIFP) Studies Technical Overview, and the various SAC guidance documents that provide information on the use and analysis of hydrological, biological, geomorphic, and water quality data and how to construct environmental flow recommendations (TIFP 2008, SAC 2008a, 2008b, 2008c, 2008d). The technical approach of the Texas Instream Flow program (TIFP) is supported by a favorable external peer review by the National Academy of Science (NAS 2005). The NAS (2005) report noted that:

State-of-the-art instream flow programs will strive to preserve whole ecosystems, ***mimic natural flow regimes***, include riparian and floodplain systems in addition to the stream channel, take an interdisciplinary approach, use a variety of tools and approaches in technical evaluations, practice adaptive management, and involve stakeholders

….**State-of-the-science programs use natural flow characteristics as a reference for determining flow needs**. Natural river systems have variable flows (also called flow regimes) within a year and among multiple years. For example, in most Texas rivers, the lowest natural flows occur during warm, growing seasons of the summer and fall. During this same period there might also be some temporary high-flow peaks driven by storms, especially in those areas of the state subject to tropical storms. This natural variability is important to sustain aquatic and riparian biota and riverine processes.

These recommendations have resulted in use of the IHA/HEFR (Indicators of Hydrologic Alteration/Hydrology Based Environmental Flow Regime) software package to define important environmental flow components including subsistence, ecological base dry, ecological base average, ecological base wet, pulse and overbank flows. It should be noted that the "base" flow condition as defined in TIFP and subsequent technical guidance documents is not equal to the classic definition of base flow used by hydrologists. It is equivalent to "low flow" as defined by Richter et al. (1998) (Hersh and Maidment 2006). This has been a major source of ongoing confusion and discussion in regards to defining this condition, since several BBEST members may have focused on the classic hydrological definition, which also has many variations in definition apparently.

Incorporated into the SAC documents is guidance on the use of IHA/HEFR and the development and use of biological overlays. Therefore the development of biological overlays using knowledge generated from *best available science* which includes IHA/HEFR output, published habitat suitability curves for specific species, TSJR specific biological data, models developed in other Texas and Southeastern states, and general life history information for focal species and associated guild species is consistent with the various agency, program, and discipline specific guidance provided for developing environmental flow recommendations including use of best available science. Inherent in these approaches is the acknowledgement of sources of bias, error and need for further research. However, acknowledgement of these factors is not intended to stop development of environmental flow recommendations, but rather to define future areas of research needed to inform and refine ongoing adaptive management both within the target river basin and other Texas river basins.

2.2.4. Biological/Ecological Justification for Instream Environmental Flow Regimes

For determining environmental flow recommendations for the Trinity and San Jacinto river basins (tributary streams and mainstem rivers), 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) biological overlay was adopted. This document provides guidance in defining and estimating subsistence flow, ecological base dry, ecological base average, and ecological base wet flow, high flow pulses, and overbanking flow pulses. A brief outline of this approach includes excerpts from the SAC guidance document, and descriptions with justifications of the Trinity/San Jacinto 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 Trinity/San Jacinto 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.

Key features of the natural flow regime include subsistence, ecological base dry, ecological base average, and ecological base wet flows, high pulse, and overbank flows. Consistent with the above definition is the definition from the TIFP Technical Overview document which defines a sound ecological environment as

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

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

Our BBEST 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., Colorado), as well as inferences based on life history information compiled from the literature, and reliance on general habitat suitability criteria developed for species from multiple regions. The University of Houston at Clear Lake Environmental Science Institute provided synopses of our focal species for both fluvial and estuarine systems (Guillen, et. al. 2009 and Espey Consultants, Inc., 2009), attached as appendices A and B).

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

The BBEST's instream flow workgroup initially selected 13 gages within the two basins. Subsequently 2 of the gages were dropped from the analysis because there was not an adequate pre-impact period-of-flow record. Information from the respective biological overlays for the Trinity and San Jacinto river basins was reviewed. The BBEST freshwater inflow workgroup compiled sources of data regarding estuarine focal species in order to guide freshwater inflow analysis. Estuarine experts from Texas Parks and Wildlife Department and the River Systems Institute of Texas were engaged to provide advice about freshwater inflow needs of estuarine species.

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

Consideration of ecological functions, rather than purely, traditional hydrologic analysis informed the flow separation procedure. Ecological/Biological considerations were used to determine seasonal definitions and the level of refinement in the number of flow regime components that were calculated. Flood stage estimated from the National Weather Service was used to set overbank magnitude. Lessons learned from the Lower Colorado River Instream Flow Study as well as references to international studies were used to define subsistence flow levels at the 5th percentile flow level.

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. Multidisciplinary integration workshops were convened to evaluate and refine the flow regime matrix and freshwater inflow matrix. The SAC recommended use of a flow regime framework consisting of subsistence flows, three different levels of normal, ecological base dry, ecological base average, and ecological base wet, high flow pulses, and overbanking flows.

2.2.5. The Trinity and San Jacinto River Ecosystems – Current Conditions and Responses of Species to Flow Components

There has been considerable work done on relating riverine ecosystems to flow conditions (Rosgen 1996, Leopold 1996, Junk et. al. 1989, Poff et. al. 1997, Stallins, et. al. 2009, Horner et. al. 2009, Rood et. al. 2003, Hughes and Rood, 2003; Naiman et al. 2005) These studies all demonstrate that flow magnitude, timing, duration, frequency, and variability (including rate of change) all play a role in determining the physical and biological components of the instream and riparian ecolosystem ("maintain the productivity, extent, and persistence of key aquatic habitats in and along the affected water bodies").

This report emphasizes the instream components of the ecosystem; however there are river riparian and floodplain habitats that are characteristic of these systems and semi-aquatic vertebrates that are dependent on a natural flow regime that follows historical patterns (Naiman et al. 2005). These habitats are flood dependent, requiring well-timed periodic floods, and tapered recession curves for regeneration. Alteration of the timing, duration and magnitude of these flows can lead to major shifts in the plant community and/or reduction of river dependent terrestrial and semi-terrestrial species of animals (Naiman et al. 2005). They also need to be sustained by sufficient flows that would fall into high base and pulse flow categories (Hughes and Rood 2003) Table 15 provides some information that relates to flows and the riparian and bottomland plant communities as they might respond to a continuum of flows.

The vegetation communities present along the river provide an excellent opportunity to relate species composition and abundance and elevation to different flow regimes because they integrate the effects of decades of flow regimes. Studies have examined the relation between flows and forest structure, species composition and abundance (Stallins et. al. 2009, Junk et. al. 1989, Horner et. al. 2009, Rood et. al. 2003). Limited work has been done on this subject in Texas (Hall 1993, Streng 1989). These riparian, forested and intermittently flooded habitats provide important food, shelter and reproductive habitat for not only fish but reptiles, birds, mammals and amphibians. They are additionally extremely important to neotropical birds for stopover habitat during migration (Hodges and Krementz 1996; Fisher 2000; Naiman et al. 2005). The long term viability of the riparian zone and its width are influenced by the amount of seasonal overbank flooding that occurs (Fisher 2000; Busch 1995). The width of this zone in turn influences the carrying capacity for various species of birds (Hodges and Krementz 1996).

Table 15 Relationship of Flow Regime to Riparian and Bottomland Plant Community

Flow	Plants	
	Benefits	Costs
Subsistence Flow	Allows plants to reach physiological peak especially during peak photosynthesis during summer and Fall. Allows colonization by wet intolerant species of marginal or river modified habitat.	If too long can cause and lead to morbidity and mortality. Allows less water tolerant species to move into water obligate habitat and upland plants into the higher floodplain zones. Allows exotics to infiltrate.
Dry Base Flow	Same function as above however sustains bank soil moisture. Important for germination of certain species including cypress .	Same as above however sustains bank soil moisture.
Normal Base Flow	Same as Dry Base Flow but supports higher elevations	If too long may cause plant communities to shift to more wet intolerant species and increase exotics.
Wet Base Flow	Increases bank storage and avails water for the riparian zone	May drown herbaceous aquatic plants in riparian zone.
Pulse Flows	Increase bank storage to higher elevations and frequency and duration inhibits certain species from colonizing more water tolerate plant communities. For example cypress-tupelo-gum community. Restores moisture into tributaries and isolated bodies sustaining the structure and composition of the plant community. Important for seed dispersal and germination of certain species.	If too frequent and too long of duration during the summer or fall certain plant communities that are situated in the higher floodplain may drown.
Overbank Flows	Restores isolated bodies and tributaries. Brings in sediments and nutrients. Important for dispersal.	If too long of duration in summer and/or fall can drown vegetation

Other vertebrate animals include semi-aquatic (wetland dependent species) of amphibians, reptiles, birds and mammals. Many of these species are dependent on many of the same habitat features created by the rivers that are important to fish and aquatic invertebrates. Many are dependent on the fish community for food and the associated forests and wetland habitats to breed. Waterbirds are dependent on seasonal patterns of flooding of wetland sites to have successful breeding and juvenile survival (Smith and Callopy 1995, Gawlik 2002, Frederick and Callopy 1989). Significant colonial bird rookeries are found along inland riverine systems and not just along the coastal nesting islands (Ortego 2009). Table 16 provides a similar response by non-fish vertebrates to different flow regimes on a continuum. Exact relationships at specific sites would depend on floodplain morphology, elevation and flow which are beyond the scope of this effort. River turtles normally nest in late spring and early summer on sandy beaches when water levels are dropping and the risk of flooding is decreasing (Moll and Moll 2004; Ernst and Lovich 2009). Drastic increases in water levels (e.g. flooding) would be disastrous for local populations of river turtle. This is particularly serious since there is some evidence that selected species of river turtle have been reduced due to overharvesting for overseas markets.

Table 16 Relationship of Flow Regime to Non-Fisheries Vertebrate Community

Flow	Non- Fisheries Vertebrates especially wetland dependent birds	
	Benefits	Costs
Subsistence Flow	Concentrates prey that colonized isolated water bodies in pulse and overbank flows and within river channel. This important especially to wading birds in the summer and fall – during reproduction and after fledging takes place for juveniles. Droughts are bottlenecks but can be beneficial for some species	If too long can cause and lead to morbidity and mortality. If it occurs in winter and spring can lead to future food shortages the following year inhibiting reproduction. If occur too frequently can lead to reductions in food source reproduction and thus future abundance. In spring and summer allows predators access to nests.
.Dry Base Flow	Same function as above. However does provide more foraging habitat within river channel.	Same function as above.
Normal Base Flow	May increase shallow water areas for forage species.	Dilutes prey
Wet Base Flow	Increases prey species on riverbank edge and in shallows. Benefits longer legged species such as great blue heron.	Further dilutes prey
Pulse Flows	Colonization of isolated water bodies by fish and macroinvertebrates. Increase habitat in tributaries. Flooding in winter and spring isolates nesting sites form predators. Maintains preferred plant community for nesting.	If they occur in summer fall will dilute prey and increase mortality of juveniles. Drown nesting vegetation. For certain species may destroy nests and young.
Overbank Flows	Restores isolated bodies and tributaries. Brings in future prey items into isolated water bodies.	If too long of duration in summer and/or fall can drown nesting vegetation, nests and young and dilute prey which can lead to increased mortality.

Analysis of the fish community of the Trinity River at Romayor illustrates relationships between flow variability and a diverse fish river community. Thirty-two species have been encountered in that reach of the river and different species have different spawning habitats and mesohabitats related to flow diversity. For example, *Macrobrachium ohione*, a species of freshwater prawn migrates to Galveston Bay with high flow pulses to spawn in the bay in the late spring. Alligator gar spawn over flooded vegetation. Other species like many of the sunfish require periods of stable flow in the spring to hatch eggs laid in nests on the bottom.

Table 17 Trinity River at Romayor Fish Community Spawning and Mesohabitat Requirements

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Spawning Habitat	Mesohabitat
Largemouth bass			Spawning temp of 15.6 , eggs hatch 5-10 days										Spawns over structure	Quiet waters
Spotted bass			Spawning temp of 17.2 , eggs hatch 2-5 days										Spawns over structure in tributaries	Fast, deep rivers
Bluegill				Spawning									Nests	Shallow, slow water
White bass			Spawning										Over structures, <3 m deep	Variety of mesohabitats
Channel catfish				Spawn under structures, eggs hatch 5-10 days, fry guarded for 7 days										Swift to slow currents
young														Young - slow riffles, aggregations in deep water from 4-10 months
adults														Adults - under structure during day, shallow at night
Blue catfish					Spawning								Nest cavity	Swift currents over sand, gravel, or rubble
Flathead catfish						Spawns in nests under structure							Nest cavity	
young														Young - riffles
adults														Adults - structure in deeper pools
Smallmouth buffalo			Spawning										Release over any substrate	Moderate currents, over silt bottoms
Freshwater drum					Spawning								Open water	Deep to medium water with soft bottom
Longnose gar				Spawning, eggs hatch 3-9 days									Deposit eggs on submerged items	Shallow near logs
Alligator gar				Spawning,									Deposit eggs on plants	Near surface in slackwater and backwater with structure. Spring floods introduce large numbers into river-bottom lakes (TPWD, 1958)
Gizzard shad				Spawning, stimulated by rising waters, eggs hatch in 2-4 days									Spawn over rock or gravel	
young														Young- close to shore, shallow water
adults														Adults - deeper waters
Threadfin shad				Spawning, eggs hatch 3 days									Spawn over objects	Upper 5 ft, flowing water, over sand, mud or detritus
Species	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Spawning Habitat**	**Mesohabitat**

Skipjack herring				Spawning								Probably in currents over sand and gravel	Current over sand and gravel
Paddlefish		Spawning, increased and sustained flow, rising water 3-5 m for 10-14 days, eggs hatch 6-9 days										Swift water over gravel or rubble	Low gradient areas, ex. backwaters
American eel	Spawning migration, at times with increased flow								Juveniles migrate upriver				Young-found under structure at higher velocities
Red shiner				Spawning								Gravel riffles or structure, eggs into crevices	Low gradient areas, backwaters, mouths of creeks
Blacktail shiner				Spawning								In crevices in flowing water	
young													Young-riffles
adults													Juveniles-sand banks
Mimic shiner				Spawning								Unknown	Near shore over sand, mud or gravel with slow to moderate current
Bullhead minnow					Spawning, eggs hatch 4-5 days							Nests in holes	Low-gradient, slow waters or pools over sand or gravel in backwaters or eddies
Inland silverside		Spawning, eggs hatch 6-10 days											Within 1-2 m of surface over sand and gravel bottoms
Macrobrachium ohionae						Juveniles migrate upstream						Reproduction cued by spring floods, reproduce in flooded terrestrial habitat.	Juveniles migrate upstream July to October
Silverband shiner					Spawning							Broadcast eggs, 1-2 m deep, strong currents	Main channel with moderate to swift currents, moderate to deep, silt, sand, gravel
Longear sunfish					Spawning							Shallow water, little current, nest on substrates	Usually flowing waters

2.2.5.1. Focal Species and Species Guilds

The focus of the environmental instream flow analysis and recommendations include the San Jacinto River Basin, the Trinity River Basin, and although not considered extensively due to limited perceived management options, the smaller coastal streams, bayous and rivers that discharge into Galveston Bay. Examples of these smaller water bodies include Clear Creek, Dickinson Bayou, Highland Bayou, Chocolate Bayou and Oyster Bayou. Conner and Suttkus (1986) reviewed the zoogeography of the Galveston Bay watershed inland fishes. At the time they found the Galveston Bay drainage has common faunal relationships with the Sabine Lake (86% of the species are the same), Calcasieu (86% of the species are the same) and Brazos River (84% of the species are the same). They also found that ten Trinity River system fishes were not recorded in the San Jacinto River system.

Prior to producing the Biological Overlay Support documents the two primary investigators had assembled data on the distribution of fish and aquatic invertebrates including unionid mussels (Table 19). This was done by reviewing historical collections and studies within the basin. Later the two investigators consulted with the Texas Parks and Wildlife Department and were presented a candidate list of "focal fish species" (Table 18). In addition, a list of focal invertebrate species included mainly unionid mussels and with a few additional invertebrate species (e.g. river prawn) (Table 20 and Table 21). These candidate focal species were presented at the Trinity-San Jacinto BBASC meeting in July 2009 (Botros 2009). These focal species were selected for several reasons including recreational and cultural value, local population risks, specialized habitat needs (e.g. fluvial specialists) and/or special state of federal conservation and protection status. Their utility is enhanced because they represent a larger assemblage of organisms with similar life history requirements. In addition, they represent several trophic and reproductive guilds of organisms. The distribution of focal species was compared with the distribution of priority gages in the San Jacinto River and Trinity River basins. For most species their historical ranges overlapped the distribution of gages. This will help facilitate the comparison of ecological needs of focal species along with the guilds they represent with actual historical and future hydrological regimes.

Table 18 List of focal fish species with important life history attributes.

					Spawning Season											
COMMON NAME	Watershed Focal Spp.	Trophic, Reproductive, tolerance Guilds	BioWest (2009) Habitat Guilds	BioWest (2009) Habitat Guilds - juveniles	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
white bass	TR	Predator, Open Sub. Spawner	Deep Pools													
alligator gar	TR	Predator, tolerant, Open and Nest Spawn	Floodplain/Oxbows													
longnose gar	SJR	Predator, tolerant, Open and Nest Spawn	Floodplain/Oxbows													
pallid shiner	SJR	Invertivore, Open substratum Spawner	Floodplain/Oxbows													
ribbon shiner	SJR	Invertivore, Open substratum Spawner	Deep Pools													
blacktail redhorse	SJR	Invertivore, Open substratum Spawner	Floodplain/Oxbows													
blackspot shiner	TR&SJR	Invertivore, Open substratum Spawner	Deep Runs													
silverband shiner	TR	Invertivore, Open substratum Spawner	Riffles													
freshwater drum	TR	Mainly invertivore, tolerant, open and nest spawner	Deep Runs													
longear sunfish	TR	invertivore, nest spawner	Shallow Pools/Backwater													
paddlefish	TR	mainly invertivore, intolerant, open spawner	Deep Runs													
creek chubsucker	SJR	omnivore, open spawner	Floodplain/Oxbows													
goldstripe darter	SJR	invertivore, intolerant	Shallow Runs													
freckled madtom	SJR	invertivore, intolerant	Riffles													
dusky darter	TR/SJR	invertivore, intolerantbrood hiders mainly	Riffles													
blue catfish	TR	predator, nest spawners	Floodplain/Oxbows													
largemouth bass	TR	predator, nest spawners	Shallow Pools/Backwater													
flathead catfish	SJR	predator, nest spawners	Deep Runs	Riffles												

Table 19 Total list of inland fish species found in the Trinity and San Jacinto River basins based on literature review (Espey Consultants Inc. 2009; Guillen et al. 2009).

Species	Trinity River	San Jacinto River
Agonostomus monticola	X	
Alosa chrysochloris	X	X
Ameiurus melas	X	X
Ameiurus natalis	X	X
Amia calva	X	X
Ammocrypta vivax	X	X
Anguilla rostrata	X	X
Aphredoderus sayanus	X	X
Aplondinotus grunniens	X	X
Atractosteus spatula	X	X
Campostoma anomalum	X	
Carpiodes carpio	X	X
Centrarchus macropterus	X	X
Cichlasoma cyanoguttatum	X (invasive)	X (invasive)
Ctenopharyngodon idella	X (invasive)	X (invasive)
Cycleptus elongatus	X	X
Cyprinella lutrensis	X	X
Cyprinella venusta	X	X
Cyprinodon variegatus	X	X
Cyprinus carpio	X	X
Dorosoma cepedianum	X	X
Dorosoma petenense	X	X
Elassoma zonatum	X	X
Erimyzon oblongus	X	X
Erimyzon sucetta	X	X
Esox americanus	X	X
Etheostoma artesiae	X	
Etheostoma chlorosomum	X	X
Etheostoma gracile	X	X
Etheostoma histrio	X	
Etheostoma parvipinne	X	X
Etheostoma proeliare	X	X
Etheostoma spectabile	X	X
Fundulus blairae	X	X
Fundulus chrysotus	X	X
Fundulus grandis		X
Fundulus notatus	X	X
Fundulus olivaceus	X	X
Fundulus pulvereus		X
Gambusia affinis	X	X
Hybognathus nuchalis	X	X
Hybognathus placitus	X	X
Hybopsis amnis	X	X
Ichthyomyzon gagei	X	X
Ictalurus furcatus	X	X
Ictalurus punctatus	X	X
Ictiobus bubalus	X	X
Labidesthes sicculus	X	X
Lepisosteus oculatus	X	X
Lepisosteus osseus	X	X
Lepomis auritus	X	X
Lepomis cyanellus	X	X

Species	Trinity River	San Jacinto River
Lepomis gulosus	X	X
Lepomis humilis	X	X
Lepomis macrochirus	X	X
Lepomis marginatus	X	X
Lepomis megalotis	X	X
Lepomis microlophus	X	X
Lepomis miniatus	X	X
Lepomis symmetricus	X	X
Lythrurus fumeus	X	X
Lythrurus umbratilis	X	X
Macrhybopsis aestivalis		X
Macrhybopsis hyostoma	X	X
Menidia beryllina	X	X
Micropterus punctulatus	X	X
Micropterus salmoides	X	X
Minytrema melanops	X	X
Morone chrysops	X	X
Morone mississippiensis	X	X
Morone saxatilis	X	X
Moxostoma poecilurum	X	X
Notemigonus crysoleucas	X	X
Notropis atherinoides	X	X
Notropis atrocaudalis	X	X
Notropis buchanani	X	X
Notropis potteri	X	X
Notropis sabinae	X	X
Notropis shumardi	X	X
Notropis stramineus	X	X
Notropis texanus	X	X
Notropis volucellus	X	X
Noturus gyrinus	X	X
Noturus nocturnus	X	X
Opsopoeodus emiliae	X	X
Oreochromis aureus	X (invasive)	X (invasive)
Percina carbonaria	X	
Percina macrolepida	X	X
Percina maculata		X
Percina sciera	X	X
Percina shumardi	X	
Phenacobius mirabilis	X	X
Pimephales promelas	X	X
Pimephales vigilax	X	X
Poecilia latipinna	X	X
Polyodon spathula	X	X (Pittman 1991)
Pomoxis annularis	X	X
Pomoxis nigromaculatus	X	X
Pterygoplichthys disjunctivus		X (invasive)
Pterygoplichthys multiradiatus		X (invasive)
Pylodictis olivaris	X	X
Semotilus atromaculatus	X	X
Number of Species	96	96
Number of Unique Species	5	5
Number of Shared Species	92	92

Table 20 List of focal invertebrate species – Trinity River

Species	Trinity	Status	Known Hosts	Spawning Season	Stressors: Notes
Lilliput (Toxolasma parvus)	X		Warmouth sunfish, green sunfish, bluegill sunfish, orangespotted sunfish, white crappie	April-August	Found in quiet waters of lakes, mud and silt, 0.25-1.07 m.
Texas Lilliput (Toxolasma texasiensis)	X		Warmouth sunfish, longear sunfish	October to June	Found in oxbows, tributaries in mud, absent in flow rivers
Fawnsfoot (Truncilla donaciformis)	X	(TWAP-SC)		May-August at minimum	Found in still to swift water, small to large rivers, sand and gravel, 2.5 to 152 cm in depth
Texas Fawnsfoot (Truncilla macrodon)	?	3 (TWAP-SC)		unknown	unknown
Tapered Pondhorn (Uniomerus declivis)	X			May-June at minimum	clay bottom lakes, intermittent streams; drought tolerant
Pondhorn (Uniomerus tetralasmus)	X		Golden shiner	April-August at minimum	mud bottom lakes, rivers and streams; drought tolerant
Little Spectaclecase (Villosa lienosa)	X			unknown	creeks, rivers and reservoirs
Giant Floater (Pyganodon grandis = Anodonta grandis)	X		Alligator gar, longnose gar, skipjack herring, gizzard shad, common carp, redfin shiner, golden shiner, creek chub, yellow bullhead, brook silverside, green sunfish, longear sunfish, bluegill sunfish, largemouth bass, black crappie, white crappie, freshwater drum	August to May	Mud bottom, 0.3-1.5 m deep, current 0-57.9 cm/s, often common in no flow
Paper Pondshell (Utterbackia imbecillis = Anodonta imbecillis)	X		Green sunfish, creek chub, western mosquitofish, largemouth bass, warmouth sunfish, bluegill sunfish, dollar sunfish	Year round	Variety of substrate, most common in silt, common in impounded water
White Heelsplitter (Lasmigona complanata)	X		Common carp, green sunfish, largemouth bass, white crappie	Sept-May	large rivers and streams, mud, mud gravel; pollution tolerant
Fragile Papershell (Leptodea fragilis)	X		Freshwater drum	Year round	Wide range of sediment, depths and flows, pollution tolerant
Texas Heelsplitter (Potamilus amphichaenus)	X	1 (TWAP-SC)		July at minimum	Sand and mud, slow water and reservoir
Pink Papershell (Potamilus ohiensis)	X		Freshwater drum, white crappie	April-September	Found mostly in flowing waters, various substrate, 2.5 to 14.2 cm depth, maybe tolerant to environmental stress
Texas Pigtoe (Fusconaia askewi)	X	1,2 (TWAP-SC)		July at minimum	Rivers with mixed mud, sand and gravel
Wabash Pigtoe (Fusconaia flava)	X		Bluegill sunfish, white crappie, black crappie	May-August	especially intolerant of changing stream environments,
Triangle Pigtoe (Fusconaia lananensis)		1		July at minimum	Mixed mud and gravel
Sothern Hickorynut (Obovaria jacksoniana)	X	3 (TWAP-SC)		October at minimum	gravel, creeks and rivers with moderate flow

Table 20. Continued.

Species	Trinity	Status	Known Hosts		Stressors: Notes
Threehorn Wartyback (Obliquaria reflexa)	X			June-August	Various substrate, medium to large rivers, depths 2.5 cm to 1.2 m in standing water, can tolerate impoundment
Louisiana Pigtoe (Pleurobema riddellii)	X	1 (TWAP-SC)		unknown	Streams
Southern Mapleleaf (Quadrula apiculata)	X			May-August	Wide range of sediment, depths,and waterbodies, very shallow to 4.6 meters
Western Pimpleback (Quadrula mortoni)	X			July-August minimum	rivers, streams and reservoirs, 1 to 3 m deep
Gulf Mapleleaf (Quadrula nobilis)	X			no data collected	no data collected
Deertoe (Truncilla truncate)	X		Freshwater drum	May-July	swift water, various substrate, 2.5 to 152 cm deep, flows of 457 cm/s, small to large rivers
Threeridge (Amblema plicata)	X		White bass, green sunfish, bluegill sunfish, warmouth sunfish, white crappie, black crappie, largemouth bass, channel catfish, flathead catfish	June-August	various substrates; drought tolerant, water quality tolerant, depth 2.5 cm to 1.5 m; velocities from 0 to 45.7 cm/s
Rock Pocketbook (Arcidens confragosus)	X	(TWAP-SC)	American eel, gizzard shad, white crappie, freshwater drum, channel catfish	Sept-June	Various substrates, flows 6 cm/s to swift, depths 10 to 107 cm; medium to large rivers
Washboard (Megalonaias nervosa)	X		Bowfin, gizzard shad, skipjack herring, American eel, black bullhead, channel catfish, flathead catfish, tadpole madtom, white bass, bluegill sunfish, largemouth bass, white crappie, black crappie, freshwater drum	Sept-Feb and April-May	large, low velocity rivers, mud or gravel, 0.3 to 22.4 meters deep
Bankclimber (Plectomerus dombevanus)	X			July	ditches, lowland rivers, various substrates, moderate to sluggish currents
Pistolgrip (Tritogonia verrucosa)	X				typical of oxygen rich riffles and runs
Round Pearlyshell (Glebula rotundata)	X			March-October	slow moving bayous, can occur In estuaries at low salinities,
Sandbank Pocketbook (Lampsilis satura)	X	1 (TWAP-SC)		unknown	small to large rivers, gravel and sand bottoms, swift currents 6.1 to 6.5 m depths
Bleufer (Potamilus purpuratus)	X		Freshwater drum	Potentially year round	Deep water streams or quiet pools with mud bottoms, large and small reservoirs or streams and rives with slow to moderate current, mud or gravel 0.5 to 3.0 m.
Louisiana Fatmucket (Lampsilis hydiana)	X		Longear sunfish (possible)	May to August at minimum	Various substrate, low flow or backwater areas; rivers, streams and reservoirs
Yellow Sandshell (Lampsilis teres)	X		Longnose gar, alligator gar, green sunfish, orangespotted sunfish, largemouth bass, black crappie, white crappie, warmouth sunfish	April-November	intolerant of drought and dewatering; actively follow flood flow onto land, then retreat back as flows return to channel; various substrates, warm water and high
Pond Mussel (Ligumia subrostrata)	X			June-August at minimum	various substrates and flows; 5.1 to 106.7 cm deep, shallow ponds, oxbox, sloughs and streams
Crustacean: Macrobrachium ohione (Ohio shrimp)	X			March to August	inhabits main stem rivers; migratory species

X = Recent Occurrences (within last 30 years)
O = Historical Occurrences (>30 years old)
? = Unknown if population still exists
Status:
TWAP-SC = Species of Concern, TPWD Texas Wildlife Action Plan 2005
1 = State Rank (S1) – Critically imperiled, extremely rare, very vulnerable to extirpation, 5 or fewer occurrences
2 = State Rank (S2) – Imperiled in state, very rare, vulnerable to extirpation, 6 to 20 occurrences
3 = Proposed for Federal Listing

Table 21 List of invertebrate species on the San Jacinto River. (Espey Consultants Inc. 2009)

Scientific Name	Common Name
Unionidae	
Amblema plicata	threeridge
Anodonta suborbiculata	flat floater
Arkansia wheeleri	Ouachita rock-pocketbook
Fusconaia lananensis	triangle pigtoe
Glebula rotundata	round pearlshell
Lampsilis bracteata	Texas fatmucket
Lampsilis hydiana	Louisiana fatmucket
Lasmigona complanata	white heelsplitter
Leptodea fragilis	fragile papershell
Ligumia subrostrata	pond mussel
Megalonaias nervosa	washboard
Obliquaria reflexa	threehorn wartyback
Obovaria jacksoniana	southern hickorynut
Pleurobema riddellii	Louisiana pigtoe)
Popenaias popeii	Texas hornshell
Potamilus amphichaenus	Texas heelsplitter
Potamilus metnecktayi	Salina mucket
Potamilus ohiensis	pink papershell
Potamilus purpuratus	bleufer
Pyganodon grandis	giant floater
Quadrula aurea (golden orb)	golden orb
Quadrula couchiana	Rio Grande monkeyface
Quadrula houstonensis	smooth pimpleback
Quadrula mortoni	western pimpleback
Quadrula nobilis	gulf mapleleaf
Quadrula nodulata	wartyback
Quadrula petrina	Texas pimpleback
Quadrula pustulosa	pimpleback
Quincuncina mitchelli	false spike
Strophitus undulatus	creeper
Toxolasma parvus	lilliput
Toxolasma texasiensis	Texas lilliput
Truncilla cognata	Mexican fawnsfoot
Truncilla macrodon	Texas fawnsfoot
Truncilla truncata	deertoe
Uniomerus declivis	tapered pondhorn
Uniomerus tetralasmus	pondhorn
Utterbackia imbecillis	paper pondshell
Arcidens confragosus	rock pocketbook
Tritogonia verrucosa	pistolgrip
Truncilla donaciformis	fawnsfoot
Villosa lienosa	little spectaclecase
Lampsilis satura	sandbank pocketbook
Fusconaia askewi	Texas pigtoe
Fusconaia flava	Wabash pigtoe
Plectomerus dombevanus	mudskipper, bankclimber
Lampsilis teres	yellow sandshell
Quadrula apiculata	southern mapleleaf
Uniomerus sp.	
Corbiculidae	
Corbicula sp	
Sphaeriidae	
Sphaerium fluminea.	
Sphaerium sp.	
INVERTEBRATE	
Macrobrachium ohione	Ohio shrimp

Most studies were conducted during higher flow periods and/or limited flow/velocity data was collected. In addition, these studies noted the presence of significant point source loads that increased base flows and biochemical oxygen demand in the receiving water. The focus of these early studies, especially in the Trinity River was to evaluate changes in dissolved oxygen and in-situ toxicity in response to effects of enhanced wastewater treatment on in-situ toxicity and hypoxia on aquatic communities. However, it may be possible to construct some relationships between observed flow and measured stream velocity, depth, and habitat use at study sites near USGS priority gage sites. Several studies did collect minimal habitat data (Raymon 1989; Kleinsasser and Linam 1989). In general, the area below Dallas exhibited very low catches and species diversity during the period up to the 1970s (TPWD 1974). After implementation and improvement of wastewater treatment in the Dallas Fort Worth area, catch rates improved and diversity increased (Kleinsasser and LInam 1989; Kiesling and Flowers 2002). The period from the 1980s to early 1990s is characterized by frequent Summer fish kills caused by frequent hypoxic and anoxic events downstream of Dallas during high flow events. Periodic anoxia caused by the "black rise" would kill fish and invertebrates that had repopulated hostile environments which previously had levels of oxygen too low to support most fish. A similar pattern of fish kills occurred in the lower portions of Buffalo Bayou in the San Jacinto River basin as water quality conditions improved during the same period due to improved wastewater treatment (Chambers and Sparks 1959; Crocker et al. 1991; Seiler et al. 1991; Guillen 1993a, 1993b, and 1995).

Espey Consultants Inc. (2009) reviewed and summarized much of the biological instream data for the San Jacinto River basin with a major focus in the upper non-tidal reaches. Much of what is presented below is extracted verbatim from that report. Various companion reports describe data collection and site characterization leading to a waste load allocation study for the West Fork San Jacinto River between Lake Conroe and the headwaters of Lake Houston (TWC 1986). Stream substrate was fine sand throughout the reach and flow steadily increased downstream as a result of significant effluent discharges (TDWR 1981, Twidwell 1983). Stream velocities ranged from 0.5 feet per second (fps) in the upper reaches to 1 fps in the middle reaches under normal flow conditions throughout the reach with flow ranging from 7 cfs to 100 cfs (TDWR 1981). Similar velocity patterns (0.34 fps to 0.45 fps) were observed for lower flow conditions (7 cfs to 47 cfs) during a later study (Twidwell 1983). Macrobenthic data indicated little utilization of predominantly sandy substrate conditions; however, areas with gravelly riffles suitable for sampling macrobenthos indicated high diversity indicative of clean water conditions during December 1979 (TDWR 1981, Davis and Buzan 1981).

During 1984, the West Fork San Jacinto River downstream of Lake Conroe to the headwaters of Lake Houston was surveyed and assessed for water quality, fish habitat, fish communities, recreational fishing and harvest. Changes to management practices for the period 1985-1989 were not recommended because no pollution problems were found, fish habitat appeared to be adequate for the existing resource, and the fish community appeared to be in relatively good condition (TPWD 1986). The total species collected in this reach was 48, whereas a study completed in 1967-68 that included this reach and smaller tributaries collected 59 species of fish (TPWD 1986). The San Jacinto River from Lake Houston downstream to the Houston Ship

Channel was sampled in February 1971 and August 1971, following a period where no releases had been made from Lake Houston since November 1970 (TPWD 1972). Freshwater flow consisted of small amounts of dam seepage and flow from the tributary, Gum Gully. Low dissolved oxygen (1.2 – 4 mg/L) was observed near the confluence with the ship channel during February 1971. Low DO (1.2 mg/L) and high chlorides (185 mg/L) were observed in August associated with a fish kill at Station 3 near the Houston Ship Channel. All other areas indicated conditions suitable for the fish population (TPWD 1972). Descriptions from 1997-1998 field studies throughout the basin characterize the water courses as meandering channels with common riffles/pool near bends and runs in straight sections (Moring 2001). Velocity, depth, substrate type and distribution data were measured in the field during the same study. Based upon a multivariate structural and riparian channel and environmental (RCE) indices and biotic indices developed from field data, seven least-impacted reference reaches were identified: Big Creek (Trinity River basin tributary with similar characteristics to SJR basin watercourses), Branch Creek, three reaches on the East Fork San Jacinto River, Luce Bayou and Caney Creek near Willis (Moring 2001). Bayou reaches with urbanized watersheds and little riparian or forest cover exhibited lower (less desirable) stream-habitat integrity and biotic indices.

Even fewer biological studies have been conducted in tidal and non-tidal coastal watersheds within the immediate Galveston Bay coastal watershed (Luedke 1994; Guillen 1996; Quigg et. al. 2009, Robinson and Culbertson 2005; Ramirez 2008). Recent studies in these areas document a heavily modified watershed with numerous channelized waterways, and in some areas, high numbers of invasive species. Despite this, these areas have in the past and can in the future support numerous priority species including various species of gar, spotted bass and longear sunfish. Many of these waterbodies in addition to supporting freshwater communities also provide critical habitat for juvenile and adult marine fishes in their lower reaches (Guillen 1996). Several freshwater species are commonly found in these coastal streams including various sunfish species, largemouth bass, black crappie, spotted gar, and blue catfish. Recently during 2008, an American eel was captured near downtown Houston in White Oak Bayou (Guillen pers. comm.).

Although specific instream flow studies have not 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., studies summarized in BIO-WEST 2009a). No species of fishes, mussels, or wetland/floodplain plants appears to have been extirpated from the basin due to reductions in flows during droughts. However the subsistence flows identified in these environmental flow regimes have not occurred in decades. There has actually been an increasing trend in base flows in the Trinity River below Dallas and in the urban bayous of San Jacinto River of having higher low flows, primarily due to wastewater effluent dominated streams and decreased land permeability (Olivera and DeFee 2007). These patterns can be expected in any watershed undergoing rapid urbanization (Konrad and Booth 2005).

Reduction and possible elimination of naturally reproducing populations of paddlefish (*Polyodon spathula*) in the two mainstem rivers was likely 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). Based on our historical review paddlefish have only been collected or observed in the mainstem Trinity River occasionally between the 1930s and 2009 (Pitman 1991). They have previously been observed as far upstream as the City of Trinidad (Pitman 1991). However, a total of 313,835 juveniles were stocked in Lake Livingston during a 10 year period (1990-1999) (Betsill 1999; Henson and Webb 2004). Many of these fish migrated downstream through the dam to the lower Trinity River (Blackwell et al. 1995). (Betsill 1999) concluded that it is unlikely that paddlefish stockings in the Trinity successfully established self-sustaining paddlefish populations in the river reaches upstream of the lowermost dams of these rivers. However he concluded that TPWD biologists have received reports of incidental catches of paddlefish by anglers in the upstream reaches since 1991 whereas prior to stocking, paddlefish had not been reported in these areas for 20-50 years (Pitman 1991). Recently, adult paddlefish have been sighted in the lower Trinity River below Lake Livingston during early 2009 by TPWD biologists conducting fisheries surveys (J. Botros pers. comm.). In addition, fishery surveys conducted below Lake Livingston during December 2007 through August 2008 yielded adult paddlefish downstream of the dam (Paul C. Rizzo and Associates, Inc. 2009).

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 recommendations appear below.

2.2.5.2. Subsistence Flows

The primary objectives of subsistence flow are to maintain water quality criteria for aquatic organisms and a minimum flow with resultant longitudinal connectivity. Secondary objectives include providing life cycle cues based on naturally occurring periods of low flow or providing habitat that ensures local populations are able to recolonize the river system once normal, base flow rates return (NRC 2005; TCEQ et al. 2008). 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 and Richter et al. 2006, and cited references therein). Subsistence flows provide minimal yet sufficient habitat of sufficient quality such that populations can recover upon return of base flow conditions. Thus, subsistence flow conditions are by definition infrequent events.

The concept of subsistence flow represents the lower threshold for 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 (Guillen et al. 2009; Espey Consultants, Inc. 2009). Water quality can become limiting to aquatic life during periods of severe drought, but we compiled little evidence that this is a significant problem in the Trinity and San Jacinto River system. The majority of anoxia, hypoxia (<2 mg/l) and low dissolved oxygen levels occurred during the 1970s and 1980s during low flows, which usually were at least 3 to 4 times greater than the calculated subsistence flows (Guillen et al. 2009). Espey Consultants, Inc. (2009) found that dissolved oxygen levels did not appear to be related to flow and were more affected by the amount of wastewater loading. In general, little water quality data exist for flows in the subsistence flow ranges generated from the HEFR hydrological analysis. Water quality modeling conducted by Alan Plummer and Associates, Inc. indicated that water quality criteria for dissolved oxygen would be met at the identified subsistence flows.

During subsistence flow conditions, larger fishes (e.g., flathead, blue and channel catfish, smallmouth buffalo, gar, freshwater drum, largemouth and spotted bass) seek refuge in the deeper and larger pools of the main channel and side channels of the lower reaches. During these periods, some floodplain aquatic habitats may dry up completely, but deeper oxbows may support populations of bass, gars, sunfishes, and small fishes (e.g., various minnows and top minnows). Under subsistence flow conditions tributary streams may cease flowing and aquatic organisms in those streams may be forced into isolated pools. During these periods fishes can be concentrated at densities in reduced volumes of water and suitable habitat with reduced flow and connectivity. Stress is generally increased via several mechanisms including increased disease/parasitism (Guillen, 2004), lower oxygen levels from reduced physical reaeration and high levels of biological respiration, exposure to suboptimal temperatures(both too hot in the summer and too cold in the winter), and increased predation. As a result, some local populations of selected species of fish can be decimated. Very few fish species will attempt to reproduce under these conditions (e.g. western mosquitofish), but even for these species with relatively high and continuous reproductive effort, recruitment success is very low under crowded conditions.

In the future, river specific habitat area-streamflow relationships and the associated modeling should be evaluated to construct new recommendations and refinements to hydrologically derived subsistence flows (Bovee et al. 1998). This type of physical habitat simulation analysis was performed for the lower Colorado River in Texas (BIO-WEST 2008a). The goal in refining subsistence flow recommendations 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 San Jacinto or Trinity River basins to inform our recommendations for subsistence flows (TPWD 1974; Kleinsasser and Linam 1989; Kiesling and Flowers 2002; Davis and Bastian 1988; Moring 1998; Moring 2001; Parsons 2003; Luedke, 1994; Moring et al. 1998; Moring 2001).

2.2.5.3. Base Flows

Ecological base flows represent the part of the flow regime between subsistence flows and high flow pulses. These flows are higher than subsistence flows, occur commonly throughout the year, and are minimally influenced by recent rainfall events. Three categories of base flow-dry, average and wet- are needed to support the aquatic species inhabiting these rivers. The key point regarding base flows is that different species have different habitat needs which are "best" supported at different flows. Additionally different river reaches have different amounts of habitat that may be available at base dry, average, and wet conditions. A constant base flow would tend to support a certain guild of species at the expense of others.

Many researchers have identified the ecological importance of flow variability (see, e.g., Lytle and Poff, 2004 and Acreman and Dunbar, 2004 and citations therein). Many different approaches have been employed to try to maintain some level of flow variability, including base flow variability. For example, the percent of flow approach (used in Florida; Locke et al., 2008) and hydrologic statistics as used in IHA and HAT are both methods that attempt to maintain some flow variability across the range of natural base flows. In the current proposal, the terminology of "wet", "average", and "dry' is used as a convenience to identify three levels of base flows, each of which has an associated attainment frequency and provides varying quantities of suitable habitat for different species guilds. This proposal is based on the expectation that three levels of base flows are more suitable for use in Texas riverine management than other approaches. As is recognized, site-specific data describing the exact flows needed to provide specific habitat amounts throughout the Trinity and San Jacinto basins are lacking. However, scientific experience suggests that the Trinity and San Jacinto Rivers will behave similarly to other rivers, namely, that varying flow levels provide varying habitats.

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. 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. Extensive and detailed habitat-hydrology research and modeling was performed recently for the lower Colorado River in Texas (BIO-WEST 2008), and many of the fish species in that system are shared by the Trinity and San Jacinto rivers. According to 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.

To guide inferences about recommended base flows during dry, average, and wet years, we examined the findings from the extensive research conducted by BIO-WEST (2008). 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 during dry-year conditions and others will have less (Figure 6). The relative availability of habitat types generally undergoes a shift with a transition to average and wet year conditions (BIO-WEST 2008). 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. This study provides a strong conceptual framework for inferring the recommendation for inter-annual variation in base flow levels for the Trinity and San Jacinto Rivers since many fish species including our focal species are shared by the Colorado River.

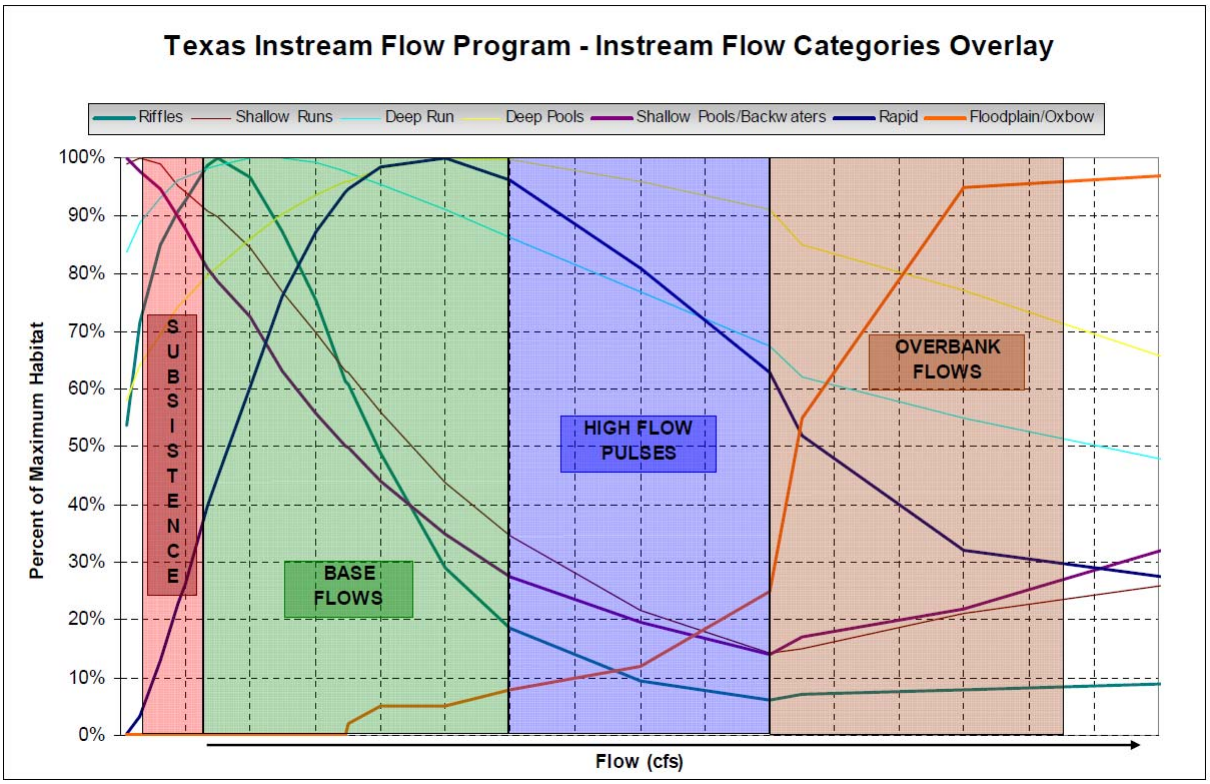

Figure 6 Habitat availability curves for seven fish habitat guilds in the lower Colorado River, Texas derived from recent instream flows research by BIO-WEST (2008a).

Ecological dry base flows:

Drier than normal periods create periods of prolonged and relatively low base flow, especially during the Summer-Fall. These periods can be beneficial for many species in terms of feeding interactions. Predatory fishes, birds, and mammals 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). More riffle, shallow run, and shallow pool habitat is available due to relatively lower water levels and velocities. These conditions are used by blacktail shiners and juvenile flathead catfish in the riffles and bluegill and longear sunfish, largemouth bass, and longnose gar in the pools. These periods allow these species to thrive, but conditions are not extreme enough to eliminate other species from the fish community. For example, the shallow pools are poor habitat for freshwater drum and blue catfish but some will continue to survive under these conditions. Base flow conditions also are important for survival of riparian plants that obtain groundwater from the hyporrheic zone during periods of low rainfall (Rypel et al. 2009; Naiman et al. 2005). Terrestrial herbaceous vegetation colonizes portions of the river bank and this vegetation may provide shelter for invertebrates and juvenile fish when flows rise, spawning habitat for species like gar that spawn over vegetation, and contribute particulate organic carbon to the food chain when submerged. Periods of base flow (summer-fall) when the riparian and bottomland plant community is not inundated allows the plants to grow without physiological stress. Under base flow conditions, isolated water bodies such as oxbows concentrate prey species utilized by fish and invertebrate dependent birds like heron and egrets; mammals, like otters; and reptiles like snapping turtles and watersnakes. Areas of concentrated prey help young of the year bird, mammal, and reptiles build reserves for the coming winter period when prey will be less abundant.

Ecological Average Base Flows:

Average flow conditions will create ecologically-based flows that are typical of normal flow conditions. These flows occur during years or periods which are neither typically dry nor wet. The area of riffles, shallow runs and pools, decreases and is replaced by increasing areas of deeper runs and pools. Deeper runs and pools are better habitat for gizzard and threadfin shad and inland silversides, all important forage fish for fish and other vertebrate predators. Deeper pools and runs increase habitat for adult blue, channel, and flathead catfish that tend to hide in deeper pools and runs during the day. Habitat for smallmouth buffalo that prefer moderate currents over muddy bottoms increases. Slight increases in inundated backwaters provides habitat for red shiners, another important forage fish. During these years, some of the minnows and sunfish may have less habitat and be more exposed to larger river predators. There are more hydrologic connections with tributaries and backwaters under these flow conditions and these connections increase habitat available to fish that enter these habitats from the mainstem river.

Ecological Wet Base Flows:

These flows occur during wetter than normal years or periods. The area of rapids, deep pools and runs, and access to backwaters and tributaries increases. Spotted bass, a typical riverine fish, thrives in the faster currents. Deeper habitats are enhanced for freshwater drum and

smallmouth buffalo. Alligator gar, largemouth bass, and some sunfish will move into the backwaters and tributaries as access increases to those areas.

2.2.5.4. High Flow Pulses

High flow pulses shape physical habitat of the river channel, transport sediments, flush silt and fine particulate matter, and provide other geomorphic and water quality functions. 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, Hughes and Rood, 2003, Rood, et. al. 2003), and much of this evidence was summarized in the SAC Biological Overlays Guidance Document (SAC 2009-05). 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 magnitude and duration of high flow pulses can also be double checked with known life history requirements. Spawning by at least two common species, gizzard shad and *Macrobrachium (Reimer et al. 1974)*, is triggered by rising flows. Paddlefish spawning is triggered by rising flow during the winter and adult American eel initiate their downstream migration to the ocean during rises in flow. An example, well documented in Mosier and Ray (1992) and BIO-WEST (2008), 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 recommendations in other river systems.

High pulse flows contribute to germination and transport of plant seeds for both riparian and bottomland species (Rood, et. al. 2003). These pulse flows which commonly occur in the winter are also responsible for maintaining the species composition of many forests by fostering water tolerant species (Stallins, et. al. 2009). This repeated flooding of floodplain waters repopulates them with fish and aquatic invertebrates which are important prey items for non-fish vertebrates. These pulse flows transport terrestrial vegetation into the river, contributing increased concentrations of particulate organic carbon to the food chain.

The evaluation of the benefits to the biota of high pulses must focus on two components: 1) timing and duration of the pulse in relation to the requirements for spawning cues, feeding opportunities of juveniles, etc., and 2) how the rise in water level interacts with local landscape topography/geomorphology to connect the stream with and enhance marginal and off-channel aquatic habitats. In evaluating the spatial aspects of high flow pulses, various kinds of maps are extremely useful (topographic, digital elevation, wetlands, vegetation categories, etc.) The Trinity River at Oakwood experienced 493 high pulse flow events greater than 2,000 cfs over the period from 1924-1964. Similarly, the Trinity River at Romayor experienced 410 high pulse flow events greater than 4,000 cfs from 1924-1968.

Tributaries: Although lateral connectivity to off-channel floodplain habitats is relatively less important in smaller headwaters and tributaries than larger mainstem reaches downstream, it is still critical, from an ecological standpoint, to have periodic high flow pulses allowing organisms to occupy marginal habitats for feeding and/or reproduction in 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).

Flathead catfish (juveniles), and dusky darter, 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. While the largest populations reside in reservoirs during other times of the year, a few individuals also inhabit larger pools of mainstem rivers during non-reproductive periods. 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 abundant 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, blue sucker, and other species characteristic of large mainstem rivers have major requirements for high flow pulses. Paddlefish spawning is episodic during early spring, and eggs are scattered and drift some distance to settle into habitats where the larvae develop and then feed on zooplankton. Alligator gar spawn over submerged vegetation or woody debris. 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 feed and seek refuge from predation in lentic backwaters. 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 re-connect off-channel habitats with the stream so 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 that

elevate flows above ecological base flows are most beneficial for spotted bass and other sunfishes when they last from 1 to 3 weeks because this provides these fishes sufficient time to construct a nest, spawn, and guard the eggs and larvae 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 ghost shiner and emerald shiner are minnows characteristic of large mainstem rivers. 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, and 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.

2.2.5.5. Overbanking Flows

As discussed in the SAC Biological Overlays Guidance Document, overbanking flows move coarse woody debris and sediments, scour deep pools, deposit sediments to form sandbanks, and transport aquatic organisms to and from ephemeral aquatic floodplain habitats. The inundation of floodplains allows seeds of bottomland hardwood tree species to disperse or germinate following flood subsidence. Species such as bald cypress 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). As with pulse flows, overbank flows transport terrestrial vegetation into the river, contributing increased concentrations of particulate organic carbon to the food chain (Naiman et al. 2005).

In addition to supporting major geomorphic processes (SAC 2009-05X), overbank flows connect the stream and 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). 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 occurrence. Above-normal precipitation resulting from hurricanes, tropical storms, and stalled frontal systems produces floods of variable magnitude and duration. 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 then into wetlands at slightly higher elevations as flows increase. 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), adults and especially juveniles commonly move onto flooded plains to feed opportunistically on insects, amphibians, and other fish that also exploit temporarily abundant food resources (Robertson et al. 2008). Many small fishes also use temporarily flooded riparian habitats to feed on terrestrial and soil invertebrates (Kwack 1988). In some cases, fishes may become stranded and perish when floodwaters 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.

2.2.6. Use of Hydrologic Data in the Development of Instream Flow Recommendations

The recommended best science approach of the National Academy of Science (NAS) and Instream Flow Council (IFC) guidance is that the natural hydrograph (inter-annual and intra-annual seasonal) be mimicked as closely as possible when making environmental flow recommendations (NAS 2005, Annear et al. 2004; Locke et al. 2008). That hydrograph is actually a large series of distributions, that are best envisioned visually. However, since these recommendations need to be communicated in quantitative terms that summarize these distributions they are converted into a list of "parameters" that can be used to summarize and describe these continuous distributions into regulatory and public policy recommendations and decisions points. As a result, one argument made against the use of IHA/HEFR is that many descriptive metrics and potential future compliance points are generated. Again, part of the reason that this occurs is that we are trying to describe what is basically a very complex continuous distribution (of flows), with relatively few descriptive points. This complex distribution is due to long-term, annual, and seasonal fluctuations in flow. Some are fairly predictable, such as seasonal trends in precipitation. However, some are not, such as long-term trends or patterns (droughts, floods etc). Due to the temporal trends in precipitation that occur and influence the flows and resulting response to those flows by biota and geomorphology, we can broadly group years into categories based on precipitation (e.g. wet, average, dry etc). These groupings recognize that within these broad categories we continue to have seasonal patterns that incorporate subsistence, pulse, base, and overbank flows. If these distributions were simple and lacked significant ecological functions associated with different parts of the distributions, we could describe them with very few points. A good example is a static distribution of many points of one variable such as a normal (bell-shaped) curve that requires only a few parameters, the mean and standard deviation to describe its shape and position (Figure 7). If you are however, trying to relate the relationship of one predictive variable with one response variable that exhibits a bell shape pattern, you now move up to a quadratic equation $Y= a +bX = cX^2$ (Figure 8). You have now moved up to several coefficients that can be used to describe this distribution. You could add additional coefficients in order to describe even more complex distributions (Figure 9). Finally in the case of describing seasonal/time varying distributions you would need to construct multiple distributions, each with their own coefficients to describe their patterns or shapes. Hence there is a need for multiple parameters (subsistence, dry base, average base etc) to describe the hydrology of the river and how it may deviate from naturalized flows.

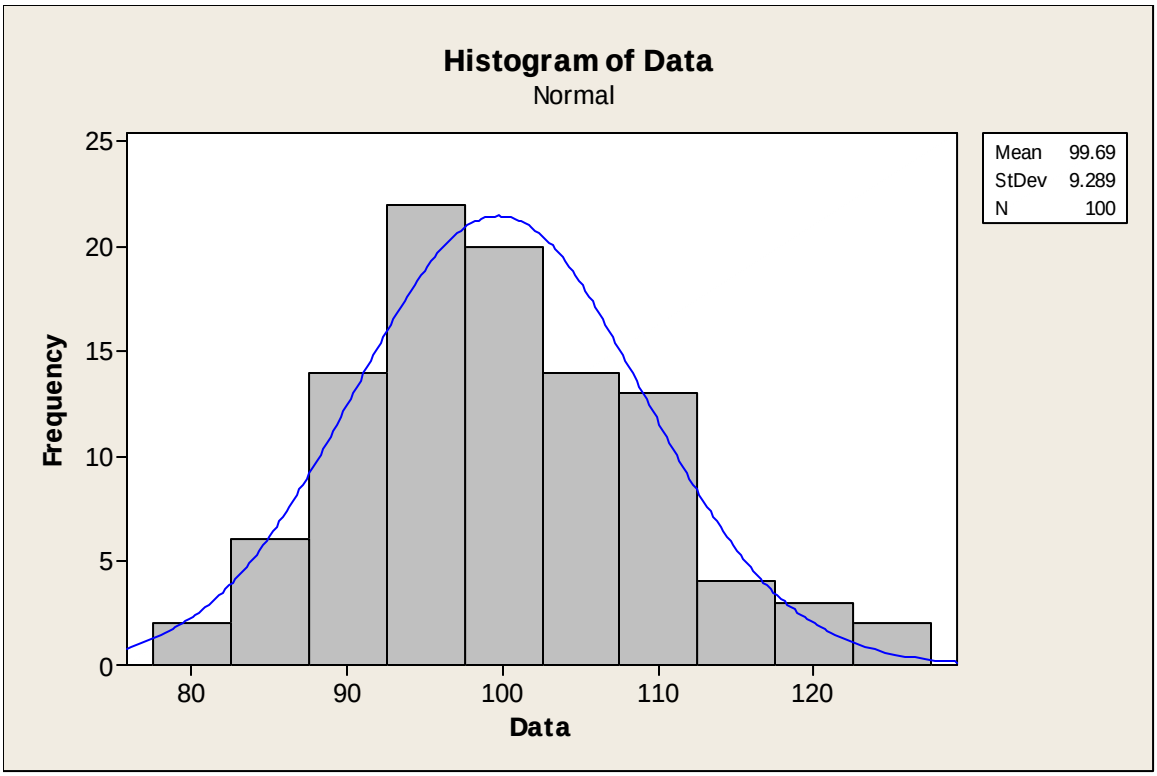

Figure 7 Simulated data (n=100 points) generated from a hypothetical mean of 100 and standard deviation of 10. Actual calculated mean from data reported in legend.

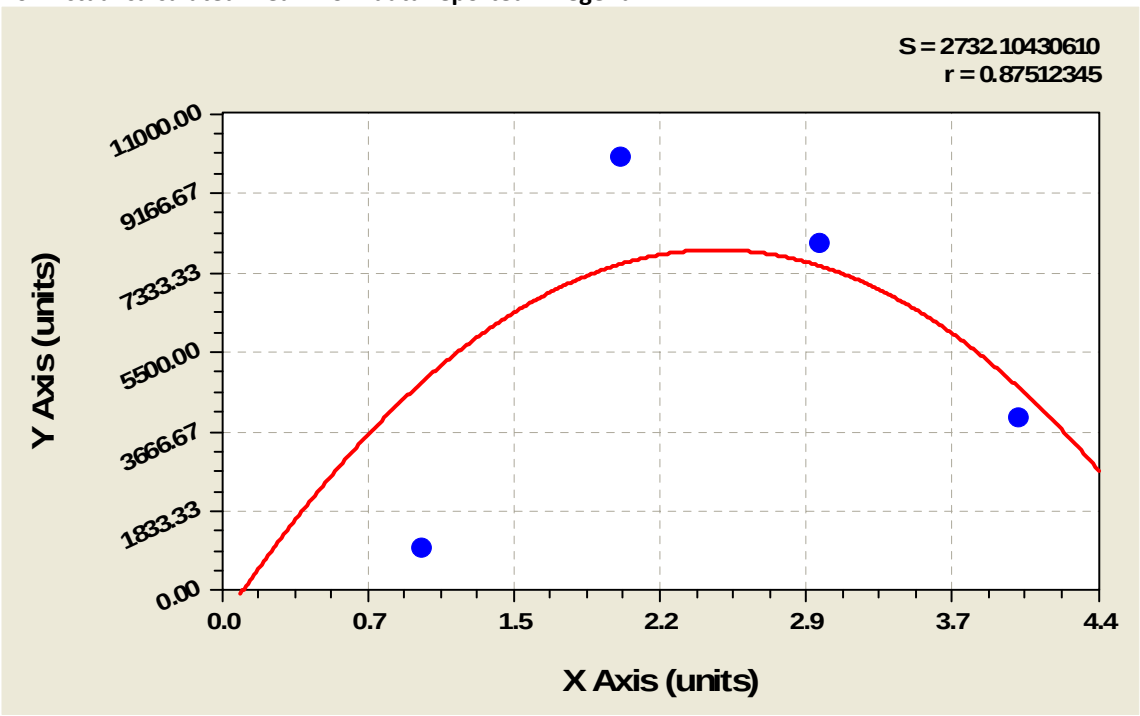

Figure 8 Relationship of X (predictive) and Y (response) variable, assuming a bell shaped curvilinear relationship. Distributions fit using quadratic equation (see text).

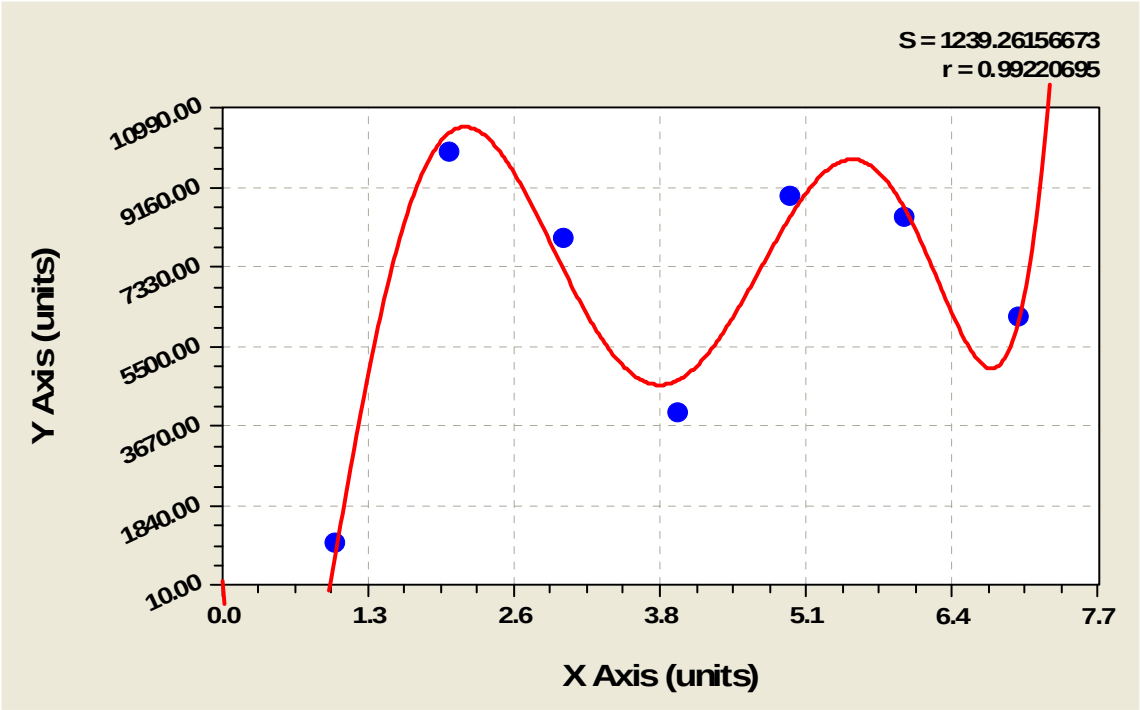

Figure 9 Relationship of X (predictive) and Y (response) variable, assuming a more complex relationship. Distributions fit using 6th degree polynomial equation. Y = a + bx + cx2 + dx3 + ex4 + fx5 + gx6.

Over the last 30 years river biologists and geologists have learned quite a bit about the functioning of rivers and the influence of flow regime on organisms and geomorphology (NAS 1992; Gordon et al. 2004; Dyson et al. 2003; NAS 2005; Thorp et al. 2006; Locke et al. 2008). Through extensive research river scientists and biologists have developed a "natural flow regime paradigm" that states that, in general, the ecological integrity of river ecosystems depends on their natural dynamic character. River flow, the master variable, influences biota, water quality and geomorphology of the rivers (Poff et al. 1997).

The flow regime is regarded by many aquatic ecologists to be the key driver of river and floodplain wetland ecosystems. Bunn and Arthington (2002) conducted a literature review focused around four key principles to highlight the important mechanisms that link hydrology and aquatic biodiversity and to illustrate the consequent impacts of altered flow regimes. These principles included 1) flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic composition; 2) aquatic species have evolved life history strategies primarily in direct response to the natural flow regimes; 3) maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species; and 4) the invasion and success of exotic and introduced species in rivers is facilitated by the alteration of flow regimes. They documented various degrees of impacts associated with altered ecology (Table 22-Table 25)

Table 22 Summary of biotic responses to altered flow regimes in relation to flow induced changes in habitat (principle 1). From: Bunn and Arthington (2002)

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

Table 23 Summary of life history responses to altered flow regimes (principle 2). From Bunn and Arthington (2002).

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

Table 24 Summary of biotic responses to loss of longitudinal or lateral connectivity (principle 3). From Bunn and Arthington (2002).

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

Table 25 Summary of biotic responses to altered flow regimes in relation to invasion and success of exotic and introduced species (principle 4).

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

Poff and Zimmerman (2009) reviewed 165 papers published over the last four decades, with a focus on more recent papers. Their aim was to determine if general relationships could be drawn from disparate case studies in the literature that might inform environmental flows science and management. They found that macroinvertebrates showed mixed responses to changes in flow magnitude, with abundance and diversity both increasing and decreasing in response to elevated flows and to reduced flows. Fish abundance, diversity and demographic rates consistently declined in response to both elevated and reduced flow magnitude. Riparian vegetation metrics both increased and decreased in response to reduced peak flows, with increases reflecting mostly enhanced non-woody vegetative cover or encroachment into the stream channel. They concluded that their analyses do not support the use of the existing global literature to develop general, transferable quantitative relationships between flow alteration and ecological response; however, they do support the inference that flow alteration is associated with ecological change and that the risk of ecological change increases with increasing magnitude of flow alteration.

Organisms are dependent upon this variability to complete their life history. For example, increased flows (pulses) are needed to stimulate spawning runs and to transport eggs and larvae downstream. In addition pulses may mobilize fine sediments and facilitate downstream transport. Flow variability appears to be a universal factor that modifies and controls the life history of many riverine organisms throughout the world including arctic, temperate and tropical rivers (Cushing et al. 2006). This variability occurs even in highly diverse stable fish communities that exist in tropical rainforests. For example, tropical rivers in South America

exhibit a range of annual maximum/minimum flow ratios of 5 to 35 (Cushing et al. 2006). Superimposed on this annual pattern is considerable daily variation in flow and water levels. So it appears that flow variability is the normal condition and may even be necessary for the functioning of diverse tropical and temperate fish communities.

Through extensive research we have gained a better understanding of the links between biological processes and aspects of flow variability with most progress being made on species of high conservation, recreational or commercial value. However, due to the complex nature of river communities and the low probability of ever being able to fully define the needs of the whole (often 100-1000s of species) biological community, the conservative alternative is to assume that the natural flow regime is the best indicator of environmental needs, since the whole community has adapted over long periods of time this regime. We compared IHA/HEFR output and recommended flows with biological data for focal target species in the Trinity and San Jacinto Rivers. Available organism and site specific biological and life history data did not contradict, and in general supported the IHA/HEFR generated recommended flow regime.

This approach and classification system, which has been adopted by the state of Texas, has been peer reviewed and endorsed by several scientific panels and organizations dealing with river restoration including the National Academy of Science and the Instream Flow Council (NAS 1992; NAS 2005; Locke et al 2008; Annear et al. 2004; TCEQ TPWD and TWDB 2008).

Therefore in addition to the statistical need for multiple parameters to describe the full range of flow regimes that rivers experience, there is also a need to try and mimic this variability as closely as possible for various practical and ecological reasons. For example, scaling environmental flows as a proportion of the natural flow maintains flow variability in a statistical sense. This approach has been advocated as “normative” flows in the literature (Locke et al. 2008). However, this approach fails to mimic natural flow variability at the scale of habitat hydraulics (temporal and spatial distribution of depth and velocity), because the channel morphology, which also controls the pattern of depth and velocity, remains unaltered (Gordon et al. 2004). Also the response of hydraulic, geomorphic and ecological characteristics and processes to changes in flow may often be non-linear and discontinuous. For example, half of the peak discharge will not move half of the sediment and half of overbank flow will not inundate half of the floodplain (Preforoff et al. 1997). It is important therefore when applying the flow variability paradigm to consider process thresholds as well as variability. The concept of thresholds is well known to fluvial geomorphologists, because the process of sediment mobilization and deposition operates at distinct thresholds.

The safest and simplest approach to insure that both natural variability and threshold conditions are restored or conserved is to mimic the natural flow pattern as closely as possible including variability patterns (wet, dry and average years, seasonal), and associated duration and magnitude of flows. This is done by using software such as IHA and HEFR that provides quantifiable endpoints that describe this distribution and recommends flow regimes that attempt to duplicate these endpoints as close as possible.

Olden and Poff (2003) reviewed 171 hydrologic indices from 420 sites across the USA and showed that the IHA method successfully characterizes all the major components of the flow regime. The results from their study showed that the IHA method adequately represented the majority of the variation explained by the entire population of 171 indices and thus captured the majority of the information available. Furthermore, the IHA analyses represent almost all of the major components of the flow regime, and therefore provide a good balance between objective selection of high information indices and accessibility in terms of computation.

Accounting for natural differences in flow variability among rivers, and understanding the importance of this for the protection of freshwater biodiversity and maintenance of goods and services that rivers provide, is a great challenge for water managers, river ecologists and scientists. Nevertheless, despite considerable progress in understanding how flow variability sustains river ecosystems, there is a growing temptation to ignore natural system complexity in favor of simplistic, static, environmental flow ''rules'' to resolve pressing river management issues (Arthington et al. 2006). The authors argue that such approaches are misguided and will ultimately contribute to further degradation of river ecosystems. In the absence of detailed empirical information of environmental flow requirements for rivers, they instead propose a generic approach that incorporates essential aspects of natural flow variability shared across particular classes of rivers that can be validated with empirical biological data and other information in a calibration process. They argue that this approach can bridge the gap between simple hydrological ''rules of thumb'' and more comprehensive environmental flow assessments and experimental flow restoration projects.

In summary, the use of IHA/HEFR is recommended by leading scientists in the field of river ecology as an approach that can be used to generate recommended interim ecologically relevant environmental flow regimes which can be subsequently monitored during implementation and revised as new site specific data (e.g. additional geology and biology) are collected and adaptive management is employed.

2.2.7. SAC identified decision points encountered when using hydrologic data to help define environmental flow recommendations

2.2.7.1. Number of Instream Flow Regime Components

This recommendation includes the six flow regime components included in the SAC guidance document and most other instream flow guidance documents developed nationally and internationally. These include subsistence flows, ecologically-derived dry, average, and wet base flows, high flow pulses and overbank flows. This recommendation includes a number of high flow pulse recommendations and ties these to variable flow conditions (dry, average and wet) but does not specifically subdivide them into large and small floods (as is done in the IHA software) or include a channel maintenance category between high flow pulses and overbank flows (as in the Lower Colorado River Authority – San Antonio Water System Water Project study). This flow regime concept is consistent with the current state of instream flow science as described in the NAS review of the TIFP (NRC 2005). The flow regime concept supersedes the existing default methodology employed in Texas (Lyons method) which relied on a single

minimum flow, which could vary by month. Regarding a single, minimum flow as derived from the Lyons method, the Science Advisory Committee on Water for Environmental Flows (SAC, 2004) stated, "It is generally agreed that such a flat-line flow regime cannot account for all of the important interrelationships between the streamflow, biology, and physiography along a particular stream reach." (SAC, 2004). The recent scientific literature further indicates the importance of variable flow regimes that are ecologically-based. The purposes of these flow regimes and the ecological rationale for these components is described in more detail in the biological overlay section. The general ecological functions of these flows are summarized in Table 26.

Table 26 Ecological Functions of Instream Flow Regime Components

Overbank Flows	Maintain riparian areas Provide lateral connectivity between the river channel and active floodplain
High Flow Pulses	Maintain important physical habitat features
	Longitudinal connectivity
	Spawning/Migratory Cues
Base Flows (cfs)	Ensure adequate habitat conditions for species dependent on High flow habitat conditions (Rapid and Deep Pool Guilds)
	Ensure adequate habitat conditions for species dependent on Moderate flow habitat conditions (Deep Run and Riffle Guilds)
	Ensure adequate habitat conditions for species dependent on Low flow habitat conditions (Shallow Run and Pool/Edge/Backwater Guilds)
Subsistence Flows (cfs)	Maintain water quality criteria, Providing life cycle cues, Providing refugia habitat

Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Winter			Spring			Summer			Fall		

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

2.2.7.2. Geographic Scope of Instream Flow Recommendations and Spatial Extent of Individual Instream Flow Recommendations

Recommendations derived from specific gage sites will apply to the river segments for which they had been formulated. Translation of individual recommendations to nearby segments may be a subject of the SB3-required workplan to be developed by the BBASC. Consistent with the Sabine Neches BBEST recommendation, it is the recommendation of the Trinity San Jacinto BBEST "that the TCEQ develop appropriate methods for interpolation of flow conditions applicable to future inter-adjacent permits and amendments from reference locations for which flow regimes supporting a sound ecological environment are established. Such methods should include, at a minimum, drainage area adjustments, but may also include consideration of springflow contributions, channel losses, aquifer recharge zones, soil cover complex, and other

factors as necessary and appropriate. It is our understanding that the TCEQ has initiated a research project focused on development of methods for geographic interpolation of flow regimes.

Philips (2008) describes geomorphic zones of the Trinity River from its confluence with the Elm Fork Trinity River downstream to Anahuac. One approach may be to apply the recommendations to the zones of the river described by Phillips (2008). Flow recommendations would represent the zone(s) which includes the gaging station from which the flow data were derived.

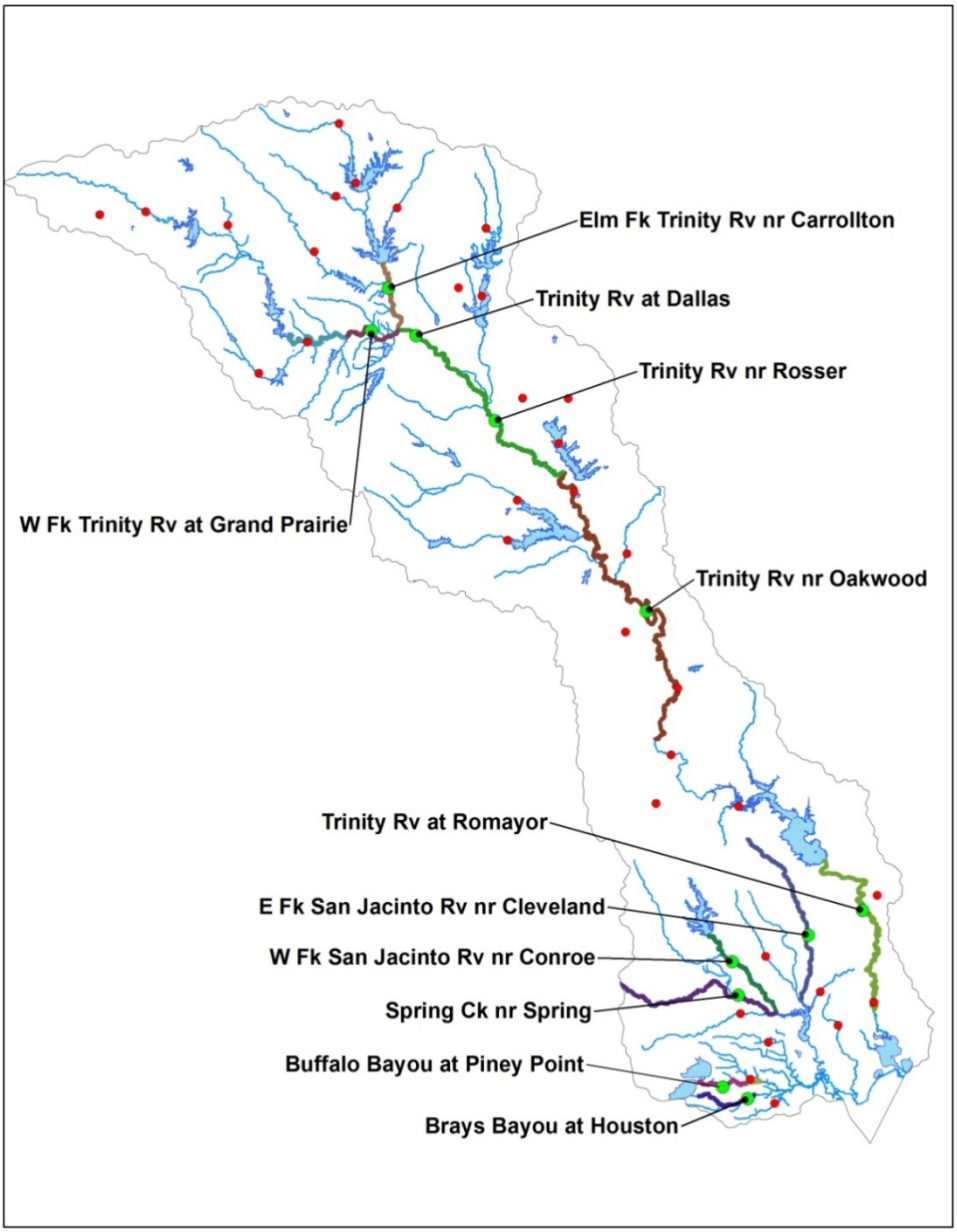

Figure 10 Map of gages with associated river segments designated by the Texas Commission on Environmental Quality (TCEQ)

Table 27 Trinity River geomorphic zones for application of flow recommendations (Phillips, 2008)

Zone(s)	Distance upstream of Anahuac (miles)	Length (miles)	Downstream Latitude	Downstream Longitude	TCEQ Segment	Description	Flow Gage
0	397		32.497	-96.501	0806 and 0822	Elm Fork and West Fork Trinity rivers upstream of their confluence	Elm Fork Trinity near Carrollton
1	393	4	32.467	-96.496	Upper reach of 0805	Upper Trinity River in Dallas downstream to SH34, Rosser	Trinity near Dallas
2-7	307	86	31.942	-96.017	Most of 0805 and upper reach of 0804	Trinity River from SH 34, Rosser, downstream to US 287 near Cayuga	Trinity near Rosser
8-13	190	117	31.053	-95.632	Most of 0804	Trinity River from US 287 downstream to SH 21	Trinity near Oakwood
18-20	24	68	29.935	-94.78	Most of the upper reach of 0802	Trinity River from FM3278 downstream to confluence with Picketts Bayou near Moss Bluf	Trinity near Romayor

Table 28 San Jacinto River Basin reaches for geographic application of flow recommendations.

TCEQ Segment	Description	Flow Gage
1003	East Fork San Jacinto River from confluence with Caney Creek upstream to US 190	East Fork San Jacinto near Cleveland
1004	West Fork San Jacinto River from confluence with Spring Creek upstream to Conroe Dam	West Fork San Jacinto near Conroe
1008	Spring Creek from confluence with West Fork San Jacinto upstream to upstream most crossing of FM 1736	Spring Creek near Spring
1014	Buffalo Bayou from Shepherd Dr to SH6 in Houston	Buffalo Bayou at Piney Point
No designation	Brays Bayou from Scott St upstream to Eldridge Parkway	Brays Bayou in Houston

2.2.7.3. Hydrologic Period of Record

The BBEST reached consensus that a flow regime as representative as possible of the natural condition is the preferable approach to develop flow recommendations. This position is consistent with the current literature and the widely accepted concept of the "Natural Flow Regime" as well as the consensus criteria method applied to regional planning in Texas. The Trinity and San Jacinto Basins have been significantly altered from their natural conditions for many years and long term flow records for most of the river segments in the basins do not exist. Even in cases where gages are distant from large impoundments, the impact of wastewater return flows from two of the nation's largest metropolitan areas have elevated the current low flow condition of the mainstem rivers. This fact requires an adjustment from thinking about natural flows to thinking about less impacted flow regimes. The assumption is

that a flow regime derived from information obtained when anthropogenic impacts on flow were lowest, will result in habitat conditions closer to "the natural habitat of a region."

For the sites analyzed in this process the period of record and the timing of major alterations were reviewed by Crespo Consulting Services, Inc. They defined periods as pre-Impact analysis period, transition period and current conditions period. The pre-impact periods were selected for the development of recommendations for all sites. Since no Pre-Impact period was identified for Trinidad and Crockett, two sites which were initially under consideration, no recommendations were developed for these sites. The time periods are presented in Table 29. These periods were not without human impacts and their selection is not intended to suggest conditions were completely natural.

Table 29 Period of Record used for Development of Flow Recommendations

Site	Start	End
08049500 W Fk Trinity Rv at Grand Prairie	1926	1956
08055500 Elm Fk Trinity Rv nr Carrollton	1907	1952
08057000 Trinity Rv at Dallas	1904	1953
08062500 Trinity Rv nr Rosser	1939	1952
08065000 Trinity Rv nr Oakwood	1924	1964
08066500 Trinity Rv at Romayor	1925	1968
08068000 W Fk San Jacinto Rv nr Conroe	1940	1973
08068500 Spring Ck nr Spring	1940	2008
08070000 E Fk San Jacinto Rv nr Cleveland	1940	2008
08073700 Buffalo Bayou at Piney Point	1964	1975
08075000 Brays Bayou at Houston	1937	1960

The selection of a pre-impact period of record to develop hydrologic flow values does not mean pre-impact flows should be restored in the waterbody. Rather, the use of pre-impact flow values simply informs the management of new permits how flow regime contributes to a sound ecological environment in these rivers.

Use of the pre-impact period of record affects the flow regime recommendation in a number of ways. Subsistence and base flow recommendations are substantially lower than if the current or entire period of records were used. Many of the recommended subsistence and base flows are less than the lowest flows observed in these systems in the past 40 years. For example, the published 7Q2 for the Trinity River at Oakwood is 716 cfs, higher than all but a few of the Base-Wet targets recommended below.) As more water is diverted or more wastewater reused (under permits authorized following enactment of SB3), habitat conditions will change, ideally towards conditions more representative of the natural habitat of the region, and this will in turn favor a more balanced and integrated community of the native and endemic species and a less welcoming one for invasives. If the decision is made to maintain the current environmental condition, higher flow requirements will be needed than those presented in this report.

2.2.7.4. Hydrologic/Climatic Condition

Based on an analysis of the ecological community, ecologists on the committee recommended four hydrologic conditions which vary seasonally to maintain habitat diversity for the range of species which utilize these rivers. As noted in the SAC guidance document "The species that make up a stream/river community of organisms will encompass a great range of habitat preferences, and thus, a mosaic of habitats with variable depths and flow velocities is desirable for maintenance of species diversity. In most fluvial systems, spatially-uniform velocities and depths constitute poor fish habitat. "

2.2.7.5. Assignment Period

Assignment periods are the appropriate time periods or seasons for assigning different recommended flows. Review of the historical hydrograph, temperature patterns, and the existing fish communities led to the decision to select the following seasonal classifications.

Spring - Wet and increasing temperature (March -Jun)
Summer - Dry and hot temperature (July - Sep)
Fall (transition from Dry to Wet) – relatively dry and decreasing temperature (Oct-Nov)
Winter (transition Cold and Wet) – relatively wet and cold temperatures (Dec-Feb)

Distribution of low flows and peak flows from the Trinity River illustrate a basis for the selection of the assignment period.

Table 30 Occurrence of low flow conditions and peaks in flow in the Trinity River at Romayor (May 1924-December 1968) and Oakwood (1924-1964)

	Trinity at Oakwood		Trinity at Romayor	
	Number of Days <12%tile flow	Number of Peaks in Flow	Number of Days <10%tile flow	Number of Peaks in Flow
January	32	65	71	41
February	19	66	28	39
March	21	67	20	33
April	23	75	33	29
May	0	75	3	50
June	56	66	24	33
July	148	56	193	26
August	295	43	388	22
September	308	49	408	31
October	297	59	416	26
November	141	63	193	34
December	107	51	109	42

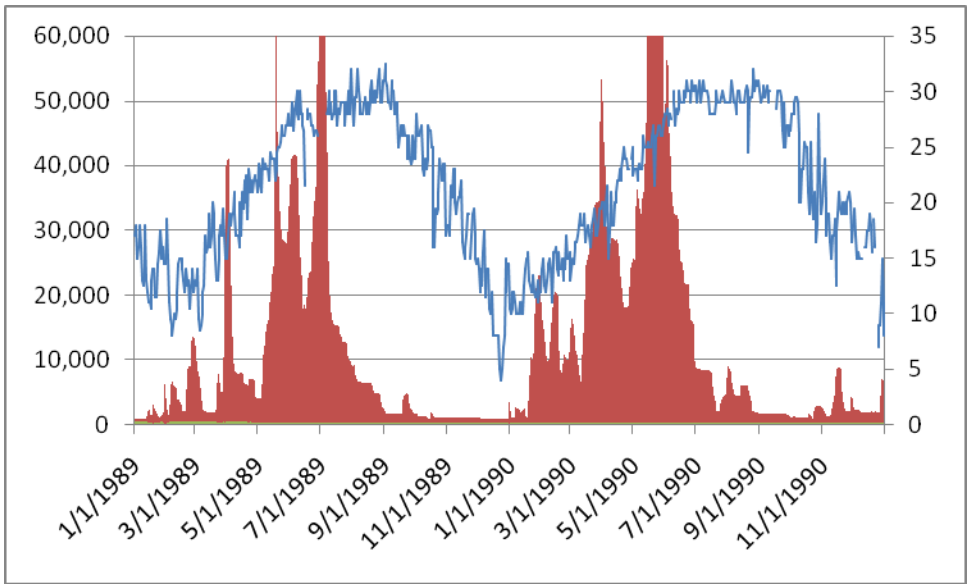

Figure 11 Daily average flow (cfs) (red columns) and daily average temperature (°C) (blue line) for the Trinity River at Romayor

2.2.7.6. Memory

The concept of "memory" refers to the effect of one season's flow recommendations to the flow recommendations for the next season. For example, if a high flow pulse is recommended at a frequency of one per season and two occurs during a season, is the recommendation in the subsequent season none or still one? Conversely, a recommendation can be phrased as "thirty high flow pulses over thirty seasons," in which case memory is implicitly included.

A hydrologic flow recommendation is based on summary statistics of a long-term period of record. As such, it is inherently recognized that climate patterns will result in some seasons having flows in excess of recommendations, and other seasons will have flows less than the recommendations. The flow recommendations in this document recognize the existence of this variability and document frequency of occurrence for subsistence and base flows to account for seasonal and interannual variability. The BBEST discussed concerns about use of environmental flow regimes in water management and agreed on two concepts:

1) Water users should not be required to provide flows in the environmental flow regime when climate conditions are not compatible. For example, if dry weather and lack of rainfall does not produce high pulse flows recommended in the environmental flow regime, water users should not be required to release water to artificially create high flow pulses, and

2) Water rights permit decisions should be based on the long-term frequency of the occurrence of environmental flows.

2.2.7.7. 7. Delineation of High Flow Pulse and Overbank Flow Components

Important characteristics of high flow pulses and overbank flows that affect environmental health include magnitude (peak flow), duration, frequency, and total volume of the events. The

environmental flow recommendations described in this document describe those four characteristics for recommended high pulse flows. Total volume is an important characteristic of high flow pulses and the manner by which volume is quantified may need further consideration during implementation to ensure volumes in addition to magnitude, duration, and frequency are representative of a sound environment.

2.2.7.8. Subsistence Flows Less Than 7Q2

The current low flow condition in many streams in the Trinity and San Jacinto basins is substantially elevated above pre-impact conditions. As a result, the 7Q2 flow (The lowest average stream flow for seven consecutive days with a recurrence interval of two years, as statistically determined from historical data and used in water quality modeling (Texas Administrative Code, 2009)) is often much larger than subsistence flow needs. In most cases, low flow conditions have increased because the volume of treated wastewater has increased with population growth. It is not known whether water quality criteria for dissolved oxygen would be met if flows eventually dropped to subsistence levels recommended below. A desired characteristic of subsistence flow is that it maintains water quality. Future implementation should ensure water rights management decisions consider possible effects of withdrawals on water quality criteria at subsistence and base flows.

The recently completed study on the Colorado provides some guidance for quantifying the subsistence flow value (Bio-West, Inc., 2008). The Lower Colorado River Water Supply Project (LWSP) study cited Hardy et al. (2006) and selected the 95th percent flow exceedence (5th percentile flow) as a starting point for the ecological subsistence flow. The LSWP then calculated the 95th percent habitat exceedence (the flow that produced the 95th percent habitat exceedence for the limiting fish habitat guild was equal to the 95th percent flow exceedence). From the LSWP "A review of the habitat duration curves, exceedence tables, and summary revealed that the 95th percent habitat exceedence level did appear to be an appropriate starting point for evaluating subsistence flow recommendations at the Austin, Bastrop, Smithville, and Columbus reaches. This level maintains very few instances where individual habitat categories during individual months go to zero or below 5%. Additionally, on average approximately 25% of the total maximum habitat is available for these reaches at that level." The LSWP also developed a water quality model and concluded that these flows protect water quality. Based on these results the 95th percent flow exceedence (5th percentile flow) was selected as the subsistence flow target for sites in the Trinity and San Jacinto (Table 31).

Table 31 Subsistence Flow Targets

		Published	Recommendation			
		7Q2	Winter	Spring	Summer	Fall
8049500	Grand_Prairie	107	24	28	15	16
8055500	Carrollton	16	24	28	15	16
8057000	Dallas	221	24	28	15	16
8062500	Rosser	607	106	212	142	125
8065000	Oakwood	717	196	280	70	101
8066500	Romayor	732	542	720	210	250
8068000	Conroe	20	23	24	9	9
8068500	Spring	15	14	14	6	6
8070000	East_Fork	18	22	18	8	10
8073700	Buffalo	51	11	13	26	13
8075000	Brays	#N/A	3	1	1	0

It should be repeated that current return flows result in minimum flows that are on the order of 5 to 10 times these values. Clearly an important research priority will be to verify that subsistence flows meet their objectives.

2.2.7.9. Number and Location of Control Points

The recommendation presented here includes instream flow targets for 11 sites in the Trinity and San Jacinto River Basins. These sites were selected for analysis by the BBEST instream flow subcommittee based on guidance provided in the SAC Geographic Scope document (SAC 2009-02). The subcommittee compromised between selecting one to two sites with relatively more ecological data (namely the mainstem Trinity in the segment identified as a priority study segment by the TIFP) or selecting all of the approximately 45 sites with flow data over a long enough period to develop a hydrologically-based recommendation. Figure 12 shows the locations of the sites selected (Primary) and the other candidate sites (Secondary). Notably given time and data constraints no tributary sites were selected as primary sites.

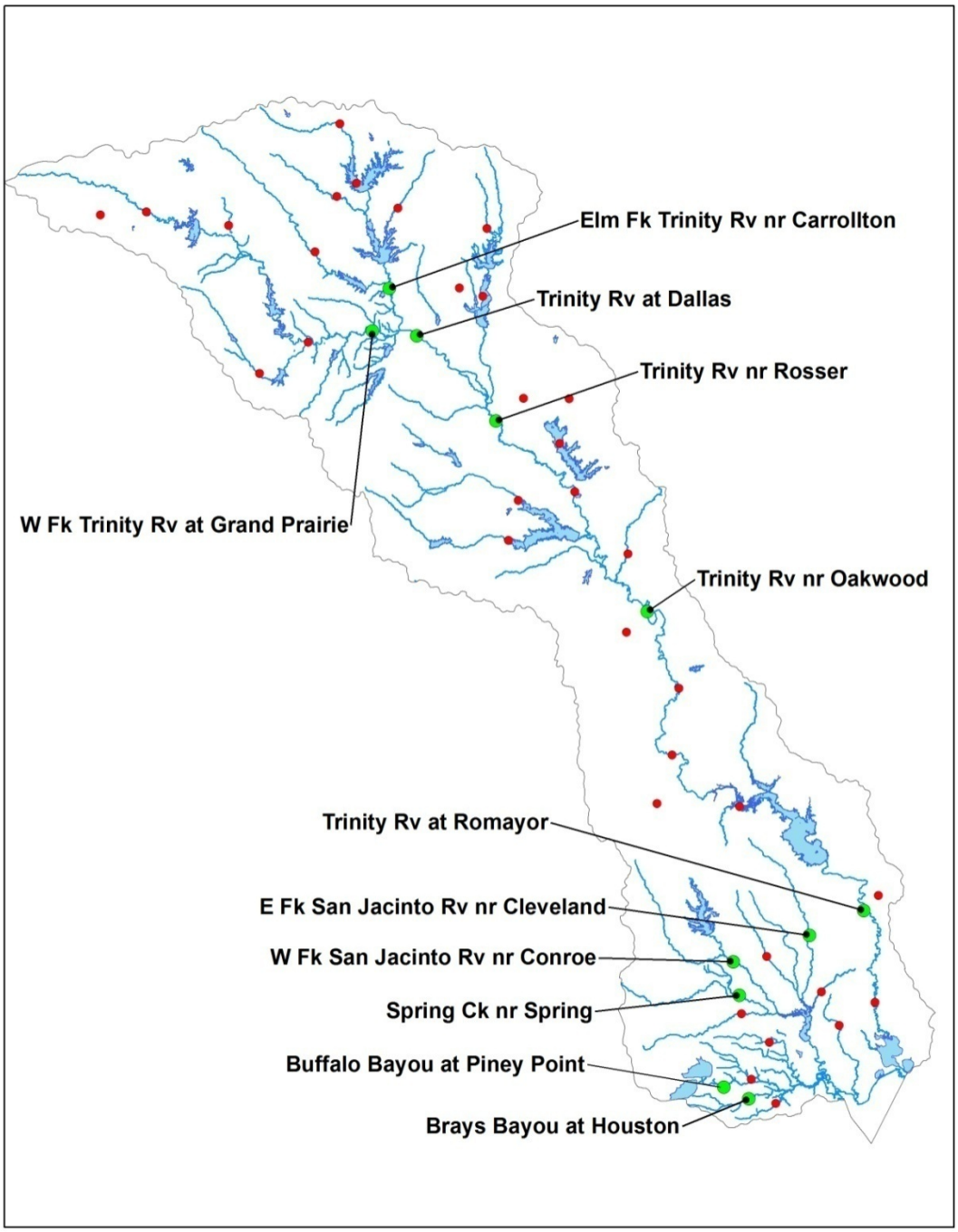

Figure 12 Map of gages selected for development of Instream Flow Recommendations. Selected gages are green and gages indicated with a red dot were considered but not selected for analysis.

2.2.7.10. Flow Recommendations For Waters not Specifically Included in These Environmental Flow Recommendations

Since these environmental flow recommendations do not apply specifically to all streams in the two basins, suggestions are made for considering water rights permit applications for streams not included in this report. One suggestion is that the TCEQ will identify the nearest, appropriate gage to the proposed permit site, and using available flow data, apply the

methodology described in this report. A second suggestion is for the TCEQ to apply a drainage area adjustment based on the size of the drainage area above the proposed permit site. The flow recommendations included in this report are considered a minimum number acceptable for guiding future water management efforts.

2.2.7.11. Daily Average versus Instantaneous Flow Data

Daily average flows from the USGS were used as input to all of the HEFR analyses. Instantaneous flow data was employed by Crespo Consulting Services, Inc. to calculate flood recurrence intervals for high flow events in to order to approximate overbank flows. However, as described in the next paragraph the high flow recurrence interval flows were used as a check on the overbank estimate derived primarily from flood stage estimates provided by the National Weather Service.

2.2.7.12. Overbank Recommendations

The overbank flow recommendations were derived primarily from data obtained from the National Weather Service (NWS). These were compared with recurrence intervals of 1.5 to 5 years using PeakFQ and an estimate of overbank flows determined by visual inspection of cross sections and their associated rating curves. Generally the flood stage (and in some cases the action stage or the estimate based on cross sections) resulted in a flow that was between the 1 per year and 1 per 2 year values calculated using HEFR. In these cases, the overbank flow was defined by the NWS or cross section estimate and assigned a 1 per 2 year recurrence target. In some cases the overbank estimates were greater than the 1 in 5 year recurrence interval flow reported in HEFR and, in these cases, the HEFR 1 in 5 year estimate was used.

Table 32 Estimates to develop Overbank Flow Recommendations

		Site										
		Grand Prairie	Carrollton	Dallas	Rosser	Oakwood	Romayor	Conroe	Spring	Cleveland	Buffalo Bayou	Brays Bayou
		National Weather Service Flood Stage										
Flood Stage		20,000	6,200	11,100	26,000	24,600	94,300	19,100	8,500	16,000	0	3,700
Action Stage		13,000	4,400	10,000	22,000	18,100	44,600	16,800	5,000	2,000	0	3,000
		Recurrence Interval Flows Calcuated Using PEAKFQ										
Return Period (Pre)	1:2.3 year	9,370	21,100	26,700	39,300	38,900	42,400	11,500	7,530	6,710	2,620	4,300
	1:1.5 year	5,980	12,700	15,800	24,900	24,400	30,100	6,130	3,950	3,410	1,990	2,780
	1:1.25 year	4,440	9,130	11,100	18,200	17,900	23,700	3,990	2,480	2,150	1,630	2,020
Return Period (Post)	1:2.3 year	15,900	7,450	30,400	38,700	48,100	64,300	11,400	-	-	4,420	18,500
	1:1.5 year	10,700	5,610	21,900	28,800	34,000	45,800	6,460	-	-	3,570	14,600
	1:1.25 year	8,330	4,680	17,600	23,800	26,700	35,600	4,440	-	-	3,060	12,200
Return Period (All)	1:2.3 year	10,500	10,000	24,300	29,900	39,500	47,800	11,500	7,530	6,710	3,710	11,200
	1:1.5 year	6,770	5,540	15,000	19,400	25,500	34,000	6,360	3,950	3,410	2,880	6,530
	1:1.25 year	5,090	3,740	10,900	14,500	18,800	26,600	4,280	2,480	2,150	2,410	4,370
		Cross Section Inflection Point (Estimated by visual inspection)										
Cross Section		11,000	11,000	10,000	20,000	30,000						
Recommendation												
Magnitude		10,700	11,000	11,100	26,000	24,600	44,600	16,800	5,000	4,000	1,990	3,700
Return Period		5	2	2	2	2	2	5	2	2	2	2
Volume		202,575	154,505	145,167	456,654	626,471	1,875,722	158,831	51,766	43,908	49,128	26,603
Duration		37	18	18	27	26	34	43	24	23	25	26

2.2.8. Decision points required in HEFR

2.2.8.1. Hydrographic Separation

Hydrograph separation in the context of SB3 refers to the parsing of the hydrograph into ecologically meaningful flow categories. As was noted in the NAS review of the TIFP "hydrologic desktop methods such as the Lyons Method or CCEFN that are based on monthly medians may lead to inconsistent and unreliable protection of base flows while generally under-protecting high flow pulses and overbank flows. Hydrologic desktop estimates can be improved by first applying a base flow separation analysis to the daily data series, and then computing estimates of normal base flows or high flows separately."

While different categories could be defined, this process has adopted the four categories, Subsistence Flows, Base Flows, High Flow Pulse and Overbanks Flows. Although the algorithms provided by the SAC separate the hydrograph into four components, the crux of this issue is the separation of high flows from base or low flows. Misunderstanding has arisen about the terms “base” and “low” flow. The concept of base flow separation has a long history in the hydrology discipline and the MBFIT tool developed by the SAC is a modification of a traditional base flow separation algorithm. This hydrologic concept of base flow is not synonymous with what base flow is intended to mean in the ecological context of the SB3 deliberations. The SAC addressed this issue directly in their hydrologic methods document and given the controversy it has created among BBEST members that description is repeated here.

> "For the purposes of establishing an appropriate environmental flow regime in the context of Senate Bill 3, multiple flow components are desired, some of which are at least partially derived from groundwater or alluvial sources (subsistence and base flows) and some of which are more a result of storm events (high flow pulses and overbank events). Because of the focus on ecosystem roles, the traditional distinction between various groundwater and runoff sources does not necessarily fit in the context of environmental flow recommendations. For the purposes of SB 3 efforts, it is perhaps less important to identify the source of water than the ecological role, or ecological significance, of varying flow magnitudes and other flow characteristics. Put simply, the hydrographic separation in HEFR is a hydrological activity for an ecological purpose and is therefore not synonymous with traditional base flow separation methodologies. In the development and application of the EFC algorithm in IHA, one consideration for the use of the term "low flow" in lieu of "base flow" has been to avoid the traditional connotation of "base flow" being purely groundwater derived (Ryan Smith, personal communication). In this light, it is more desirable to separate the hydrograph into biologically and ecologically meaningful components than components based on the water source. A description of the primary objectives of the different flow components considered important for describing environmental flow prescriptions as used in HEFR is provided in Section 2.2

> For efforts associated with SB3, it is important to identify the ecologically and biologically important components of the flow regime to develop recommendations that provide ecological benefits such as those listed in Section 2.2. Very small runoff events, while classified as runoff by traditional hydrographic separation algorithms, may not provide any of the ecological benefits associated with high flow pulses. Similarly, during the leading and trailing limbs of storm hydrographs, fish may not be hiding in velocity shelters and may be exploiting habitats made available by these flows. Thus the ecological role of some leading and trailing limbs may be more akin to base flows than high flow pulses. Conversely, very high flows, even if sustained for a period, may not serve the habitat functions of base flows, even if identified as base flows by a particular hydrographic separation algorithm. Hence, the ecological benefits associated with the various flow conditions are not solely dependent on flow rate, but also on volume, timing, rate of change, and duration (e.g., to move significant sediments, higher flows for sustained periods may be required)."

It is the focus on the ecological benefits of the various flow components that informs the selection and application of the available base flow separation algorithms and ultimately forms the basis for the quantification of flow recommendations presented in this report. Although a detailed discussion of the various algorithms employed to perform the tools developed by the SAC is beyond the scope of this document, it is perhaps necessary to briefly discuss some of the basic concepts. Traditional hydrologic base flow separation techniques focus on the concept of rate of change. If stream flow has been generally constant for some period of time and suddenly increases rapidly, this rate of change is used to identify the effects of a storm event and the classification of the flow as a high flow event. In fact the MBFIT approach developed by the SAC retains the "turning point" terminology from when hydrologists visually identified these increases and then connected these turning points to separate the hydrograph into components of base flow (ground water or alluvial source) and pulse (storm derived source). In this conception of base flow the concept of persistence is central.

As clearly explained above, this is not a proper interpretation of the base flow within the ecological context. In the ecological context flow magnitude takes on a more important role. Since different flow rates produce a range of physical habitat conditions defined in part by depth, velocity and substrate, aquatic biota respond to these habitat changes produced at different flow magnitudes rather than to the source of the water or whether that magnitude is produced by a long term persistent level or is the descending limb of a high flow pulse. While there is room for subjectivity on this issue and clearly rate of change is an important factor in the ecological function of some flows (e.g. the declining limb of hydrograph may produce different sediment transport than the ascending limb) the recommendation in this report gives significant weight to the selection of the magnitude threshold as a tool to define base flow from an ecological perspective. It is recognized that this quantification of ecological base flow will include some runoff from antecedent storm events and will not be solely based on aquifer discharge and wastewater return flows.

Although the SAC provided two options for parsing the hydrograph (IHA and MBFIT), both tools include sufficient flexibility to produce a wide range of statistical results. Crespo Consulting Services, Inc. (2009) concluded that they were unable to objectively render an opinion as to the superiority of one tool over the other. Both tools include options for setting threshold magnitudes and dealing with rate of change. The threshold parameters allow the user to define a lower threshold below which flows are always considered low flows and an upper threshold above which flows are always considered high flows (with an intermediate "grey zone" where classification is based on rate of change characteristics). They differ in their approach to rate of change and some have contended that IHA misclassifies more days than MBFIT. Nonetheless reasonable parameterization ranges can be assigned for either tool to produce essentially the same results for the 25th, 50th and 75th percentile statistics. A more critical issue than tool selection is the choice of parameters within the tools and specifically, given the SAC guidance discussed above, the selection of the threshold parameters.

Some guidance on how to set these parameters may be found from the LWSP study (Bio-West, Inc., 2008). The LSWP employed the BFI software program (the BFI in MBFIT) to determine a threshold value below which flows would be considered base flow for the purposes of instream habitat modeling. The value that was eventually settled upon was 5,840 cfs based on pre-development flow data at the Columbus gage on the Colorado River. This value represents the 87th percentile flow for that gage over period of record for which it was developed. The default values in HEFR for the upper and lower thresholds are the 75th and 25th percentile flows. This means that without even considering rate of change, to categorize flows between 25th and 75th percentile values, the default settings would automatically almost double the number of days that are removed from the base flow category. If the 25th percentile value had been applied in the LSWP then flows as low as 540 cfs could be considered high flow pulses. This value is less that the Base-Average targets for the Columbus for all but one month. The point is that the default values in HEFR remove far too many days from the base flow category when considering the ecological (instream habitat function) that these flows are defined to protect. The result of this misclassification is that the percentile statistics and thus the preliminary flow estimates are very low. These low estimates were observed and noted by river ecologists in evaluating early iterations of the HEFR results.

A more reasonable, yet still low, lower threshold, was chosen based on the default parameters in the IHA program. IHA has been used in evaluating/determining environmental flows in over 18 states on over 63 rivers and in 8 countries. It has been applied to parts of the Trinity River flow regimes. In Texas, it has been used on Cypress Creek, the Sabine River, the Neches River, and the Colorado River. In IHA the lower threshold is the median, thus flows below median are considered base flows, those between median and the 75th percentile flow are evaluated by their rate of change, and flows above the 75th are considered high flows. While other parameterizations were investigated by Crespo Consulting Services, Inc. and others on the BBEST, none were able to demonstrate a "better" set of parameters from the perspective of ecological roles. This assessment and the fact that IHA has been employed in many studies in Texas and around the world recommend the adoption of the IHA parameters for the base flow separation pre-processor for HEFR. Theses default parameters are given in Figure 13.

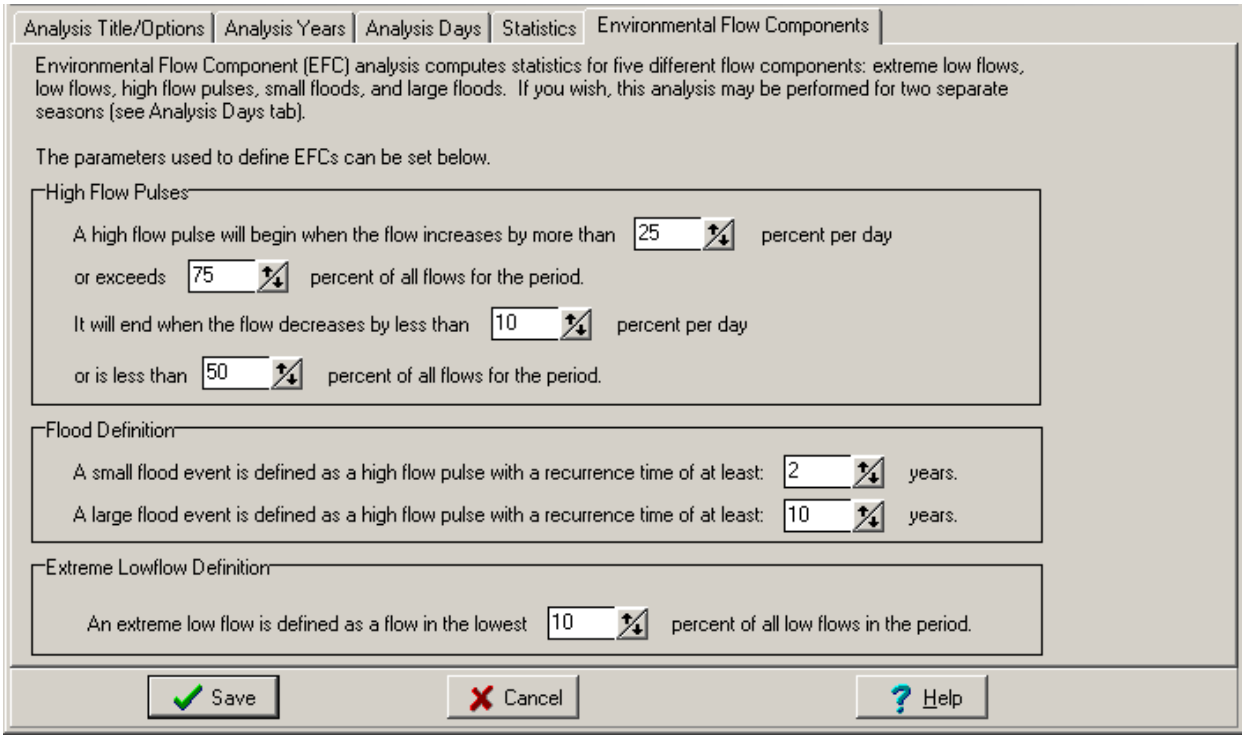

Figure 13 Default parameters for baseflow separation

When the 25th, 50th and 75th percentile statistic are calculated from this base flow separated hydrograph they are roughly equivalent to the 20th, 35th, and 50th percentile flows when compared to the unseparated record, results which are reasonably consistent with those found in the LSWP study.

2.2.8.2. Seasonality

The issue of seasonality is addressed in the section on SAC identified decision points encountered when using hydrologic data to help define environmental flow recommendations under the title assignment period.

2.2.8.3. Percentiles

The section of percentiles for which to assign flow targets for base flows, especially in the absence of site specific analysis and a well understood relationship between flow and mesohabitat, is necessarily subject to professional judgment. Given the explicit mandate in the SB3 legislation and the predominance of research supporting the need for variable habitat conditions, identification of a range of base flow targets is considered necessary to satisfy the legislative mandate and fully describe environmental flow needs. Selecting the default 25th percentile for dry, 50th percentile for average and 75th percentile for wet base flow conditions represents a reasonable approach consistent with TIFP which states "The primary objective of base flow recommendations will be to ensure adequate habitat conditions, including variability, to support the natural biological community of the specific river sub-basin. These habitat conditions are expected to vary from day to day, season to season, and year to year. This

variability is essential in order to balance the distinct habitat requirements of various species, guilds, and assemblages."

While it is possible and, even likely, that the base flow targets developed based on these frequencies will be refined based on the site specific studies to be conducted under SB2, it is also reasonable to expect that the habitat conditions produced by these flow ranges will meet these defined objectives. An important factor to consider is that achievement frequencies associated with these targets will be informed by their historical frequencies. This implies that if it is determined that the base-wet should be lower than the 75th percentile, the corresponding achievement would be shifted appropriately.

The recommendation of dry (25th percentile), average (50th), and wet (75th) base flows does not presuppose or mandate a specific duration (or persistence) of such flows. For example, following a large storm event, the tailing hydrograph will reach a point where more of the ecological functions of wet base flows are being achieved rather than the ecological functions of high flow pulses. Later, in the absence of additional precipitation, flows commensurate with average and dry base flows will occur, each providing somewhat different habitats and ecological functions in different portions of the river.

2.2.8.4. Episodic Events Calculations

Similar to the base flow percentiles above, the definition of episodic event or high flow pulse and overbank events requires the application of professional judgment. The recommendation included in this report includes a range of high flow pulse events calculated using the alternative frequency based approach available in the HEFR program. While a range of recurrence interval flows were investigated this recommendation includes peak flows, durations and volumes calculated based on five recurrence interval calculations. These are the 2 per season flows, the 1 per season flows, the 2 per year flows and an estimate approximating the overbank flow which was generally set at a 1 per 2 year recurrence but in all cases had a greater frequency of occurrence based on statistical analysis.

2.2.8.5. Subsistence Percentile

As described above, the subsistence flow targets developed for this recommendation are based on the 5th percentile flow consistent with published literature and site specific studies conducted in Texas. It is notable the default methodology in HEFR which calculates the subsistence flow based on the median of the lowest 10th percentile low flows, results in a significantly lower target, closer to the 2nd or 3rd percentile flow. The 5th percentile flow at Dallas and Carrolton, based on the pre-impact flow record are often zero. Professional judgment suggests that zero flow is unlikely to maintain objectives of subsistence level flows at these locations, therefore the subsistence recommendations at these sites were replaced by the 5 th percentile flows at the Grande Prairie site.

2.2.8.6. Multipeaks_Multiplier

Due to time constraints this option and it implications were not investigated in this analysis. In their hydrologic analyses, the Sabine-Neches BBEST also did not use this function in HEFR.

2.2.9. Flow recommendations

2.2.9.1. Subsistence and Base Flow Attainment Frequencies

For our ecological analysis, the HEFR-derived base flows for dry, average, and wet conditions for each gage were compared to the ecology of focal species. Base flow estimates from the HEFR analysis were deemed ecologically suitable. Adoption of base flow benchmarks for dry, average, and wet conditions 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 at frequencies substantially greater than historical frequencies, unless it has been determined from independent data sources that the region has entered into a prolonged, severe drought.
The following subsistence flows are based on the 5th percentile flows and are recommended for maintenance of water quality and provision of habitat refuges. The base flows are derived from HEFR analysis and are recommended for maintenance of habitat and its associated ecological processes.

Attainment frequencies were defined by their historical frequencies for the period of record upon which the targets were developed. These frequencies are based on the entire flow record rather than on a flow separated record. These attainment frequencies are not strictly synonymous with the percent of time that the condition may be designated as a drought (subsistence), dry, average or wet conditions, thus it is anticipated that an implementation approach will need to be developed to ensure that these targets are achieved at levels as close as possible to their historic frequencies.

Although attainment frequencies were defined by historical frequencies, this is not synonymous with declaring that there is no water for beneficial human uses. As in the Consensus Criteria (CCEFN) that has been used in Texas water planning for over ten years, maintaining the historical frequency of discrete points on a flow duration curve does allow for diversions at all other points on the flow duration curve.

West Fork Trinity River at Grand Prairie

- Base flow, Winter, Subsistence Condition: 24 cfs with attainment frequency of 96% of the time
- Base flow, Winter, Dry Condition: 52 cfs with attainment frequency of 82% of the time
- Base flow, Winter, Average Condition: 84 cfs with attainment frequency of 66% of the time
- Base flow, Winter, Wet Condition: 118 cfs with attainment frequency of 50% of the time
- Base flow, Spring, Subsistence Condition: 28 cfs with attainment frequency of 95% of the time
- Base flow, Spring, Dry Condition: 53 cfs with attainment frequency of 87% of the time
- Base flow, Spring, Average Condition: 84 cfs with attainment frequency of 76% of the time
- Base flow, Spring, Wet Condition: 138 cfs with attainment frequency of 63% of the time
- Base flow, Summer, Subsistence Condition: 15 cfs with attainment frequency of 96% of the time
- Base flow, Summer, Dry Condition: 40 cfs with attainment frequency of 74% of the time
- Base flow, Summer, Average Condition: 55 cfs with attainment frequency of 60% of the time
- Base flow, Summer, Wet Condition: 82 cfs with attainment frequency of 46% of the time
- Base flow, Fall, Subsistence Condition: 16 cfs with attainment frequency of 95% of the time
- Base flow, Fall, Dry Condition: 39 cfs with attainment frequency of 76% of the time
- Base flow, Fall, Average Condition: 54 cfs with attainment frequency of 61% of the time
- Base flow, Fall, Wet Condition: 79 cfs with attainment frequency of 46% of the time

This station is just above the confluence with the Elm Fork of the Trinity River. Upstream of the site the river contains significant riparian areas as well as tracts of hardwoods with sloughs and meander scars. The area is used for flood control purposes and accommodates the flashy nature of urban runoff. Instream habitat includes shoals, sandbars, and downed trees. Sufficient habitat exists to support populations of terrestrial and wetland vertebrate piscivores.

Elm Fork Trinity River near Carrollton

- Base flow, Winter, Subsistence Condition: 24 cfs with attainment frequency of 78% of the time
- Base flow, Winter, Dry Condition: 61 cfs with attainment frequency of 73% of the time
- Base flow, Winter, Average Condition: 102 cfs with attainment frequency of 60% of the time
- Base flow, Winter, Wet Condition: 165 cfs with attainment frequency of 46% of the time
- Base flow, Spring, Subsistence Condition: 28 cfs with attainment frequency of 87% of the time
- Base flow, Spring, Dry Condition: 65 cfs with attainment frequency of 81% of the time
- Base flow, Spring, Average Condition: 112 cfs with attainment frequency of 70% of the time
- Base flow, Spring, Wet Condition: 185 cfs with attainment frequency of 58% of the time
- Base flow, Summer, Subsistence Condition: 15 cfs with attainment frequency of 75% of the time
- Base flow, Summer, Dry Condition: 42 cfs with attainment frequency of 68% of the time
- Base flow, Summer, Average Condition: 106 cfs with attainment frequency of 52% of the time
- Base flow, Summer, Wet Condition: 210 cfs with attainment frequency of 35% of the time
- Base flow, Fall, Subsistence Condition: 16 cfs with attainment frequency of 77% of the time
- Base flow, Fall, Dry Condition: 60 cfs with attainment frequency of 68% of the time
- Base flow, Fall, Average Condition: 101 cfs with attainment frequency of 55% of the time
- Base flow, Fall, Wet Condition: 161 cfs with attainment frequency of 40% of the time

This site is just below Lake Lewisville within a significant urban area. There are considerable water features associated with the river within the floodplain. They may be for flood control purposes, or used as amenity lakes or borrow areas. There are some natural sloughs and meander scars that hold water. However, the hydrology may be controlled in this area to accommodate flood protection. Significant portions are leveed to the confluence with the West Fork of the Trinity River. Significant habitat features exist within the managed sections of the river including hydrologically isolated features. The in-channel habitat may be too flashy to support certain aquatic species; however, the associated riparian, bottomlands, and ponded areas do support vertebrate species such as herons and egrets, river otters, and other piscivores.

Trinity River at Dallas

- Base flow, Winter, Subsistence Condition: 24 cfs with attainment frequency of 91% of the time
- Base flow, Winter, Dry Condition: 51 cfs with attainment frequency of 81% of the time
- Base flow, Winter, Average Condition: 132 cfs with attainment frequency of 65% of the time
- Base flow, Winter, Wet Condition: 272 cfs with attainment frequency of 50% of the time
- Base flow, Spring, Subsistence Condition: 28 cfs with attainment frequency of 92% of the time
- Base flow, Spring, Dry Condition: 71 cfs with attainment frequency of 84% of the time
- Base flow, Spring, Average Condition: 152 cfs with attainment frequency of 74% of the time
- Base flow, Spring, Wet Condition: 304 cfs with attainment frequency of 63% of the time
- Base flow, Summer, Subsistence Condition: 15 cfs with attainment frequency of 91% of the time
- Base flow, Summer, Dry Condition: 44 cfs with attainment frequency of 76% of the time
- Base flow, Summer, Average Condition: 104 cfs with attainment frequency of 60% of the time
- Base flow, Summer, Wet Condition: 225 cfs with attainment frequency of 44% of the time
- Base flow, Fall, Subsistence Condition: 16 cfs with attainment frequency of 91% of the time
- Base flow, Fall, Dry Condition: 50 cfs with attainment frequency of 76% of the time
- Base flow, Fall, Average Condition: 112 cfs with attainment frequency of 61% of the time
- Base flow, Fall, Wet Condition: 198 cfs with attainment frequency of 45% of the time

This site is proximally downstream from the Elm Fork Trinity River near Carrollton gage site. That description applies here to the confluence of the West Fork of the Trinity River.

Trinity River near Rosser

- Base flow, Winter, Subsistence Condition: 106 cfs with attainment frequency of 95% of the time
- Base flow, Winter, Dry Condition: 248 cfs with attainment frequency of 77% of the time
- Base flow, Winter, Average Condition: 466 cfs with attainment frequency of 64% of the time
- Base flow, Winter, Wet Condition: 821 cfs with attainment frequency of 50% of the time
- Base flow, Spring, Subsistence Condition: 212 cfs with attainment frequency of 95% of the time
- Base flow, Spring, Dry Condition: 398 cfs with attainment frequency of 88% of the time
- Base flow, Spring, Average Condition: 625 cfs with attainment frequency of 79% of the time
- Base flow, Spring, Wet Condition: 1,078 cfs with attainment frequency of 67% of the time
- Base flow, Summer, Subsistence Condition: 142 cfs with attainment frequency of 95% of the time
- Base flow, Summer, Dry Condition: 266 cfs with attainment frequency of 77% of the time
- Base flow, Summer, Average Condition: 401 cfs with attainment frequency of 59% of the time
- Base flow, Summer, Wet Condition: 574 cfs with attainment frequency of 41% of the time
- Base flow, Fall, Subsistence Condition: 125 cfs with attainment frequency of 95% of the time
- Base flow, Fall, Dry Condition: 208 cfs with attainment frequency of 72% of the time
- Base flow, Fall, Average Condition: 320 cfs with attainment frequency of 57% of the time
- Base flow, Fall, Wet Condition: 626 cfs with attainment frequency of 41% of the time

This stretch of the river appears to have levees restricting flows to an area wider than the main channel in several places. Within the leveed areas, floodplain forest is present in much of the reach. There are intermittent and perennial streams present that provide additional instream habitat. Instream habitat includes shoals, riffle and pool areas, trees, and creek confluences.

Trinity River near Oakwood

- Base flow, Winter, Subsistence Condition: 196 cfs with attainment frequency of 95% of the time
- Base flow, Winter, Dry Condition: 340 cfs with attainment frequency of 85% of the time
- Base flow, Winter, Average Condition: 623 cfs with attainment frequency of 72% of the time
- Base flow, Winter, Wet Condition: 1,110 cfs with attainment frequency of 58% of the time
- Base flow, Spring, Subsistence Condition: 280 cfs with attainment frequency of 95% of the time
- Base flow, Spring, Dry Condition: 458 cfs with attainment frequency of 89% of the time
- Base flow, Spring, Average Condition: 820 cfs with attainment frequency of 79% of the time
- Base flow, Spring, Wet Condition: 1,398 cfs with attainment frequency of 66% of the time
- Base flow, Summer, Subsistence Condition: 70 cfs with attainment frequency of 95% of the time
- Base flow, Summer, Dry Condition: 257 cfs with attainment frequency of 69% of the time
- Base flow, Summer, Average Condition: 411 cfs with attainment frequency of 53% of the time
- Base flow, Summer, Wet Condition: 682 cfs with attainment frequency of 36% of the time
- Base flow, Fall, Subsistence Condition: 101 cfs with attainment frequency of 95% of the time
- Base flow, Fall, Dry Condition: 265 cfs with attainment frequency of 73% of the time
- Base flow, Fall, Average Condition: 439 cfs with attainment frequency of 57% of the time
- Base flow, Fall, Wet Condition: 819 cfs with attainment frequency of 41% of the time

A review of aerial photography and STEL 7.5 minute topographic maps eight miles upstream and downstream of the gage site indicates significant habitat and geomorphological features reflecting conditions supported by the range and variability of flows in the environmental flow recommendations. Features include intermittent and perennial tributaries, adjacent water bodies with channels (dry or wet) connected to the river, large trees, sand bars and shoals. Twenty-one features were identified including several large tracts (Big Lake Wildlife Management Area) containing innumerable habitat features providing habitat for aquatic and wetland dependent species.

Trinity River at Romayor

- Base flow, Winter, Subsistence Condition: 542 cfs with attainment frequency of 95% of the time
- Base flow, Winter, Dry Condition: 875 cfs with attainment frequency of 86% of the time
- Base flow, Winter, Average Condition: 1,500 cfs with attainment frequency of 74% of the time
- Base flow, Winter, Wet Condition: 2,590 cfs with attainment frequency of 61% of the time
- Base flow, Spring, Subsistence Condition: 720 cfs with attainment frequency of 95% of the time
- Base flow, Spring, Dry Condition: 1,160 cfs with attainment frequency of 89% of the time
- Base flow, Spring, Average Condition: 1,860 cfs with attainment frequency of 78% of the time

- Base flow, Spring, Wet Condition: 3,033 cfs with attainment frequency of 65% of the time
- Base flow, Summer, Subsistence Condition: 210 cfs with attainment frequency of 95% of the time
- Base flow, Summer, Dry Condition: 580 cfs with attainment frequency of 68% of the time
- Base flow, Summer, Average Condition: 915 cfs with attainment frequency of 52% of the time
- Base flow, Summer, Wet Condition: 1,550 cfs with attainment frequency of 34% of the time
- Base flow, Fall, Subsistence Condition: 250 cfs with attainment frequency of 95% of the time
- Base flow, Fall, Dry Condition: 630 cfs with attainment frequency of 71% of the time
- Base flow, Fall, Average Condition: 1,000 cfs with attainment frequency of 55% of the time
- Base flow, Fall, Wet Condition: 1,720 cfs with attainment frequency of 39% of the time

This stretch of the Trinity River contains large sandbars, sloughs, meander scars, oxbows, and intermittent and perennial streams. Large tracts of swamp and bottomland forests exist below the gage site. Above the site, the river contains riffle and pool habitat with shoals in the river. Bankfull discharge events would affect forested areas and water features. Below the gage site, the abundance and variety of habitats increase dramatically. Significant off channel water bodies exist and are affected by pulse and overbank flows, with some features affected by wet base flows. Former main stem river channels exist such as Old and Lost rivers as well as other significant tracts of bottomland and swamp forests and marshlands with associated hydrologic features. These habitats support very high numbers of fish and wildlife species. Several colonial bird rookeries, bald eagles and ospreys as well as significant numbers of over-wintering waterfowl utilize these habitats. Other vertebrate dependent species can also be found within these areas such as otters, alligator snapping turtles, and water snakes.

West Fork San Jacinto River near Conroe

- Base flow, Winter, Subsistence Condition: 23 cfs with attainment frequency of 95% of the time
- Base flow, Winter, Dry Condition: 36 cfs with attainment frequency of 89% of the time
- Base flow, Winter, Average Condition: 58 cfs with attainment frequency of 77% of the time
- Base flow, Winter, Wet Condition: 111 cfs with attainment frequency of 61% of the time
- Base flow, Spring, Subsistence Condition: 24 cfs with attainment frequency of 96% of the time
- Base flow, Spring, Dry Condition: 37 cfs with attainment frequency of 87% of the time
- Base flow, Spring, Average Condition: 56 cfs with attainment frequency of 74% of the time
- Base flow, Spring, Wet Condition: 88 cfs with attainment frequency of 59% of the time
- Base flow, Summer, Subsistence Condition: 9 cfs with attainment frequency of 95% of the time
- Base flow, Summer, Dry Condition: 18 cfs with attainment frequency of 67% of the time
- Base flow, Summer, Average Condition: 26 cfs with attainment frequency of 49% of the time
- Base flow, Summer, Wet Condition: 38 cfs with attainment frequency of 32% of the time
- Base flow, Fall, Subsistence Condition: 9 cfs with attainment frequency of 95% of the time
- Base flow, Fall, Dry Condition: 22 cfs with attainment frequency of 71% of the time
- Base flow, Fall, Average Condition: 29 cfs with attainment frequency of 57% of the time
- Base flow, Fall, Wet Condition: 47 cfs with attainment frequency of 42% of the time

Habitat features include substantial sand shoals and bars, intermittent and perennial streams, and felled trees. Riparian vegetation includes river birch, green ash, American sycamore, black willow, and eastern cottonwood. Availability of open shallow water habitat is important for fish and invertebrate feeding birds such as herons and egrets, bald eagles, and osprey. Large tracts of bottomland forests associated with tributaries such as Lake Creek as well as Spring Creek exist along the river floodplain.

Spring Creek near Spring

- Base flow, Winter, Subsistence Condition: 14 cfs with attainment frequency of 96% of the time
- Base flow, Winter, Dry Condition: 22 cfs with attainment frequency of 86% of the time
- Base flow, Winter, Average Condition: 36 cfs with attainment frequency of 74% of the time
- Base flow, Winter, Wet Condition: 59 cfs with attainment frequency of 60% of the time
- Base flow, Spring, Subsistence Condition: 14 cfs with attainment frequency of 96% of the time
- Base flow, Spring, Dry Condition: 24 cfs with attainment frequency of 86% of the time
- Base flow, Spring, Average Condition: 36 cfs with attainment frequency of 72% of the time
- Base flow, Spring, Wet Condition: 52 cfs with attainment frequency of 57% of the time
- Base flow, Summer, Subsistence Condition: 6 cfs with attainment frequency of 95% of the time
- Base flow, Summer, Dry Condition: 17 cfs with attainment frequency of 71% of the time
- Base flow, Summer, Average Condition: 24 cfs with attainment frequency of 56% of the time
- Base flow, Summer, Wet Condition: 35 cfs with attainment frequency of 39% of the time
- Base flow, Fall, Subsistence Condition: 6 cfs with attainment frequency of 95% of the time
- Base flow, Fall, Dry Condition: 17 cfs with attainment frequency of 75% of the time
- Base flow, Fall, Average Condition: 24 cfs with attainment frequency of 61% of the time
- Base flow, Fall, Wet Condition: 37 cfs with attainment frequency of 45% of the time

Large tracts of bottomland forest with sloughs containing bald cypress and other obligate wetland plants are associated with Spring Creek. Sloughs vary from open water to completely forested. Hardwoods are typical of floodplain forests with species such as overcup oak, American sycamore, laurel oak, sweetgum, and river birch. Instream habitat includes sandbars, felled trees, mudstone/sandstone, riffles/pools and shoals

East Fork San Jacinto River near Cleveland

- Base flow, Winter, Subsistence Condition: 22 cfs with attainment frequency of 95% of the time
- Base flow, Winter, Dry Condition: 30 cfs with attainment frequency of 88% of the time
- Base flow, Winter, Average Condition: 43 cfs with attainment frequency of 77% of the time
- Base flow, Winter, Wet Condition: 80 cfs with attainment frequency of 62% of the time
- Base flow, Spring, Subsistence Condition: 18 cfs with attainment frequency of 96% of the time
- Base flow, Spring, Dry Condition: 28 cfs with attainment frequency of 86% of the time
- Base flow, Spring, Average Condition: 42 cfs with attainment frequency of 72% of the time
- Base flow, Spring, Wet Condition: 64 cfs with attainment frequency of 56% of the time
- Base flow, Summer, Subsistence Condition: 8 cfs with attainment frequency of 95% of the time
- Base flow, Summer, Dry Condition: 18 cfs with attainment frequency of 68% of the time
- Base flow, Summer, Average Condition: 24 cfs with attainment frequency of 52% of the time
- Base flow, Summer, Wet Condition: 34 cfs with attainment frequency of 33% of the time
- Base flow, Fall, Subsistence Condition: 10 cfs with attainment frequency of 95% of the time
- Base flow, Fall, Dry Condition: 19 cfs with attainment frequency of 75% of the time
- Base flow, Fall, Average Condition: 27 cfs with attainment frequency of 57% of the time
- Base flow, Fall, Wet Condition: 38 cfs with attainment frequency of 41% of the time

This portion of the river is extremely sinuous and flows through pine/deciduous hardwoods with a riparian zone most likely comprised of green ash, water elm, water hickory, sycamore, black willows and cottonwoods. Below Highway 59, vegetation along the river reflects wetter flow regimes dominated by bottomland hardwoods in significantly sized tracts. Loblolly pine is restricted to higher elevations along the river. Sandbars become more frequent. The river has intermittent streams and perennial streams flowing into it between the gage site and its confluence with Peach Creek. While adjacent floodplain waterbodies (oxbows, meander scars, etc.) are not abundant, they are present. Lower reaches provide a more open channel with shallows important to fish eating birds.

Buffalo Bayou at Piney Point

- Base flow, Winter, Subsistence Condition: 11 cfs with attainment frequency of 96% of the time
- Base flow, Winter, Dry Condition: 25 cfs with attainment frequency of 80% of the time
- Base flow, Winter, Average Condition: 38 cfs with attainment frequency of 68% of the time
- Base flow, Winter, Wet Condition: 58 cfs with attainment frequency of 55% of the time
- Base flow, Spring, Subsistence Condition: 13 cfs with attainment frequency of 95% of the time
- Base flow, Spring, Dry Condition: 26 cfs with attainment frequency of 81% of the time
- Base flow, Spring, Average Condition: 37 cfs with attainment frequency of 67% of the time
- Base flow, Spring, Wet Condition: 51 cfs with attainment frequency of 54% of the time
- Base flow, Summer, Subsistence Condition: 26 cfs with attainment frequency of 95% of the time
- Base flow, Summer, Dry Condition: 45 cfs with attainment frequency of 87% of the time
- Base flow, Summer, Average Condition: 66 cfs with attainment frequency of 74% of the time
- Base flow, Summer, Wet Condition: 96 cfs with attainment frequency of 60% of the time
- Base flow, Fall, Subsistence Condition: 13 cfs with attainment frequency of 96% of the time
- Base flow, Fall, Dry Condition: 33 cfs with attainment frequency of 81% of the time
- Base flow, Fall, Average Condition: 49 cfs with attainment frequency of 69% of the time
- Base flow, Fall, Wet Condition: 75 cfs with attainment frequency of 56% of the time

Buffalo Bayou is unusual because it is a primarily natural channel in an urban area setting where most streams are channelized and or rectified. Because of hydrograph patterns associated with urban runoff, the stream is not stable and experiences a high rate of erosion. Additionally, water quality issues exist in the bayou caused by nonpoint source pollution and several treated domestic wastewater discharges to the stream. The riparian zone includes black willow, American sycamore, eastern cottonwood, and river birch. Due its unstable geomorphology, there are limited low flow habitat features such as riffles. Despite its unbalanced urban nature, there is a recent record of a paddlefish as well as a manatee observed in Buffalo Bayou.

Brays Bayou at Houston

- Base flow, Winter, Subsistence Condition: 3 cfs with attainment frequency of 95% of the time
- Base flow, Winter, Dry Condition: 6 cfs with attainment frequency of 84% of the time
- Base flow, Winter, Average Condition: 9 cfs with attainment frequency of 72% of the time
- Base flow, Winter, Wet Condition: 10 cfs with attainment frequency of 67% of the time
- Base flow, Spring, Subsistence Condition: 1 cfs with attainment frequency of 97% of the time
- Base flow, Spring, Dry Condition: 5 cfs with attainment frequency of 79% of the time
- Base flow, Spring, Average Condition: 8 cfs with attainment frequency of 60% of the time
- Base flow, Spring, Wet Condition: 10 cfs with attainment frequency of 50% of the time
- Base flow, Summer, Subsistence Condition: 1 cfs with attainment frequency of 97% of the time
- Base flow, Summer, Dry Condition: 5 cfs with attainment frequency of 72% of the time
- Base flow, Summer, Average Condition: 8 cfs with attainment frequency of 57% of the time
- Base flow, Summer, Wet Condition: 10 cfs with attainment frequency of 47% of the time
- Base flow, Fall, Subsistence Condition: 0 cfs with attainment frequency of 95% of the time
- Base flow, Fall, Dry Condition: 5 cfs with attainment frequency of 71% of the time
- Base flow, Fall, Average Condition: 7 cfs with attainment frequency of 58% of the time
- Base flow, Fall, Wet Condition: 9 cfs with attainment frequency of 48% of the time

The site is within a major urbanized city. This site and most of the bayou upstream and downstream of the site is channelized and hardened with a concrete channel for flood protection. Despite these constraints, some organisms use the bayou. Recent studies (Guillen) have shown that organisms use tributaries that are more natural than the main channel and migrate between the two. Fish utilize the bayou and concentrate in areas where tributaries empty into the main stem. Estuarine species such as mullet and menhaden feed on algae and are able to utilize this habitat. Turtles include American snapping turtles and soft-shelled species. Certain fish eating birds use the bayou such as Great Blue Heron and snowy egret. The habitat is sub-optimal for support of significant populations.

2.2.9.2. Flow Regime Recommendations

The following tables present full flow regime recommendations. It is anticipated that these flow regimes will be implemented similarly to the LSWP, namely that other, simpler, operating rules and permit restrictions will be evaluated through a long-term simulation model (WAM) and adjusted until the recommended flow regime is predicted to be achieved.

Overbank Flows	Q: 10,700 cfs with Frequency 1 per 5 years Volume is 202,575 Duration is 37			
High Flow Pulses	Q: 3,580 cfs with Frequency 2 per year Volume is 41,739 Duration is 17			
	Q: 1,380 cfs with Frequency 1 per season Volume is 16,418 Duration is 9 Q: 392 cfs with Frequency 2 per season Volume is 3,830 Duration is 4	Q: 3,540 cfs with Frequency 1 per season Volume is 35,438 Duration is 15 Q: 1,280 cfs with Frequency 2 per season Volume is 8,345 Duration is 8	Q: 535 cfs with Frequency 1 per season Volume is 5,749 Duration is 5 Q: 293 cfs with Frequency 2 per season Volume is 1,899 Duration is 3	Q: 338 cfs with Frequency 1 per season Volume is 3,475 Duration is 3
Base Flows (cfs)	118	138	82	79
	84	84	55	54
	52	53	40	39
Subsistence Flows (cfs)	24	28	15	16
	Dec, Jan, Feb	Mar, Apr, May, Jun	Jul, Aug, Sep	Oct, Nov
	Winter	Spring	Summer	Fall

Hydrologic Conditions	
	Wet
	Average
	Dry
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Figure 14 Flow Recommendations for West Fork Trinity River at Grand Prairie

Overbank Flows	Q: 11,000 cfs with Frequency 1 per 2 years Volume is 154,505 Duration is 18			
High Flow Pulses	Q: 6,900 cfs with Frequency 2 per year Volume is 94,502 Duration is 14			
	Q: 2,380 cfs with Frequency 1 per season Volume is 29,629 Duration is 9 Q: 418 cfs with Frequency 2 per season Volume is 2,218 Duration is 3	Q: 6,560 cfs with Frequency 1 per season Volume is 87,056 Duration is 14 Q: 2,980 cfs with Frequency 2 per season Volume is 34,860 Duration is 9	Q: 1,270 cfs with Frequency 1 per season Volume is 7,160 Duration is 5 Q: 361 cfs with Frequency 2 per season Volume is 1,975 Duration is 2	Q: 830 cfs with Frequency 1 per season Volume is 5,485 Duration is 5
Base Flows (cfs)	165	185	210	161
	102	112	106	101
	61	65	42	60
Subsistence Flows (cfs)	24	28	15	16
	Dec, Jan, Feb	Mar, Apr, May, Jun	Jul, Aug, Sep	Oct, Nov
	Winter	Spring	Summer	Fall

Hydrologic Conditions	
	Wet
	Average
	Dry
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Figure 15 Flow Recommendations for Elm Fork Trinity River near Carrollton

Overbank Flows	Q: 11,100 cfs with Frequency 2 per year Volume is 145,167 Duration is 18			
High Flow Pulses	Q: 8,720 cfs with Frequency 2 per year Volume is 110,120 Duration is 15			
	Q: 3,420 cfs with Frequency 1 per season Volume is 46,147 Duration is 9 Q: 758 cfs with Frequency 2 per season Volume is 3,968 Duration is 3	Q: 8,800 cfs with Frequency 1 per season Volume is 105,155 Duration is 15 Q: 4,120 cfs with Frequency 2 per season Volume is 41,998 Duration is 9	Q: 1,740 cfs with Frequency 1 per season Volume is 18,760 Duration is 6 Q: 660 cfs with Frequency 2 per season Volume is 685 Duration is 3	Q: 1,100 cfs with Frequency 1 per season Volume is 8,524 Duration is 5
Base Flows (cfs)	272	304	225	198
	132	152	104	112
	51	71	44	50
Subsistence Flows (cfs)	24	28	15	16
	Dec, Jan, Feb	Mar, Apr, May, Jun	Jul, Aug, Sep	Oct, Nov
	Winter	Spring	Summer	Fall

Hydrologic Conditions	
	Wet
	Average
	Dry
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Figure 16 Flow Recommendations for Trinity River at Dallas

Overbank Flows	Q: 26,000 cfs with Frequency 1 per 2 years Volume is 456,654 Duration is 27			
High Flow Pulses	Q: 12,600 cfs with Frequency 2 per year Volume is 164,647 Duration is 16			
	Q: 5,400 cfs with Frequency 1 per season Volume is 105,276 Duration is 10 Q: 2,650 cfs with Frequency 2 per season Volume is 30,078 Duration is 6	Q: 13,600 cfs with Frequency 1 per season Volume is 159,551 Duration is 16 Q: 6,400 cfs with Frequency 2 per season Volume is 70,661 Duration is 9	Q: 2,660 cfs with Frequency 1 per season Volume is 19,745 Duration is 5 Q: 1,100 cfs with Frequency 2 per season Volume is 10,751 Duration is 3	Q: 2,210 cfs with Frequency 1 per season Volume is 22,748 Duration is 4
Base Flows (cfs)	821	1078	574	626
	466	625	401	320
	248	398	266	208
Subsistence Flows (cfs)	106	212	142	125
	Dec, Jan, Feb	Mar, Apr, May, Jun	Jul, Aug, Sep	Oct, Nov
	Winter	Spring	Summer	Fall

Hydrologic Conditions	
	Wet
	Average
	Dry
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Figure 17 Flow Recommendations for Trinity River near Rosser

Overbank Flows	Q: 24,600 cfs with Frequency 1 per 2 years Volume is 626,471 Duration is 26			
High Flow Pulses	Q: 15,000 cfs with Frequency 2 per year Volume is 326,119 Duration is 18			
	Q: 11,200 cfs with Frequency 1 per season Volume is 257,289 Duration is 14 Q: 3,200 cfs with Frequency 2 per season Volume is 18,931 Duration is 5	Q: 15,700 cfs with Frequency 1 per season Volume is 362,910 Duration is 19 Q: 7,840 cfs with Frequency 2 per season Volume is 141,705 Duration is 11	Q: 2,930 cfs with Frequency 1 per season Volume is 26,246 Duration is 5 Q: 1,180 cfs with Frequency 2 per season Volume is 4,866 Duration is 2	Q: 3,050 cfs with Frequency 1 per season Volume is 39,239 Duration is 5
Base Flows (cfs)	1110	1398	682	819
	623	820	411	439
	340	458	257	265
Subsistence Flows (cfs)	196	280	70	101
	Dec, Jan, Feb	Mar, Apr, May, Jun	Jul, Aug, Sep	Oct, Nov
	Winter	Spring	Summer	Fall

Hydrologic Conditions	
	Wet
	Average
	Dry
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Figure 18 Flow Recommendations for Trinity River near Oakwood

Overbank Flows	Q: 44,600 cfs with Frequency 1 per 2 years Volume is 1,875,722 Duration is 34			
High Flow Pulses	Q: 22,700 cfs with Frequency 2 per year Volume is 499,009 Duration is 18			
	Q: 19,600 cfs with Frequency 1 per season Volume is 316,434 Duration is 16 Q: 8,860 cfs with Frequency 2 per season Volume is 85,975 Duration is 7	Q: 20,400 cfs with Frequency 1 per season Volume is 473,174 Duration is 17 Q: 11,300 cfs with Frequency 2 per season Volume is 172,144 Duration is 9	Q: 4,430 cfs with Frequency 1 per season Volume is 65,285 Duration is 5	Q: 5,420 cfs with Frequency 1 per season Volume is 119,525 Duration is 5
Base Flows (cfs)	2590	3033	1550	1720
	1500	1860	915	1000
	875	1160	580	630
Subsistence Flows (cfs)	542	720	210	250
	Dec, Jan, Feb	Mar, Apr, May, Jun	Jul, Aug, Sep	Oct, Nov
	Winter	Spring	Summer	Fall

Hydrologic Conditions	
	Wet
	Average
	Dry
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Figure 19 Flow Recommendations for Trinity River at Romayor

Overbank Flows	Q: 16,800 cfs with Frequency 1 per 5 years Volume is 158,831 Duration is 43			
High Flow Pulses	Q: 3,600 cfs with Frequency 2 per year Volume is 44,771 Duration is 18			
	Q: 1,820 cfs with Frequency 1 per season Volume is 33,557 Duration is 15 Q: 420 cfs with Frequency 2 per season Volume is 3,679 Duration is 7	Q: 3,430 cfs with Frequency 1 per season Volume is 44,140 Duration is 17 Q: 1,100 cfs with Frequency 2 per season Volume is 12,377 Duration is 9	Q: 193 cfs with Frequency 1 per season Volume is 1,301 Duration is 3 Q: 74 cfs with Frequency 2 per season Volume is 380 Duration is 2	Q: 345 cfs with Frequency 1 per season Volume is 2,833 Duration is 5
Base Flows (cfs)	111	88	38	47
	58	56	26	29
	36	37	18	22
Subsistence Flows (cfs)	23	24	9	9
	Dec, Jan, Feb	Mar, Apr, May, Jun	Jul, Aug, Sep	Oct, Nov
	Winter	Spring	Summer	Fall

Hydrologic Conditions	
	Wet
	Average
	Dry
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Figure 20 Flow Recommendations for West Fork San Jacinto River near Conroe

Overbank Flows	Q: 5,000 cfs with Frequency 1 per 2 years Volume is 51,766 Duration is 24			
High Flow Pulses	Q: 2,670 cfs with Frequency 2 per year Volume is 29,045 Duration is 17			
	Q: 1,410 cfs with Frequency 1 per season Volume is 18,911 Duration is 15 Q: 359 cfs with Frequency 2 per season Volume is 2,711 Duration is 7	Q: 2,440 cfs with Frequency 1 per season Volume is 23,987 Duration is 15 Q: 628 cfs with Frequency 2 per season Volume is 5,852 Duration is 8	Q: 367 cfs with Frequency 1 per season Volume is 2,595 Duration is 5 Q: 137 cfs with Frequency 2 per season Volume is 898 Duration is 3	Q: 304 cfs with Frequency 1 per season Volume is 2,019 Duration is 5 Q: 74 cfs with Frequency 2 per season Volume is 664 Duration is 2
Base Flows (cfs)	59	52	35	37
	36	36	24	24
	22	24	17	17
Subsistence Flows (cfs)	14	14	6	6
	Dec, Jan, Feb	Mar, Apr, May, Jun	Jul, Aug, Sep	Oct, Nov
	Winter	Spring	Summer	Fall

Hydrologic Conditions	
	Wet
	Average
	Dry
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Figure 21 Flow Recommendations for Spring Creek near Spring

Overbank Flows	Q: 4,000 cfs with Frequency 1 per 2 years Volume is 43,908 Duration is 23			
High Flow Pulses	Q: 2,030 cfs with Frequency 2 per year Volume is 23,386 Duration is 16			
	Q: 1,400 cfs with Frequency 1 per season Volume is 16,483 Duration is 15 Q: 475 cfs with Frequency 2 per season Volume is 5,055 Duration is 8	Q: 1,700 cfs with Frequency 1 per season Volume is 17,889 Duration is 13 Q: 687 cfs with Frequency 2 per season Volume is 6,769 Duration is 8	Q: 223 cfs with Frequency 1 per season Volume is 1,454 Duration is 4 Q: 94 cfs with Frequency 2 per season Volume is 288 Duration is 2	Q: 249 cfs with Frequency 1 per season Volume is 1,417 Duration is 4 Q: 56 cfs with Frequency 2 per season Volume is 188 Duration is 2
Base Flows (cfs)	80	64	34	38
	43	42	24	27
	30	28	18	19
Subsistence Flows (cfs)	22	18	8	10
	Dec, Jan, Feb	Mar, Apr, May, Jun	Jul, Aug, Sep	Oct, Nov
	Winter	Spring	Summer	Fall

Hydrologic Conditions	Wet
	Average
	Dry
	Subsistence

High Flow Pulse Characteristics	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Figure 22 Flow Recommendations for East Fork San Jacinto River near Cleveland

Overbank Flows	Q: 1,990 cfs with Frequency 1 per 2 years Volume is 49,128 Duration is 25			
High Flow Pulses	Q: 783 cfs with Frequency 1 per season Volume is 12,220 Duration is 10 Q: 521 cfs with Frequency 2 per season Volume is 6,301 Duration is 7	Q: 1,080 cfs with Frequency 1 per season Volume is 19,364 Duration is 12 Q: 569 cfs with Frequency 2 per season Volume is 7,316 Duration is 6	Q: 799 cfs with Frequency 1 per season Volume is 14,321 Duration is 13 Q: 395 cfs with Frequency 2 per season Volume is 4,734 Duration is 7	Q: 423 cfs with Frequency 1 per season Volume is 4,730 Duration is 6 Q: 231 cfs with Frequency 2 per season Volume is 325 Duration is 3
Base Flows (cfs)	58	51	96	75
	38	37	66	49
	25	26	45	33
Subsistence Flows (cfs)	11	13	26	13
	Dec, Jan, Feb	Mar, Apr, May, Jun	Jul, Aug, Sep	Oct, Nov
	Winter	Spring	Summer	Fall

Hydrologic Conditions	
	Wet
	Average
	Dry
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Figure 23 Flow Recommendations for Buffalo Bayou at Piney Point

Overbank Flows	Q: 3,700 cfs with Frequency 1 per 2 years Volume is 26,603 Duration is 26			
High Flow Pulses	Q: 1,440 cfs with Frequency 2 per year Volume is 10,972 Duration is 16			
	Q: 735 cfs with Frequency 1 per season Volume is 5,167 Duration is 14 Q: 239 cfs with Frequency 2 per season Volume is 1,444 Duration is 7	Q: 707 cfs with Frequency 1 per season Volume is 4,222 Duration is 10 Q: 263 cfs with Frequency 2 per season Volume is 1,367 Duration is 6	Q: 197 cfs with Frequency 1 per season Volume is 1,032 Duration is 6 Q: 69 cfs with Frequency 2 per season Volume is 385 Duration is 3	Q: 246 cfs with Frequency 1 per season Volume is 1,505 Duration is 6 Q: 26 cfs with Frequency 2 per season Volume is 90 Duration is 2
Base Flows (cfs)	10	10	10	9
	9	8	8	7
	6	5	5	5
Subsistence Flows (cfs)	3	1	1	1
	Dec, Jan, Feb	Mar, Apr, May, Jun	Jul, Aug, Sep	Oct, Nov
	Winter	Spring	Summer	Fall

Hydrologic Conditions	
	Wet
	Average
	Dry
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Figure 24 Flow Recommendations for Brays Bayou at Houston

2.2.10. Application

It is tempting to include recommendations for how these flow regimes should be implemented. SB 3, however, is rather specific on the roles of the BBESTs and the stakeholders groups or BBASCs. Recommendations for implementation must be developed based on the goals and concerns of stakeholders.

In fact, the skills and expertise required to develop recommendations for implementation and management are clearly a different set than the skills required to evaluate the ecological needs of rivers and bays, which in SB 3 terms is done "without regard to the need for water for other uses." BBASCs are given the role of balancing a wide range of concerns which are clearly beyond the limited realm of strict application of science. The BBEST members were selected based on their qualifications "with special expertise regarding the river basin and bay system or regarding the development of environmental flow regimes." For these reasons, consideration of implementation issues, including the present and future needs for water for other uses was specifically delegated to the BBASCs.

To delve into the issue of implementation might be viewed as a usurpation of the role of BBASCs. It might have the effect of limiting the options available to the BBASCs. However, as has been recognized by numerous individuals throughout this process, stakeholder decisions related to implementation will likely be informed by technical input and the scientists on the BBESTs may find their advice needed by the BBASCs.

2.2.11. Knowledge Gaps, Research priorities and Adaptive Management

SB 3 recognized the need for continuing assessment of environmental flow needs in the future:

> "(p) In recognition of the importance of adaptive management, after submitting its recommendations regarding environmental flow standards and strategies to meet the environmental flow standards to the commission, each basin and bay area stakeholders committee, with the assistance of the pertinent basin and bay expert science team, shall prepare and submit for approval by the advisory group a work plan. The work plan must:
>
> (1) establish a periodic review of the basin and bay environmental flow analyses and environmental flow regime recommendations, environmental flow standards, and strategies, to occur at least once every 10 years;
>
> (2) prescribe specific monitoring, studies, and activities;
>
> and

(3) establish a schedule for continuing the validation or refinement of the basin and bay environmental flow analyses and environmental flow regime recommendations, the environmental flow standards adopted by the commission, and the strategies to achieve those standards.

Specific gages were utilized to determine flow recommendations primarily over the period from 1924 to 1964. The BBEST initially chose 13 priority gage stations for developing recommendations. In most cases, one gage is used to characterize a significant stretch of river. For example the Romayor gage characterizes most of the reach between Lake Livingston and the Wallisville Salt Water Barrier. To refine recommended flows for the basin's rivers and streams, an analysis of recommended flows for each priority station should be extrapolated to other stations and their respective river reaches. This analysis should incorporate overlapping periods of record and include additional watersheds. An assessment should be made as to the environmental resources that are affected including instream and floodplain habitats. With regard to the Romayor gage, for example, an analysis can be made to determine how recommended flows might behave at 5 gage stations further downstream (or upstream). Specific habitat features associated with a particular tributary may be significantly different downstream or upstream of the priority gage site.

There is a need to develop a precipitation-based metric to help determine watershed moisture levels. There are metrics such as the Palmer Drought Index, but these are focused on drought episodes. Flow recommendations are based on a period of record. There are limited methods to determine whether a given year or month is in a dry, normal or wet period. This is important to enhance our understanding and recommendations for pulse flows.

SB 3 includes provisions for the development of a workplan in cooperation with the BBASC. It is assumed that some of this issues (knowledge gaps and research priorities) will be addressed by the planned SB 2 studies in the basin. The following list was adapted from Richter etal. 2006. This list was used to help develop the biological overlay scopes of work and, along with the TIPD technical overview document, will provide a starting point for the workplan development.

Hydrology

1. Do stream gauges exist along the river, and if so, where are they located, who maintains them, and how long have they been in operation?
2. What are/were the typical seasonal patterns of natural river flow variation (e.g. when do higher flows tend to occur, when do the lowest flows occur)?
3. To what extent have the low, high pulse, and flood flows in the river changed over time in response to human influences? Have extreme low flows become more frequent or extreme? How do hydrographs from recent years compare to predevelopment hydrographs?

4. What are the primary human influences on the flow regime, and where do these impacts occur? Do certain human impacts appear to dominate over other human influences?
5. What types of water development activities are planned for the future, and how might those developments influence river flows?
6. How important are ground water contributions to base flows? What is the nature of hydraulic connections between river stage and alluvial water table levels? How might these connections be altered by future water developments?

Suggested approaches:

- Prepare a schematic drawing of the drainage network, noting the mean annual flow and drainage basin area at all available stream gauge stations.
- Provide a tabular summary of water uses and water structures, at the finest level of detail available.
- Prepare "typical" hydrographs (both annual and decadal hydrographs) for undeveloped and developed conditions at all river and lake monitoring stations.
- Categorize the natural hydrologic regime into ecological flow components: subsistence flows, base flows, high pulse flows, overbank flows. Using the IHA software, estimate quantitative values for each of these components under natural, historic, present, and future conditions (if hydrologic simulation data are available). Assess changes in the magnitude, duration, timing, and frequency of each flow component.
- Prepare flow duration curves for undeveloped and developed conditions at all stream gauges.
- Characterize typical groundwater-surface water interactions using monitoring well data or other sources of information.

Hydraulics

1. Has any hydraulic modeling been performed for the river? Has any flood hazard mapping been undertaken?
2. How well are relationships between river stages (water elevations) and river flow levels understood?
3. How well are relationships between river flow and the distribution of velocities and depths in the river channel understood?
4. Is there longitudinal (upstream to downstream) connectivity in flow or are there major discontinuities (i.e. diversion dams), and if so where?
5. Has the lateral connectivity between the river and its floodplain been altered in any way?

Suggested approaches:

- Develop river stage-discharge relationships (e.g., at flow monitoring stations or from hydraulics models).

- Plot the relationship between flow and estimated percent floodplain inundated at representative river transects (e.g., at stream gauges or from aerial photos).
- Develop flow depth and velocity estimates across river transects (e.g., at stream gauges or using hydraulics models)

Geomorphology

1. Have any topographical surveys been conducted of the river channel or floodplain (including any surveying for bridges, roads, floodplain mapping, etc.)?
2. Is the channel and floodplain system in dynamic equilibrium or disequilibrium? Is the sediment input to each segment in equilibrium with the capacity of the channel to transport it through the segment? Are there detectable trends in the elevation of the river bed or lake bottom, indicating degradation or aggradation? Has the river's longitudinal profile changed over time?
3. Has the channel or floodplain width changed over time?
4. Has the channel's planform changed over time, such as between meandering and braided forms?
5. Has the size distribution of stream bed sediments changed over time?
6. Has the availability of in-stream physical habitats changed over time (e.g. changes in availability of pools or riffles)?
7. Is lateral channel migration or bar formation important ecologically (e.g. to support riparian plant communities)?
8. Has human activity and land use significantly altered the stream channel and floodplain morphology and processes?

Suggested approaches:

- Plot the river's present-day longitudinal profile from topographic maps or field survey information.
- Characterize historical changes in longitudinal river slope, if adequate data are available (e.g., at multiple river flow monitoring station locations).
- Review historical aerial photographs to assess changes in river plan form and floodplain over time.
- Assess changes in channel cross-sectional shape, if data are available (e.g., at stream gauges).
- Develop sediment budget estimates for appropriate representative time periods, such as historic, pre-dam agricultural, and post-dam periods.
- Estimate flows necessary to entrain river sediments (to maintain desired streambed composition or move sediment downstream to lake).
- Estimate channel forming flows necessary to maintain desired channel geometry.
- Estimate channel migration flows needed to sustain floodplain development and riparian ecosystem.

Water quality

1. Have water quality data been collected for the river, and if so, by whom, where, for how long, and of what type?
2. How do water quality conditions vary spatially in the river?
3. What is known about water quality problems in the river?
4. Is wastewater discharged into the river? Where, and how much? What proportion of the low flows in the river arises from upstream wastewater discharges?
5. What is known about daily, seasonal, annual fluctuations in key parameters such as dissolved oxygen or temperature in the river?
6. How do human activities affect water chemistry, temperature or dissolved oxygen in the river?
7. What water quality components are of greatest concern to the target organisms, life stages or riverine processes (e.g. dissolved oxygen, suspended sediment, temperature, chemical elements, nutrients)? Are species distributions or abundances thought to be affected by water pollution?
8. Is large woody debris an important component of the aquatic ecosystem?
9. Are any invasive plant species an issue of concern?

Suggested approaches:

- Characterize natural and post-development patterns of water temperature, including seasonal and diurnal fluctuations.
- Characterize natural and post-development patterns of dissolved oxygen in the water, including seasonal and diurnal fluctuations.
- Identify known relationships between reservoir releases and discharge of contaminants present in the reservoir.

Freshwater ecology

1. What type of biological data have been collected for the river? Who collected these data, over what time frame, and how often?
2. Has the abundance or distribution of certain species changed over time? Are these changes thought to be linked to changes in river flow or water quality? Are data available to document these trends?
3. What species (fish, birds, mammals, invertebrates, aquatic plants or riparian vegetation) are of greatest concern from either ecological or socio-economic or recreational standpoints?
4. What is known about the linkages between river flow and life histories of aquatic species? What times of year are most critical for indicator species, life stages or species assemblages?
5. Can the flow needs of certain indicator species be used to represent the flow needs of assemblages of organisms (e.g. fish communities, riparian vegetation)?

6. If the river flow regime has been altered by human influences, are necessary flow conditions still properly sequenced to enable successful life cycle completion for indicator species?
7. Which habitats are most limiting, and what is the importance of drought, flooding and intermediate flow conditions for developing and maintaining these habitats?
8. Are aquatic floodplain habitats critical for maintaining fish populations in rivers?
9. Is the aquatic ecosystem dependent upon energy subsidies (e.g. detrital matter) that are brought into the river from the floodplain during floods?
10. Do certain species require particular flow levels to facilitate movements in the river?
11. If reservoir releases are proposed in order to provide recommended flows, could there be effects on the ecology and fisheries in the reservoir?

Suggested approaches:

- Define life history stages for a diverse cross-section of species, such as aquatic plants, invertebrates, and resident and anadromous fishes, along with any known relationships to flow components and their seasonality. Specific life history aspects to consider include adult foraging, survival, and gonadal development; spawning migration and activity; egg, larva, and juvenile development; juvenile growth and survival.
- Define relationships between flow components and maintenance or access to critical habitats for completion of life history stages for key species.
- Describe ways in which flow components will influence primary productivity, decomposition processes, and nutrient dynamics.

Riparian ecology

1. Have the riparian plant communities or distributions of riparian plant or animal species been surveyed or characterized?
2. Have they changed over time?
3. What is known about relationships between river flows, alluvial water table levels, floodplain inundation patterns, and the influence of these hydrologic conditions on riparian plants or animals?
4. Do certain riparian plants or animals depend upon physical habitat conditions that are shaped by river flows? Is lateral channel migration or bar formation important in forming these physical habitats?

Suggested approaches:

- Define life history stages for a diverse cross-section of riparian obligate flora and fauna species, along with known relationships to flow components and the seasons in which they occur.
- Define relationships between flow components and maintenance or access to riparian habitat conditions.

- Describe relationships between flow components and vulnerability to disturbances such as fire or introduced species invasions.
- Describe ways in which flow components will influence primary productivity, decomposition processes, and nutrient dynamics.

3. FRESHWATER INFLOW RECOMMENDATIONS FOR GALVESTON BAY

Endorsed by:

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The recommendations contained in this report are in response to a mandate from the Texas Legislature contained in SB 3 and guidance provided by the SAC tasked to oversee the work of the BBESTs. In the document provided by the SAC entitled "Methodologies for Establishing a Freshwater Inflow Regime for Texas Estuaries within the Context of the Senate Bill 3 Environmental Flows Process," a set of recommended procedures are provided.

This is not the first effort to establish recommendations for environmental flows in Texas or to Galveston Bay. A multi-stakeholder group, the Galveston Bay Freshwater Inflow Group (GBFIG) met for many years with the support of the Galveston Bay Estuary Program. They employed a methodology developed by the relevant state agencies, Texas Commission on Environmental Quality, Texas Parks and Wildlife Department and Texas Water Development Board to estimate the freshwater inflows necessary to maintain productivity of the bay. The recommendations produced by the group are shown below. This was a voluntary effort and did not have the legislative mandate that the current process has.

After reviewing water availability and demand models, GBFIG recommended that the Region H Planning Group consider environmental flows when constructing its regional plan. The Group noted that successful management of inflows to Galveston Bay must consider quantity, quality, seasonality (monthly flows), and location of inflows. The chart below contains the group's recommendations.

Inflow Scenario	Quantity Needed (acre-feet/year)	Historical Frequency	Target Minimum Frequency
Max H	5.2 million	66%	50%
Min Q	4.2 million	70%	60%
Min Q-Sal	2.5 million	82%	75%
Min Historic	1.8 million	98%	90%

Scenario Descriptions

Max H: Inflows required for maximum bay and estuary fisheries harvest as recommended by Texas Parks and Wildlife Department.

Min Q: Minimum inflow required to maintain the bay and estuary fisheries harvest.

Min Q-Sal: Minimum acceptable inflow required to maintain the salinity needed for bay and estuary fisheries productivity.

Figure 25 This text box contains the summary of the recommendations developed by the Galveston Bay Freshwater Inflow Group in a stakeholder process that preceded the current process, taken from 2006 Region H Water Plan.

The SAC guidance for the current process provides some specific suggestions about how the BBEST should proceed. The preceding state methodology has been modified based on new legislative mandates and revised opinions on best practices. One recommendation by the SAC is that limited deterministic models and data from the estuary be used to infer responses of the system to inflows. A second recommendation is to use a simple conceptual model that retains only the most salient inflow effects. The

model suggested is shown in the Figure 26 below (labeled 2.1-2). This calls for modeling of the flow-salinity-biology relationships that can be extracted from the data available.

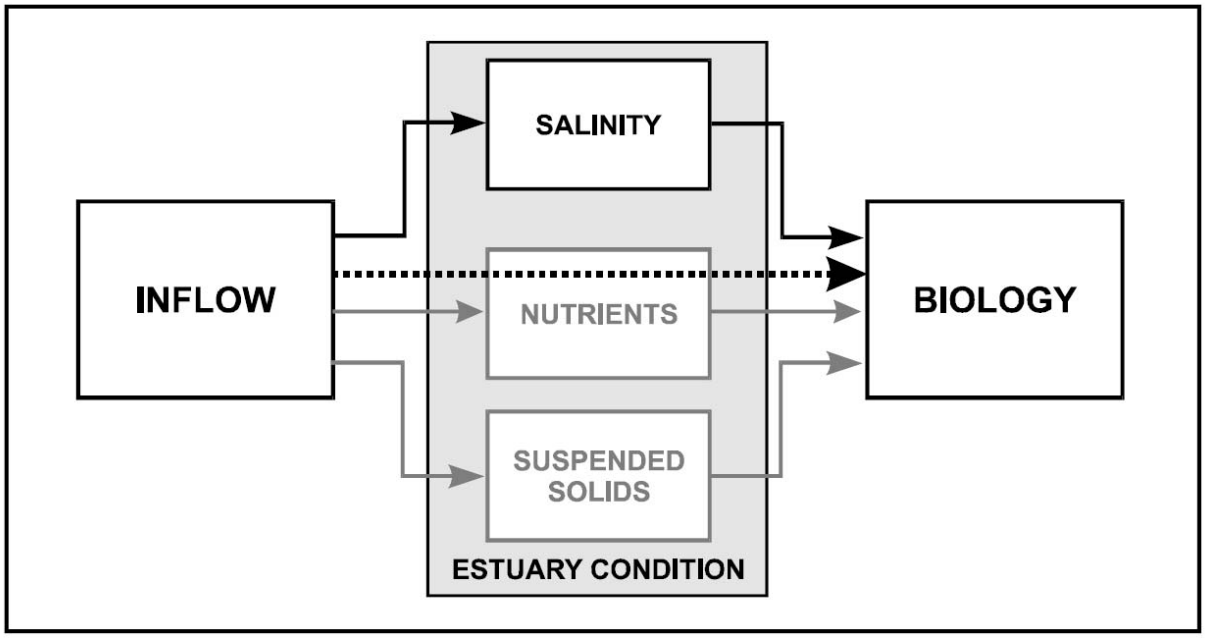

Figure 2.1-2 – Schematic of Relation of "Biology" to "Inflow" (Compressed from Figure 2.2-1)

Figure 26 Illustration taken from the Science Advisory Committee guidance document on establishing freshwater inflow regimes for Texas estuaries.

This dependence on a flow – salinity – ecology model is problematic for the development of biological indicators. Estuaries are a transition zone between freshwater and oceanic water. It is their nature to have variable salinity and all organisms that are adapted to life in estuaries can tolerate a wide range of salinities. It is very unusual for the salinity in Galveston Bay to reach a high or low level that affects the abundance of common organisms by causing mortality. If the salinity is above or below the salinity niche range of a mobile organism, then it simply relocates to another part of the system or into the Gulf of Mexico. If such a condition affects a sessile or planktonic organism, some species have adaptations, such as shells, that protect them from the condition and others will experience mass mortalities. However, unlike a few other estuaries on the Texas coast, Galveston Bay does not have sufficient data on benthic invertebrates collected with the spatial and temporal distribution needed for this purpose. Most of the species associated with recreational and commercial fisheries have salinity niche ranges that make them unsuitable as biological indicators for this committee.

The committee discussed the weakness of the flow – salinity – ecology relationships when compared to flow – nutrients – ecology relationships, but determined that there is

sufficient flow-salinity data and insufficient flow-nutrient data for our purposes. Nutrients in various forms have a more direct impact on the abundance of estuarine species than salinity. More data on the relationship of freshwater and nutrient content of those flows should be collected in the future as part of the adaptive management program.

The weakness of the salinity–abundance relationships for most common species in the estuary led the work group to seek relationships with life history stages that were more sensitive than adults, e.g. seed germination in *Vallisneria* and larval survival in *Rangia cuneata.* The same logic resulted in a focus, not on the abundance of oysters, but on the level of parasitism in the oysters.

Galveston Bay has an abundance of data on the spatial and temporal abundance of fish and macroinvertebrates obtained from a long term fisheries independent monitoring program of Texas Parks and Wildlife (TPWD). Also the Texas Water Development Board (TWDB) has collected substantial data on the salinity of Galveston Bay from datasondes distributed along a salinity gradient from Trinity Bay to Lower Galveston Bay. Inflow data has been collected by a variety of agencies, the primary source being gauges monitored by USGS. TWDB has augmented the gauge data through modeling to provide estimated total inflows to Galveston Bay for a period from 1983 to 2005. Discussion of the flow and salinity data and models employed in the evaluation of flow – salinity – biology relationships to obtain the following recommendations can be found in the final report labeled "Technical Support for the Analysis of Historical Flow Data from Selected Flow Gauges in the Trinity, San Jacinto, and Adjacent Coastal Basins Galveston Bay: Salinity Zonation Analysis for the Trinity-San Jacinto and Galveston Bay Basin and Bay Expert Science Team" by Tony Smith and Joe Trungale provided as Appendix A.

Tony Smith (Espey Consultants) and Joe Trungale (Trungale Engineering) assessed the use of statistical analyses of the flow – salinity relationships in comparison to the use of the TXBlend model to inform the evaluation of impacts of flow alteration on the selected biological indicators. Based on their results and advice from the SAC, it was decided to proceed using the TXBlend modeling approach. TXBlend provides sufficient spatial detail in modeling salinity that it is possible to map the predicted salinity effects of flow levels across the Galveston Bay system. Two such results of the salinity pattern that obtains from a flow at the 50th percentile level (Figure 27) and a flow at the 75th percentile level (Figure 28) are shown below.

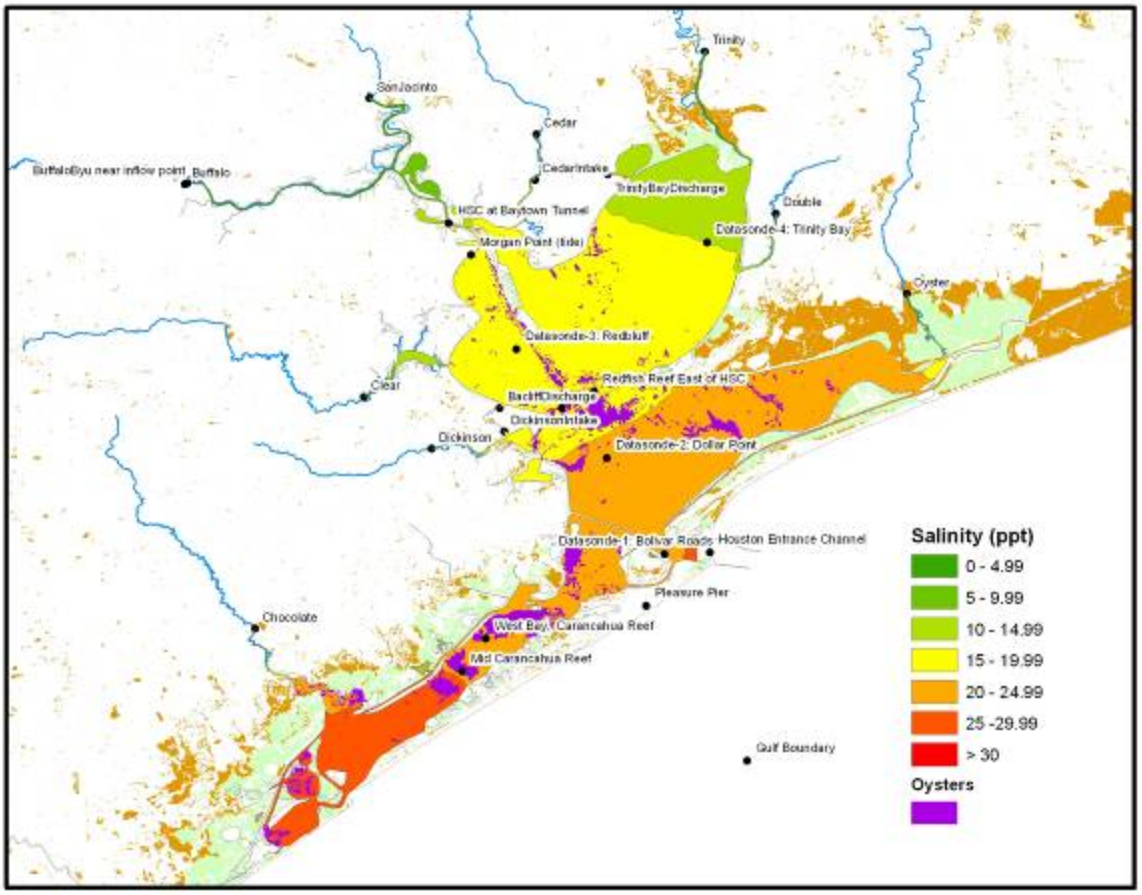

Figure 27 Map of salinity areas in Galveston Bay based on 5 psu isohalines for the flow pattern of May 2000 using the TXBlend model to estimate the flow-salinity relationship. This flow level represents the 50th percentile of flows from the period of record used by TXBlend.

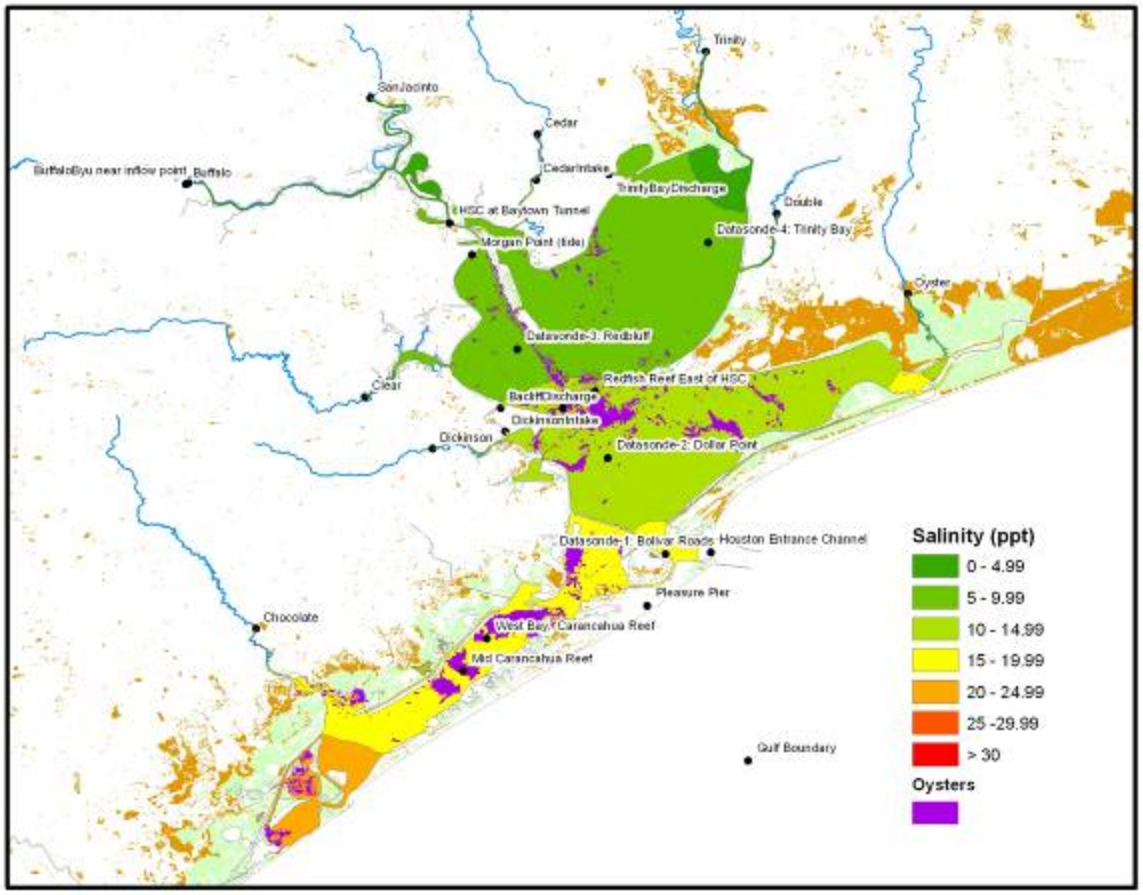

Figure 28 Map of salinity areas in Galveston Bay based on 5 psu isohalines for the flow pattern of May 1994 using the TXBlend model to estimate the flow-salinity relationship. This flow level represents the 75th percentile of flows from the period of record used by TXBlend.

The degree to which the modeled flow – salinity relationship is representative of the observed pattern of flow and salinity is of great importance because model results form the basis for assessing the impact of flow levels on the biology of the estuary. In their final report, Smith and Trungale provide some analyses of the relationships at the several locations in the bay where datasondes have been collecting salinity data. The greatest bias in the TXBlend model is expressed in upper Trinity Bay. Figure 29 below (labeled 2.3-2) shows the variation around a polynomial regression line of the salinity flow relationship. The level of variation is a caution that any flow – salinity relationship assumed in the evaluation of biological indicators will have a high level of uncertainty associated with it.

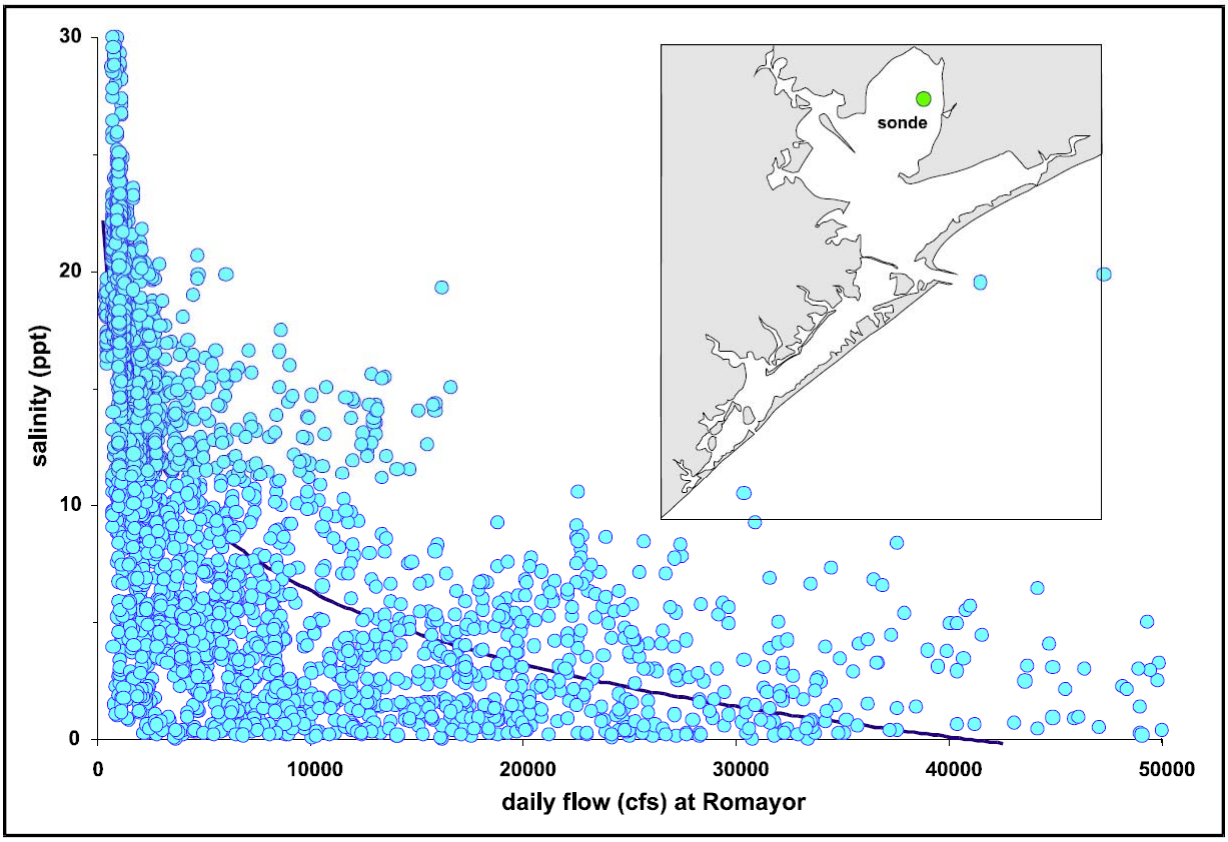

Figure 2.3-2 Surface Daily-Mean Salinity at Trinity Bay Sonde Versus Trinity River Flow at Romayor with 30-Day Lag of Salinity Behind Flow for 1986-2007
(from data files of Texas Water Development Board)

Figure 29 Illustration taken from the final report of Smith and Trungale showing the residual variation in the relationship of observed salinity and flow at the TWDB datasonde in Trinity Bay and the USGS gauge at Romayor.

The Trinity-San Jacinto BBEST organized a subcommittee to work on the freshwater inflow recommendation for Galveston Bay. The subcommittee invited experts on estuarine ecology from multiple agencies and Texas universities. That subcommittee met four times. The summaries of those meetings are attached in Appendix C.

The first task of the work group was to develop a set of biological indicators that have known sensitivities to salinity. This was facilitated by analyses performed by the Houston Advanced Research Center based on the Galveston Bay Status and Trends Project of the Galveston Bay Estuary Program (www.galvbaydata.org). Statistical relationships of organism abundance and salinity measured by TPWD at each collection event permitted the screening of approximately 100 common organisms. The candidate species were discussed by the group and those shown in Table 33 were selected. The salinity niche parameters of particular life stages were obtained from sources or agreed upon based on the best professional judgment of the ecological experts on the work group from the BBEST, agencies and universities. In several cases, the salinity

parameters associated with reproduction were employed because that is the most critical aspect of the salinity-biology relationship. The critical season for reproduction was determined from the literature or knowledge of participating experts. In the case of oysters, the relevant biological indicator is the level of infection by the parasite *Perkinsus marinus* or predation by the oyster drill. The relationship of salinity to infection and oyster survival is complicated by the importance of a temperature-salinity interaction. Therefore, the basic indicator for protection of oysters from high mortality due to infection is confined to months that typically have high water temperatures: July, August and September. Table 33 lists the salinity criterion associated with the indicator and the period of time in which the desired salinity conditions would be analyzed.

Table 33 Identified Biological Indicators for Evaluating Freshwater Inflow Needs to Galveston Bay. Emphasis was placed on the sessile organisms: wild celery, Atlantic *rangia* and oyster parasites and predators.

	Common Name	Scientific Name	Criterion	Period of Concern
Habitat Indicator	Wild Celery	*Vallisneria americana*	<5 psu for germination and establishment	Spring
	"	"	<10 psu for survival	Summer and Fall
Low Salinity Indicators	Atlantic *Rangia*	*Rangia cuneata*	2 – 10 psu for spawning and larval survival	Spring and Fall
	Gulf menhaden	*Brevoortia patronus*	5 – 15 psu for occurrence as forage fish	Winter and Spring
	Blue catfish	*Ictalurus furcatus*	<10 psu for occurrence as predator	Single pulse in winter or spring
High Salinity Indicators	Mantis shrimp	*Squilla empusa*	>25 psu for abundance	Summer - Fall
	Pinfish	*Lagodon rhomboides*	>25 psu for abundance	Summer - Fall
Oyster Health Indicators	Dermo and oyster drill impacts on oyster	Dermo= *Perkinsus marinus* Oyster drill= *Stramonita haemastoma* Oyster= *Crassostrea virginica*	10 – 20 psu to prevent excessive parasitism and predation	July - September
	"	"	<5 psu to remove parasite load from central reefs	2 weeks at 10 year intervals

Once the biological indicators had been chosen and their salinity niches decided upon, the areas of the bay in which these conditions were to be targeted were determined. Each species had a record of spatial distribution either in the TPWD monitoring database or in other monitoring studies. The habitat area of wild celery was based on a mapping study provided by TPWD. The areas of Atlantic *Rangia*, Gulf menhaden, blue

catfish, mantis shrimp and pinfish were based on maps of occurrence provided by HARC derived from the TPWD database. One such map for Atlantic *Rangia* is shown in Figure 30. It clearly shows the association between this clam and shallow, low salinity habitats in Trinity Bay.

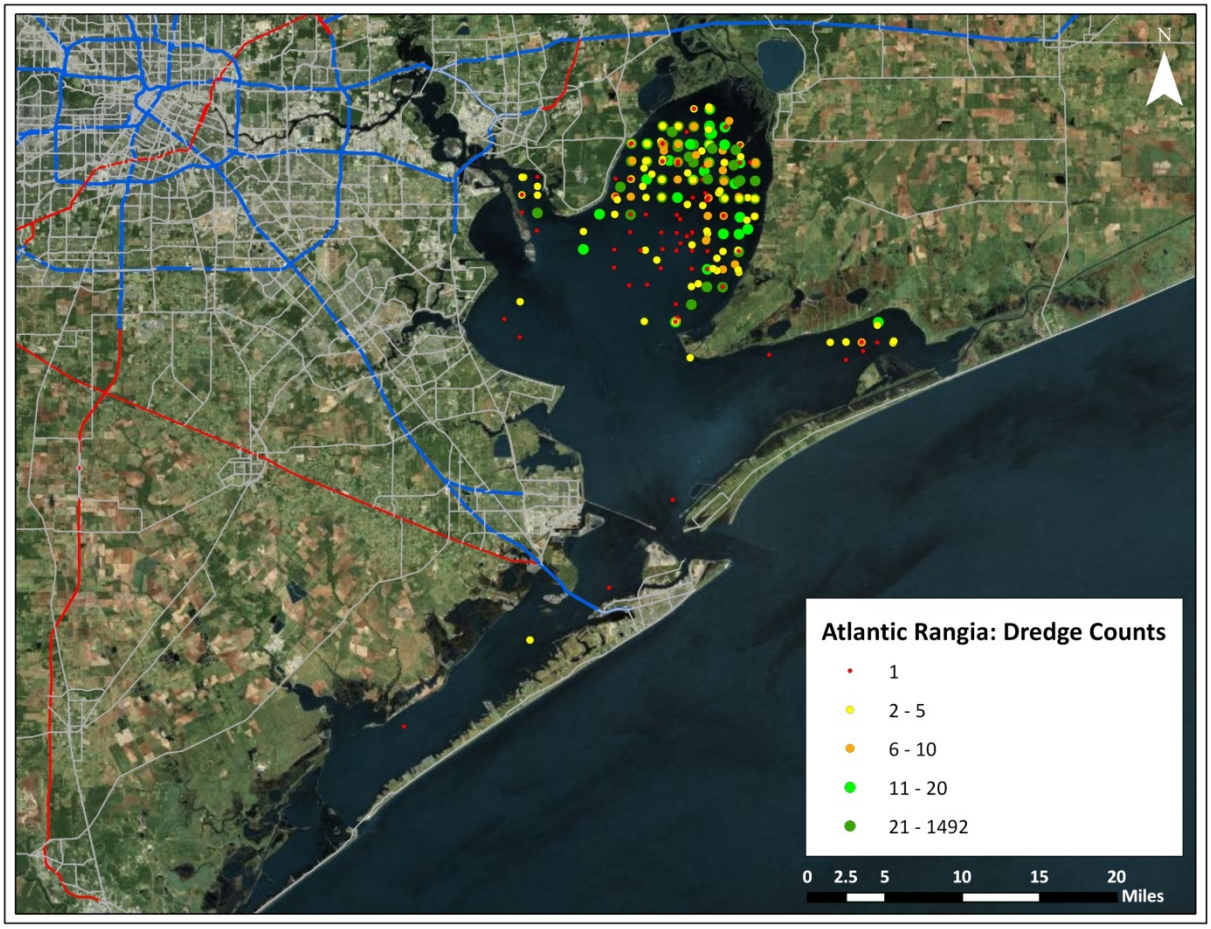

Figure 30 Map of the collections of Atlantic *Rangia* by TPWD in dredge samples and the abundance of clams in each collection.

Oysters occur all over Galveston Bay and are capable of colonizing areas in which the population has been decimated. The work group decided that oysters are extremely important to the ecology of the bay, but only a refuge must be protected for the maintenance of a characteristic ecology. Based on the input of Dr. Sammy Ray, a venerable oyster expert, the oyster refuge area was established as an ellipse in the area from Hanna's Reef at the mouth of East Bay to near Eagle Point on the western shore. The regions assigned to all of the biological indicator organisms are shown in the following Figure 31.

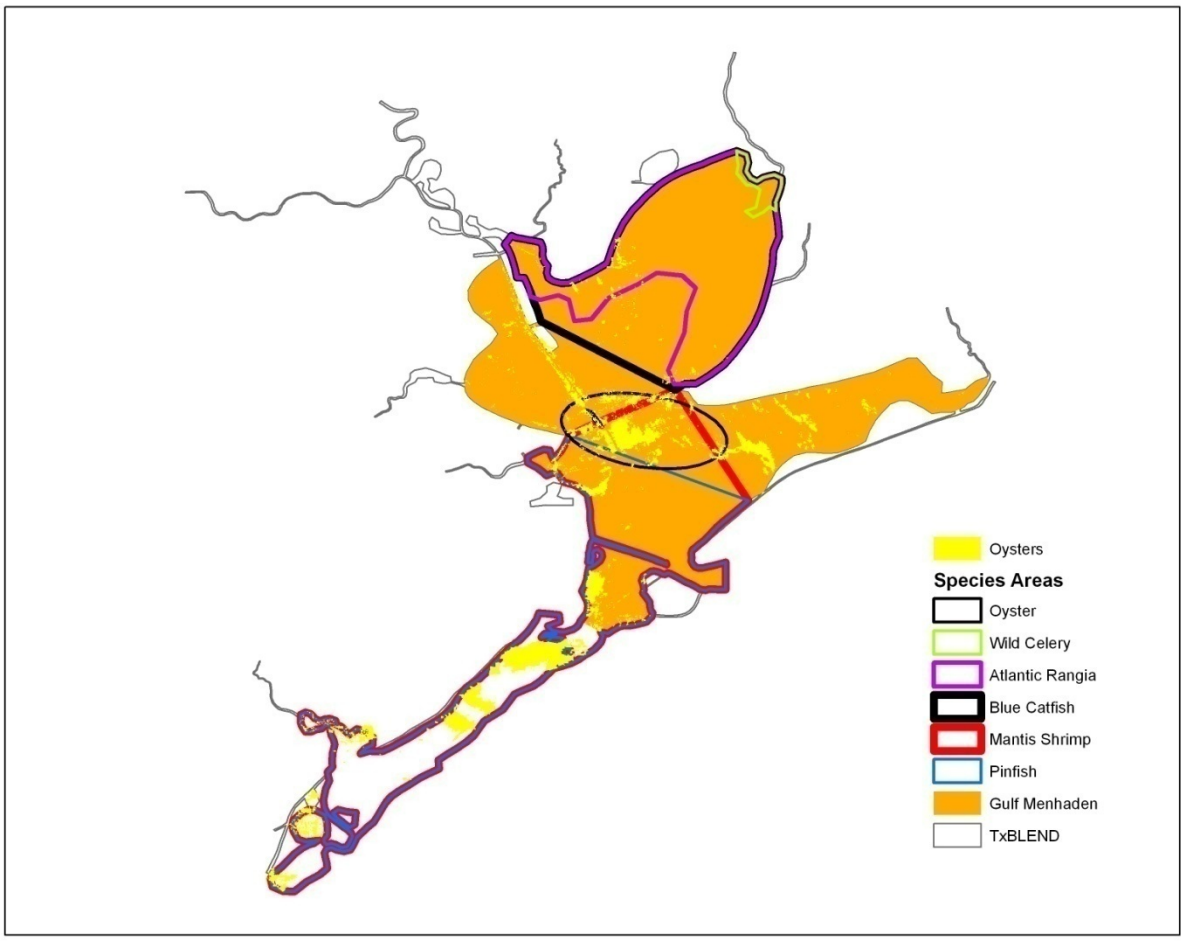

Figure 31 Map of the areas assigned to each biological indicator for evaluation of flow effects on the suitability of the salinity conditions. The areas assigned to high salinity indicator species were not used in determining the recommendations.

Once the biological indicators and their areas had been established, there was a discussion about the relationship between flow and the establishment of suitable salinity conditions in those areas. Tony Smith and Joe Trungale provided assessments of how often in the period of record of TxBLEND a suitable salinity had existed for the indicator area and how much of the area had been covered by the desired conditions. An example of the output of such analyses is shown in Figure 32. This pattern of meeting 100% of the area a significant portion of the time contributed to the work group's decision to base recommended flow rates on achievement of all or nearly all of the designated area.

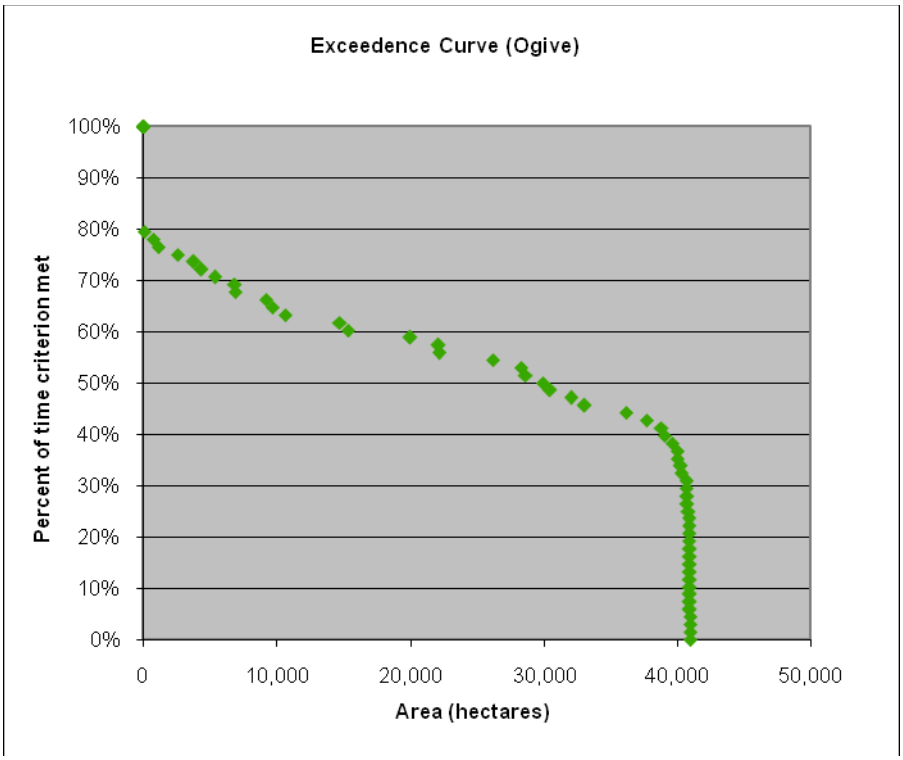

Figure 32 This plot shows the percentage of spring months (March, April, May) in a TXBlend run that a given area of the Atlantic *Rangia* designated area meets the salinity criterion set (2-10 psu).

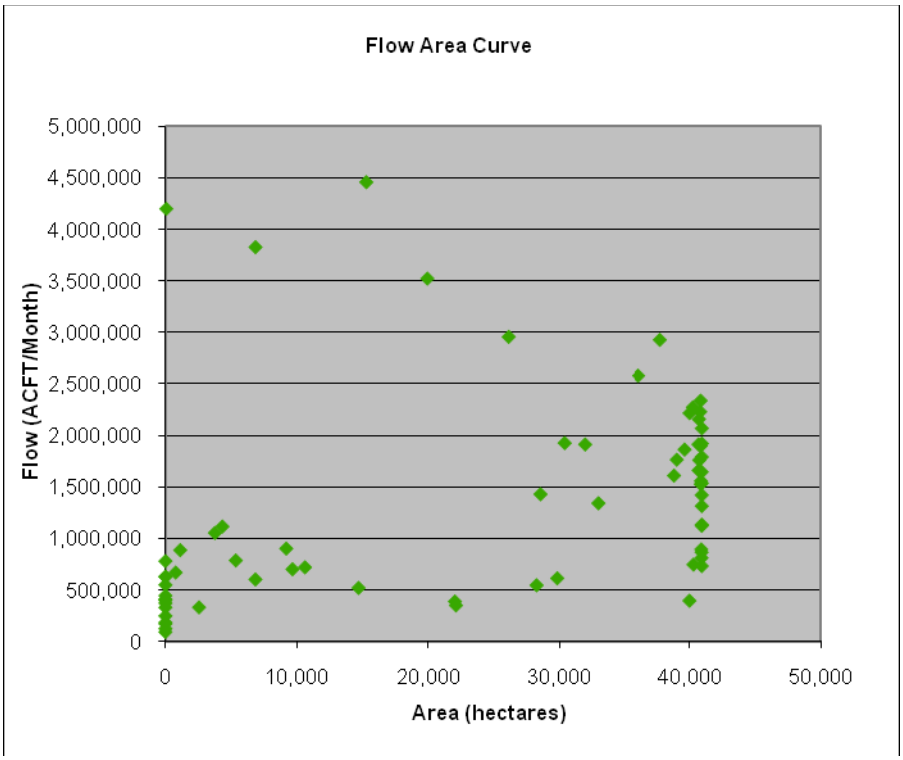

Figure 33 This graph shows the flows that contributed to the plot in Figure 32 of frequency of meeting the criterion for portions of the indicator area of Atlantic *Rangia*. When a suitable salinity for *Rangia* exists across 10,000 to 20,000 hectares of Trinity Bay the contributing flows can differ greatly.

During the discussions of the work group on how best to obtain flow values from the analysis of the TxBLEND model of salinity results from freshwater inflows, it was decided that a logistic regression seemed to represent well the behavior of the salinity patterns of several of the biological indicators. Especially the area assigned to *Vallisneria* habitat seemed to change in a stepwise fashion from unsuitable to suitable. The logistic regression analysis can yield a range based on a confidence level. It was decided that the lower, more conservative value would be incorporated into the recommendations. Figure 34 below shows a comparison of a logistic regression and a polynomial regression using data for monthly flows and the area inside the oyster ellipse with suitable salinity (10 – 20 psu) when the antecedent salinity was high.

Joe Trungale demonstrated to the work group the importance of considering the antecedent salinity condition when applying this analysis. It is intuitive that a salty bay will require a higher flow to reach a low salinity when the current conditions are high salinity. The conundrum associated with this approach is that high salinity conditions are likely to be associated with dry periods when additional volumes of water are not available or likely. However, this approach was applied in several cases when the importance of a short term inflow to the biological indicator seemed to warrant it.

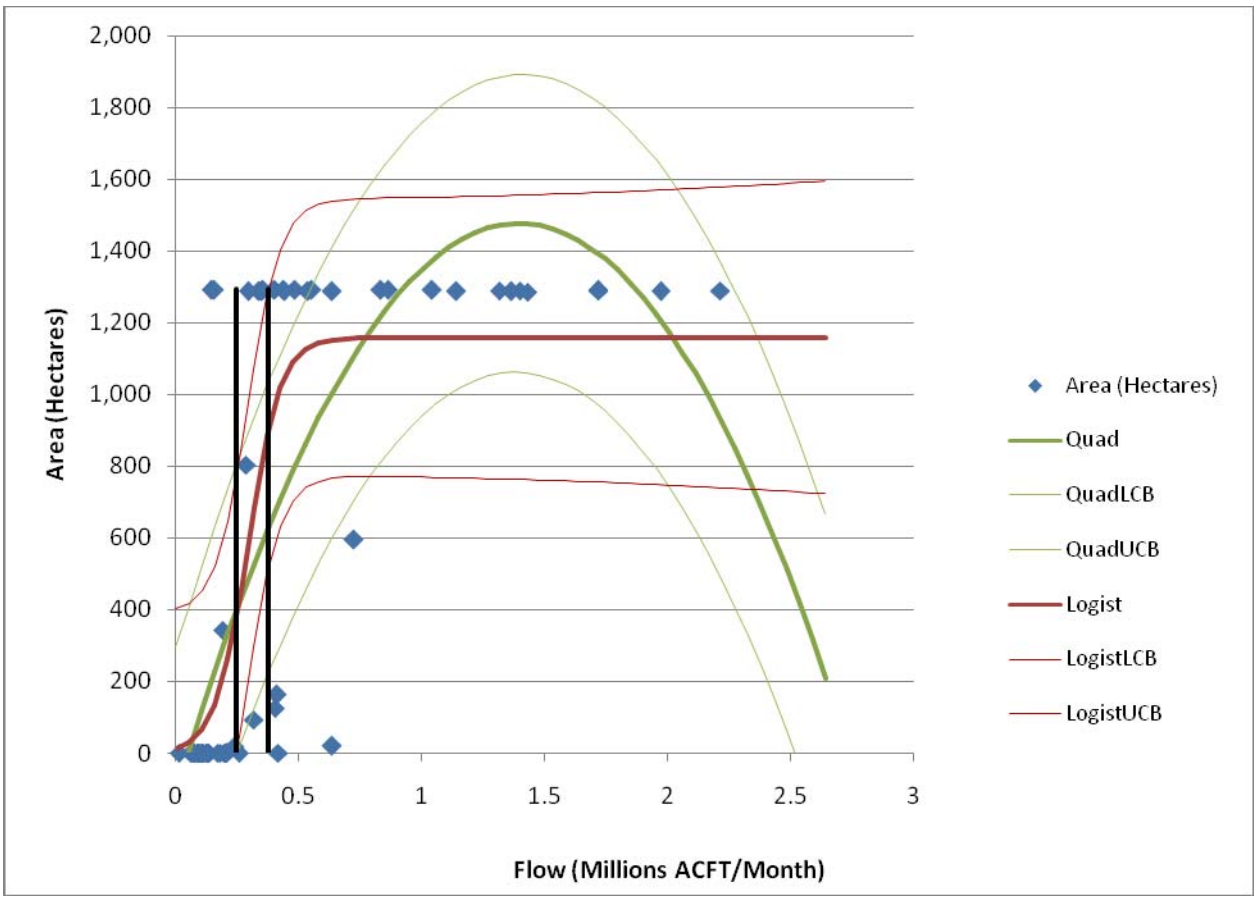

Figure 34 An example of a regression analysis of the relationship between summer inflow and the salinity conditions in the area assigned to the *Vallisneria* indicator. Note that the logistic regression curve provides a better fit to the points than the polynomial regression labeled Quad.

Using the methods described above, the BBEST has arrived at a set of recommended freshwater inflow values. The tables below present flow recommendations stated in acre-feet per month. There are values for three flow sources: Trinity River, San Jacinto River and coastal streams (e.g. Clear Creek, Dickinson Bayou, Cedar Bayou). Each flow source has recommendations for three seasons: Spring (March, April, May), Summer (June, July, August), and Fall (September, October, November). In the case of flows in Winter (December, January, February), no consensus was reached. One of the biological indicators listed in Table 33, Gulf menhaden, was assigned a large area in the bay in which it occurs in the winter. The area covers so much of the bay that the apportionment of conditions in this area to any particular source of freshwater inflow seems inappropriate. The use of this biological indicator for the development of a flow recommendation is discussed at the end of the recommendation section.

3.1. Trinity River Flow Recommendations

Flows from the Trinity River in spring, summer and fall are based on the modeling done by Joe Trungale and Tony Smith to obtain a salinity regime suitable for wild celery (*Vallisneria*). The desired salinity for spring is 0 to 5 psu based on the salinity range best suited to germination and establishment of plants. The salinity range modeled for summer and fall was 0 – 10 psu based on the requirement of established *Vallisneria* plants for survival. Germination and establishment can occur in 30 days, and survival is diminished by unsuitable salinities of duration longer than 30 days. Thus the salinity range for germination should be met for one month in the spring and the salinity range for survival should be met for 2 of 3 months in summer and fall. Figure 35 shows a graph of two regression analyses of the data for flow and area with suitable salinity for *Valllisneria* germination in spring months when the antecedent salinity condition is suitable. In this case, the logistic regression fits the points quite well. Figure 36 shows the regression analysis of spring flow to *Rangia* area to illustrate the fact that the recommendation based on *Vallisneria* would be protective of *Rangia* also.

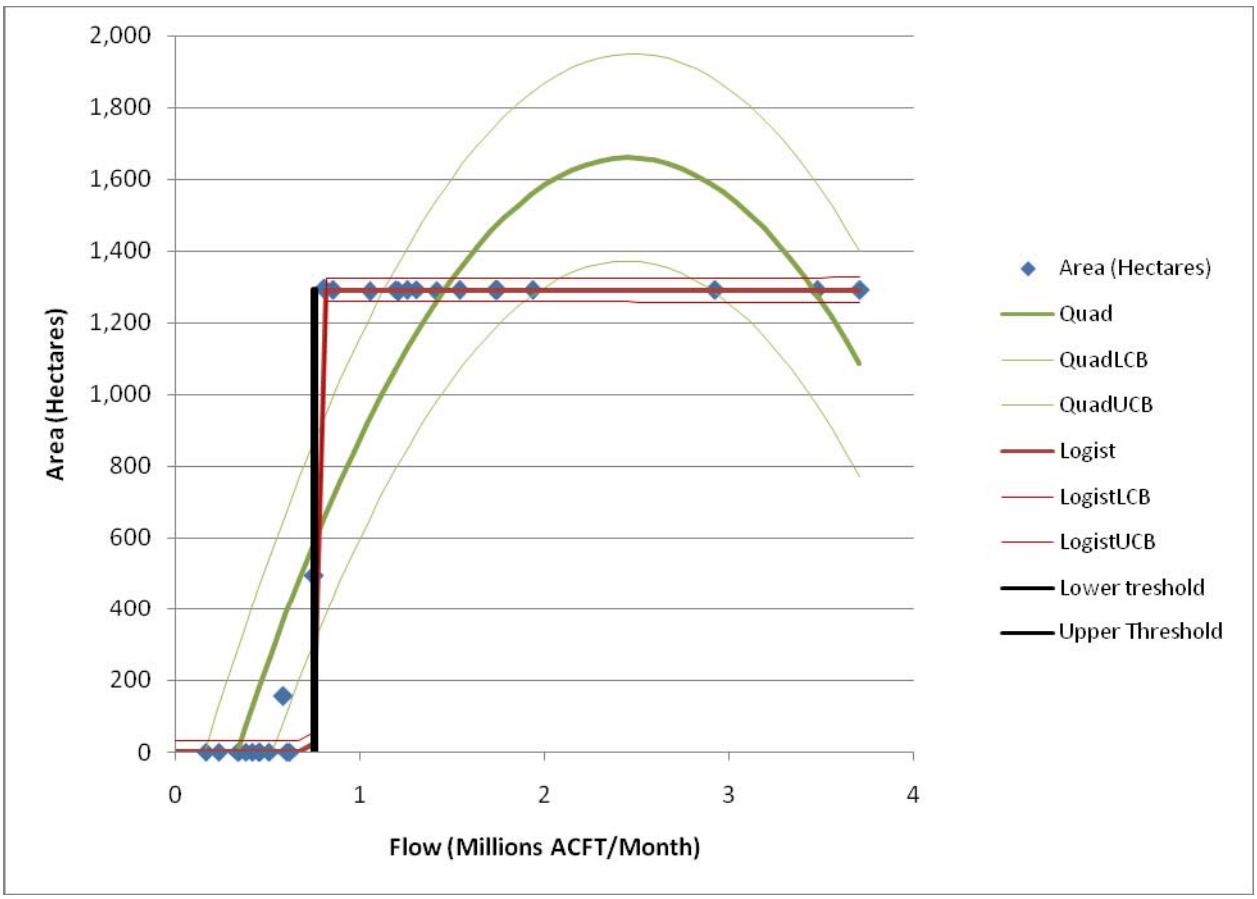

Figure 35 Graph of a logistic regression and polynomial regression of hectares of wild celery habitat exhibiting suitable salinity values at varying flows during spring. The vertical lines show a range around the inflection in the logistic regression that reflects the uncertainty of the analysis and is used to develop the flow recommendation. In this case the lower and upper thresholds are only 16,000 ac-ft apart.

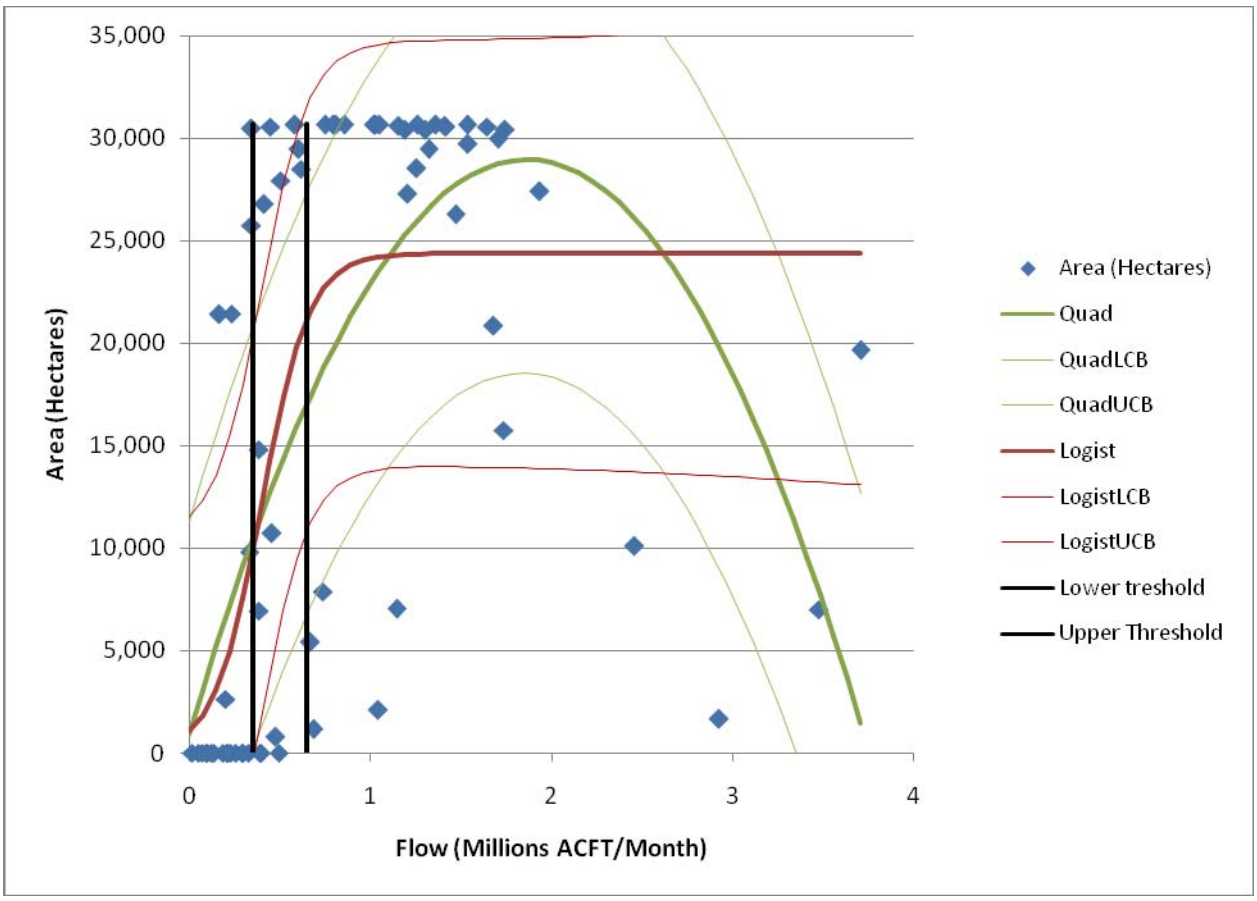

Figure 36 Plot of spring flow from the Trinity River and the hectares of habitat assigned to Atlantic *Rangia* with suitable salinity values for survival of larvae. Note that the range of flows within the upper and lower thresholds are consistent with the recommended flow based on the *Vallisneria* indicator shown in Figure 31.

Similar regression analyses for summer and fall (salinity <10 psu) yielded flow recommendations based on the lower confidence interval. Figures 37 and 38 show the logistic regression plots of summer and fall flows from the Trinity River and the area of *Vallisneria* habitat covered by suitable salinity regime.

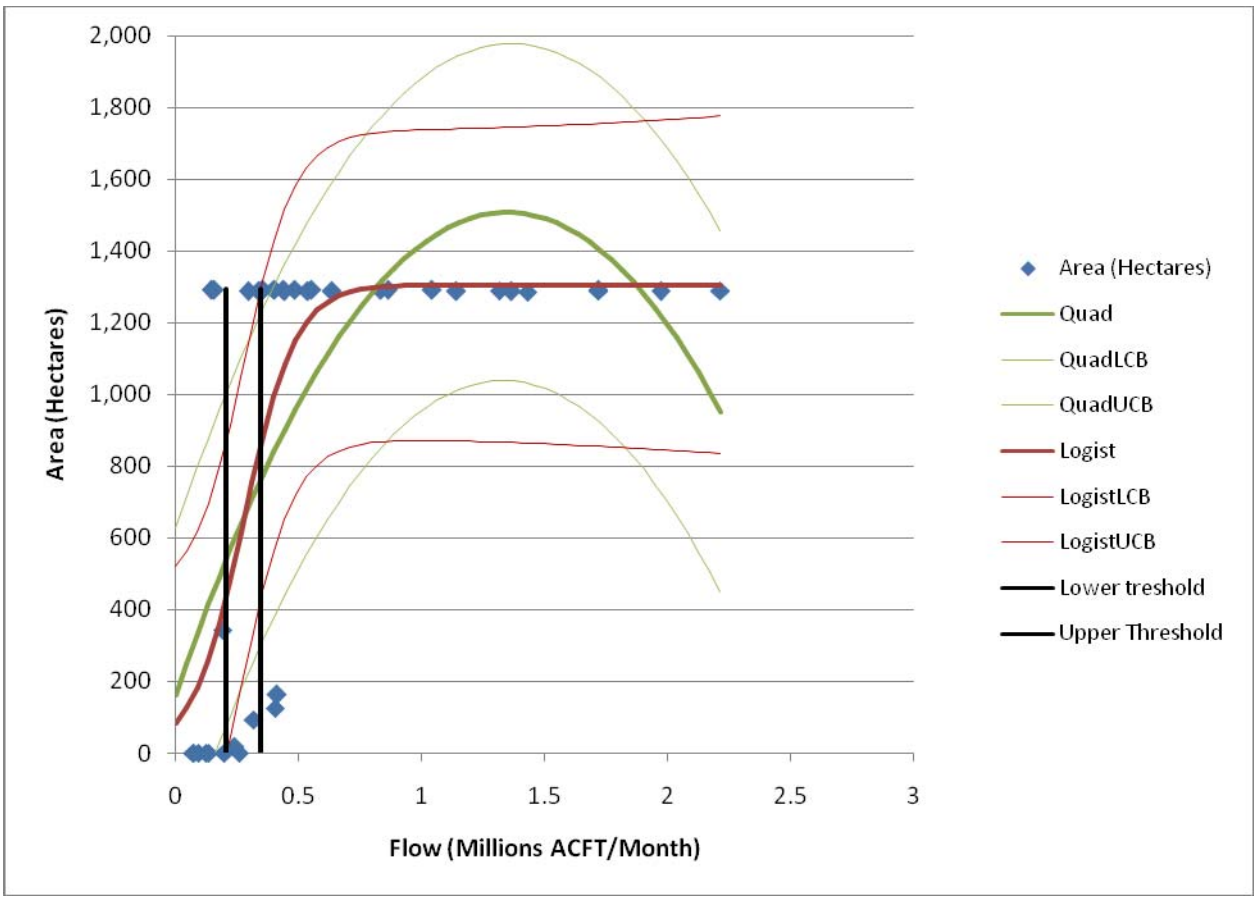

Figure 37 Plot of the *Vallisneria* survival indicator for summer flow after a spring with suitable salinity and the area of habitat covered in summer months by suitable salinity according to the TXBlend model. The lower threshold is used as the recommendation for summer in Table 34.

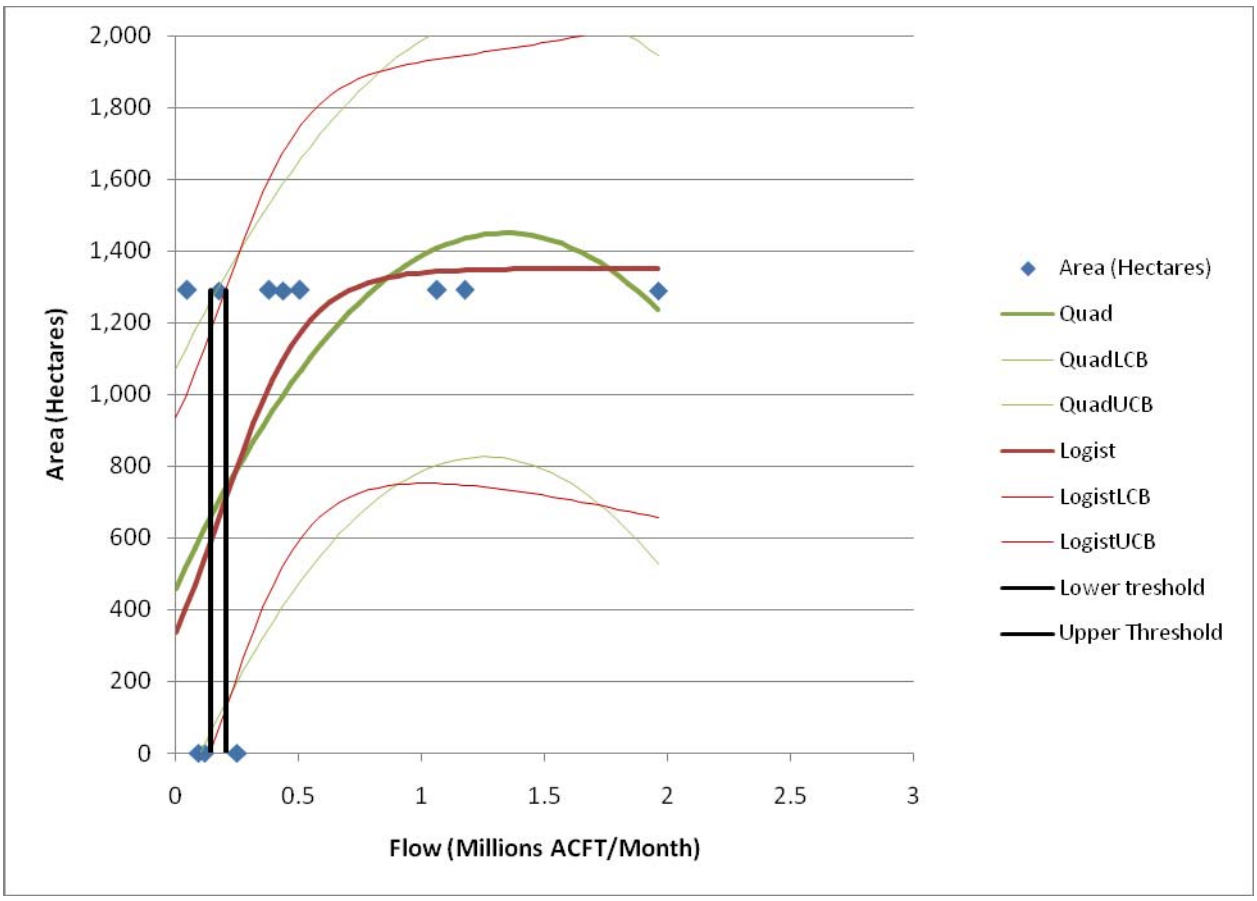

Figure 38 Regressions of flows in fall months following a month with suitable salinities over *Vallisneria* habitat and the areas of *Vallisneria* habitat obtaining at the various flows. The lower threshold is 141,000 and is adopted as the recommendation in Table 34 below.

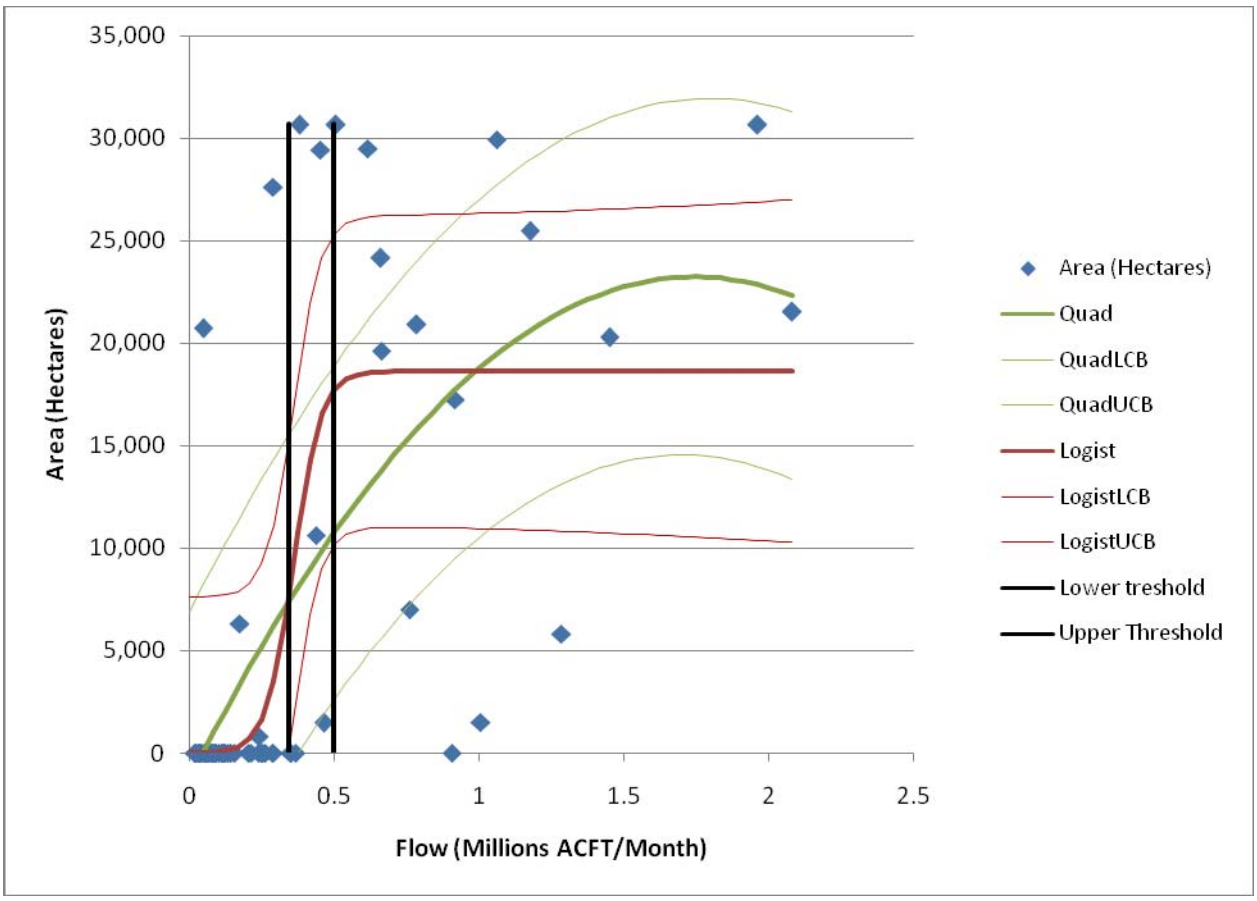

Figure 39 Regressions of Trinity River flows in all fall months over *Rangia* habitat and the areas of *Vallisneria* habitat obtained at the various flows. The lower threshold is 141,000 and is adopted as the recommendation in Table 34 below.

Figure 39 shows the regression of fall flow from the Trinity River and the area of *Rangia* habitat with salinity suitable for larval survival. In this case, the satisfaction of salinity niche conditions for *Rangia* appear to require a higher flow than that required for *Vallisneria*. However, the *Vallisneria* indicator is so intimately associated with the flow of the Trinity River that it was deemed a better indicator for purposes of developing flow recommendations. As noted above, failure to achieve a second spawning season for *Rangia* is not critical.

The group did not agree on a suitable biological indicator for the winter flows from the Trinity River and discussed using recommendations derived from instream flow analyses (see Section 3.4).

Table 34 The resulting recommendations for seasonal flows from the Trinity River are shown with the recommended periodicity, the historical occurrence of the criterion on an annual basis and the recommended annual frequency of future occurrence. These values are based on the logistic regression analyses of the *Vallisneria* salinity conditions in an area around the mouth of the Trinity River.

	Spring	Summer	Fall	Winter
Criterion	742,000	205,000	141,000	
Periodicity	1 of 3 months	2 of 3 months	2 of 3 months	
Annual Occurrence	18 of 23 years	12 of 23	11 of 23 years	
Recommended Annual Frequency	1 in 2 years	1 in 2 years	1 in 3 years	

The recommendations in Table 34 only apply to a subset of months in a year. A HEFR analysis of the flow regime for the Romayor gauge could be used to determine a recommended flow from the Trinity River to Galveston Bay for any months not covered by a recommended flow level. Any of the base flows in an approved flow regime could be used to calculate a monthly flow for months not covered by the recommendation above.

The analysis of historical flows in the Trinity River by Smith and Trungale showed that the flow regimes of the most recent 30 year period exceeded the flow levels of the 1940's to 1970's by approximately 6%. Therefore, the threshold values shown in the above table should be reduced by 6% to more closely approximate natural flow patterns before the advent of high return flows. The table below shows the recommended flows with the adjustment made.

Table 35 The adjusted flow recommendations at 94% of the calculated flows shown in Table 34. The adjustment is justified by the difference of flows in the period of record used in TXBlend modeling and flows that occurred in the earlier, more natural period of record.

	Spring	Summer	Fall	Winter
Criterion	696,000	193,000	133,000	HEFR Table
Periodicity	1 of 3 months	2 of 3 months	2 of 3 months	
Recommended Annual Frequency	1 in 2 years	1 in 2 years	1 in 3 years	

3.2. San Jacinto River Flow Recommendations

Flows from the San Jacinto River are based on the TXBlend flow – salinity – ecology analyses for a variety of indicator organisms. *Rangia cuneata* clams are one of the selected indicators and the range of salinity used in the modeling was that required for successful spawning, 2 – 10 psu. Larvae must survive and grow as zooplankton for at least three weeks to successfully metamorphose into clams. *Rangia* has two spawning

seasons each year if conditions are suitable, but only one is necessary to preserve the adult population. The spring spawn is the primary one. The flow most conducive to larval survival in the spring would be that needed to obtain the desired salinity even if the bay is salty at the beginning of the season. The modeling performed for this antecedent condition results in a minimum value of 302,000 ac.-ft./mo. for one month in spring from the San Jacinto River. Figure 40 shows the logistic regression analysis of the TXBlend results for the relationship between spring flows following high salinity conditions and the amount of *Rangia* habitat coverd by suitable salinities for larval survival.

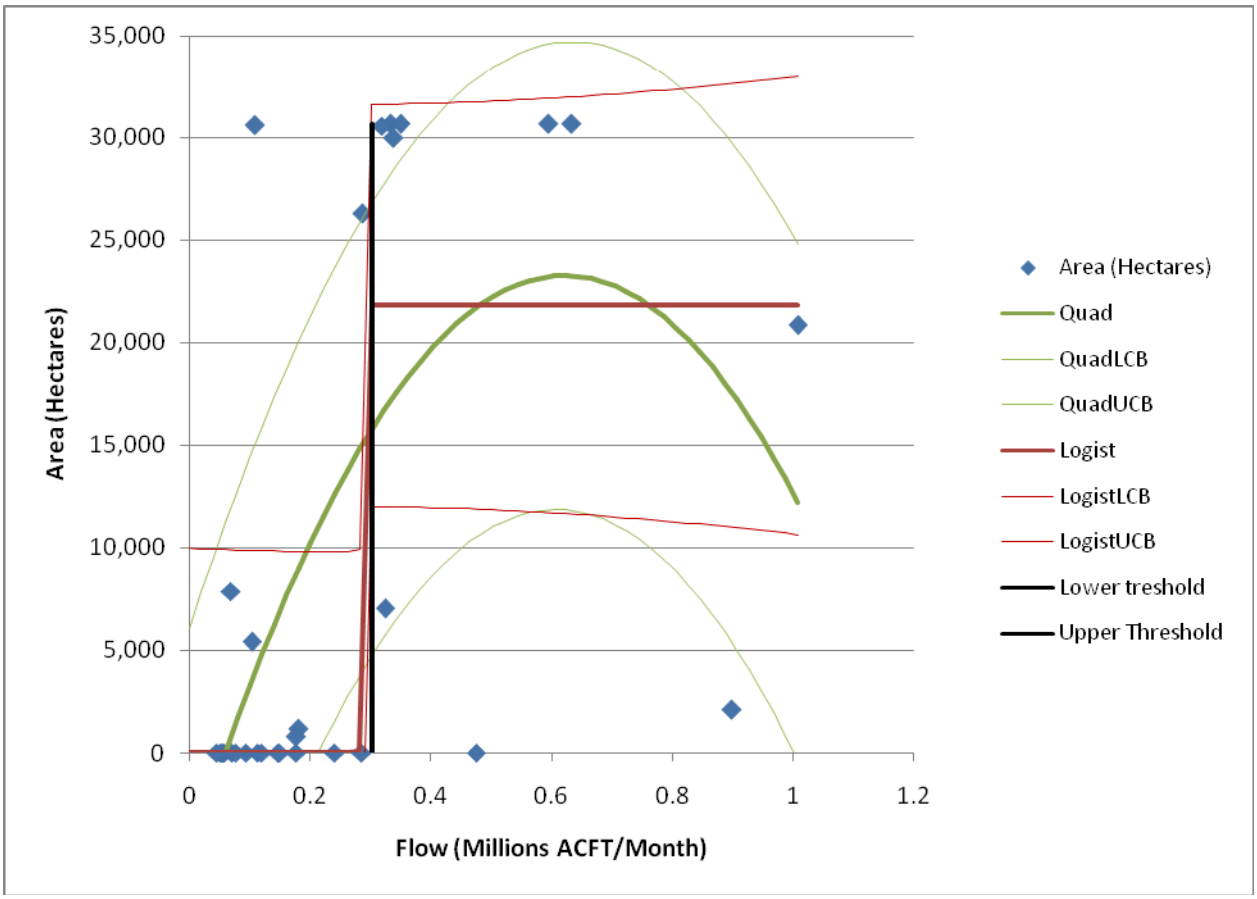

Figure 40 Graph of a logistic regression and polynomial regression of hectares of *Rangia* habitat exhibiting suitable salinity values at varying flows from the San Jacinto River during spring when the antecedent condition is higher than suitable salinity. Note that in this case the inflection of the regression line is so sharp that the higher and lower threshold values are identical.

The flow used for the fall *Rangia* spawning season was based on the assumption that the salinity in the bay was good for *Rangia*. If the antecedent conditions are too salty, then the fall spawning season may not be successful, but failure of one spawn in a year is an acceptable risk. Figure 41 shows that these conditions yield a limited number of points for the regression analysis and the resultant regression provides a weak relationship between flow and habitat salinity. The small number of observations in this category and the weak relationship means that there is high uncertainty attached to this

recommendation. This indicator and recommendation should be the subject of future study for improvement.

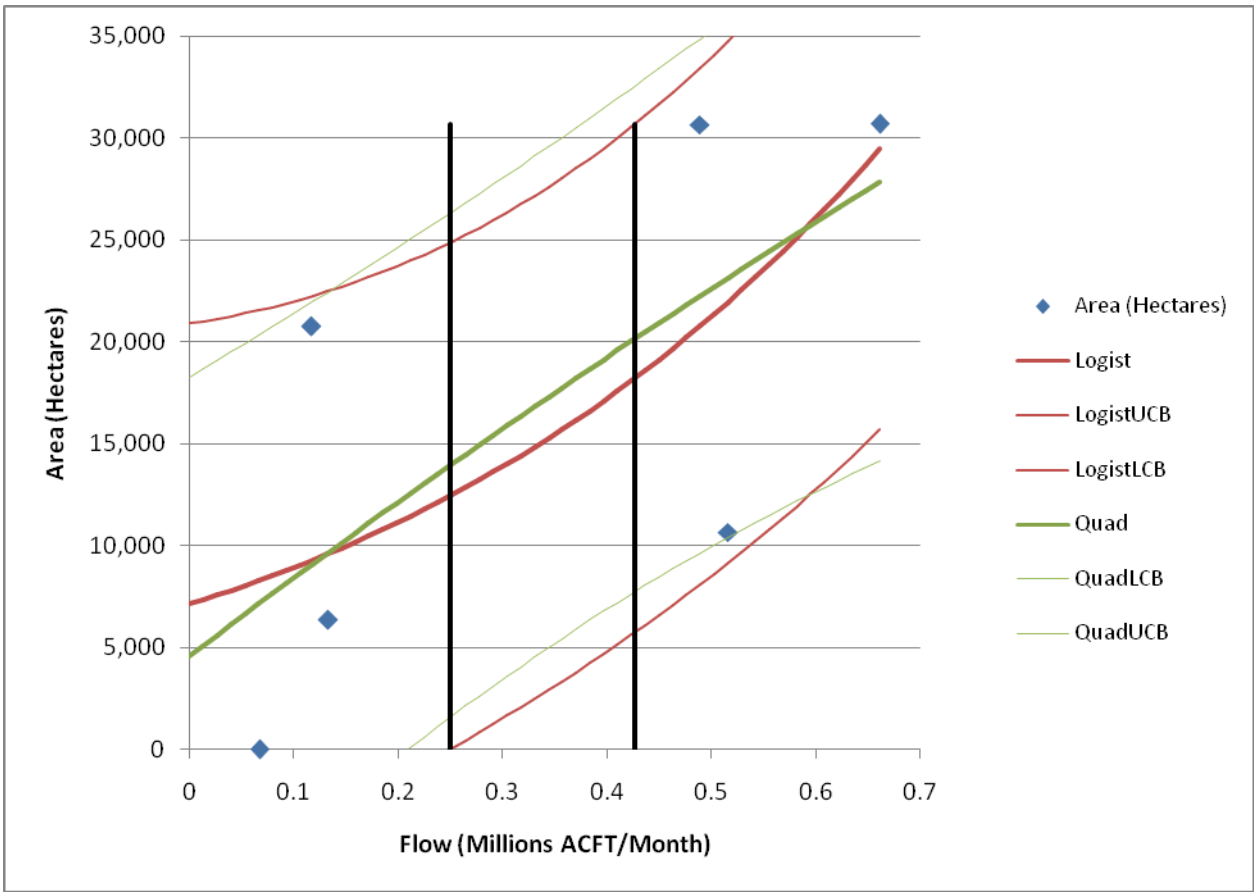

Figure 41 Graph of a logistic regression and polynomial regression of hectares of *Rangia* habitat exhibiting suitable salinity values at varying flows from the San Jacinto River during fall when the antecedent condition is suitable. Note that in this case the regression lines do not provide an inflection pattern that offers well defined thresholds.

The status of oysters in the bay is most affected by the combined impact of salinity and temperature during July, August and September on predator and parasite abundance. The flow models were applied to these three months only. In Figure 42, a regression analysis of summer flow values following high salinity periods and the area of the oyster habitat assigned to the oyster indicator with suitable salinity is shown. The relationship does not fit a logistic regression well, but the lower threshold appears to be located at a defensible point among the flows that yielded large areas with suitable salinity in the designated area. In Table 36 below, the lowest flow value that produced a suitable salinity when the antecedent conditions were salty was used for the entire summer season.

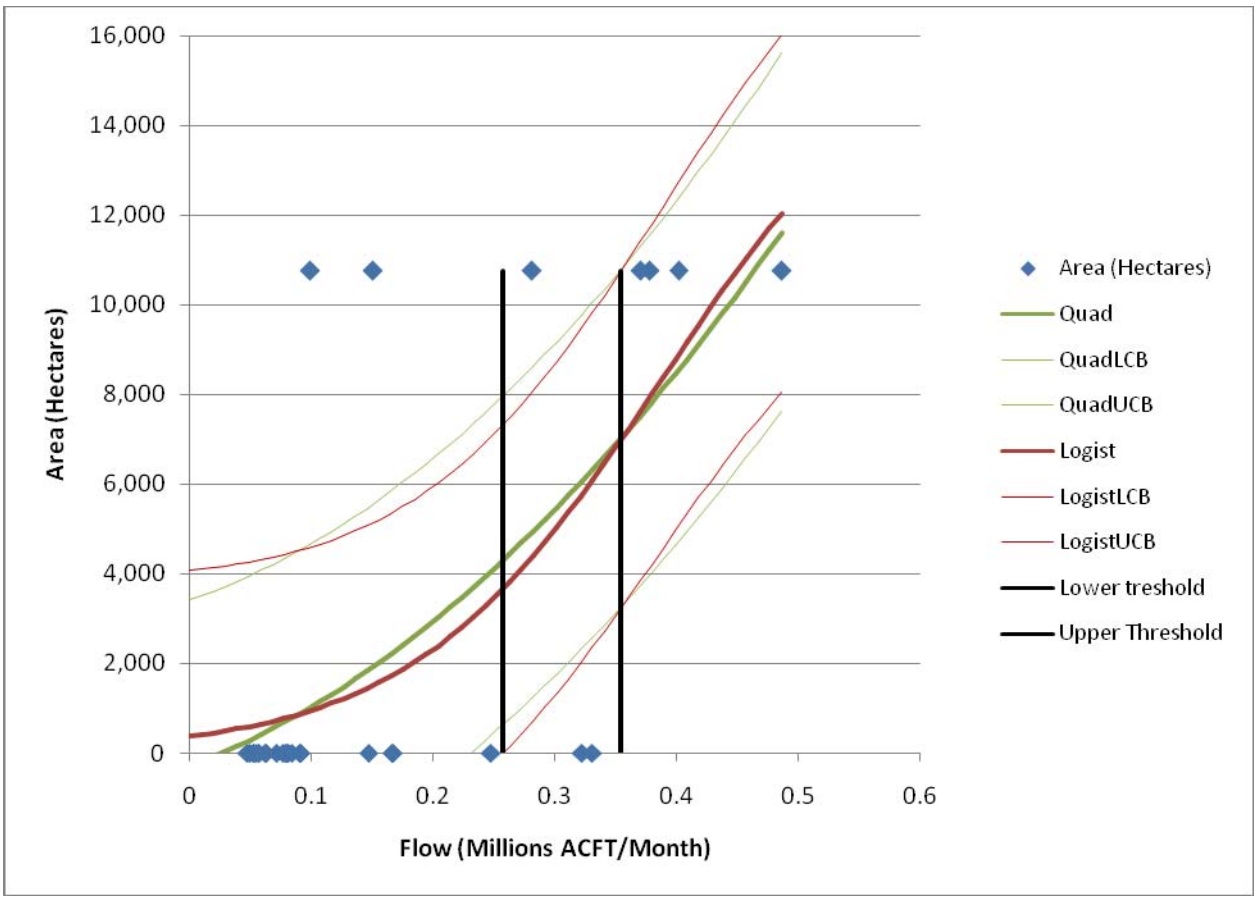

Figure 42 Plots of logistic and polynomial regressions based on summer flows from the San Jacinto River and the salinity in the area of the bay assigned to the oyster health indicator. Note that this regression is not strongly inflected, but the lower threshold is reasonably located in the range of flow values that have produced suitable salinities over 100% of the designated area.

The spring and fall flow recommendations in Table 36 are based on models of the desirable salinity for *Rangia* larvae in spring and fall, 2 – 10 psu. The summer flow recommendation is based on minimizing oyster infection and predation while maximizing survival during the period from July to September.

Table 36 Suggested flow recommendations for the San Jacinto River are shown below by season with the recommended periodicity, the historical annual occurrence and the recommended future annual occurrence. These recommendations are based primarily on the indicator organisms, *Rangia* and oysters.

Season	Spring	Summer	Fall	Winter
Flow	302,000	257,000	250,000	
Periodicity	1 of 3 months	2 of 3	1 of 3	
Annual Occurrence	15 of 23 years	5 of 23	13 of 23	
Recommended Annual Frequency	1 in 2 years	1 in 5 years	1 in 2 years	

3.3. Coastal Streams Flow Recommendations

The TWDB developed estimated freshwater inflows for the entire Galveston Bay system. These flow estimates were used in the flow – salinity – ecology modeling performed for our committee and total inflow requirements were generated to obtain suitable salinity regimes for the indicator organisms as described above. Two indicator organisms which participants agree are highly credible for inflow modeling purposes are *Rangia* clams and oysters. The coastal streams flow into Galveston Bay from a variety of locations, but have historically provided approximately 18% of the freshwater input. Thus these streams are a component of the flow – salinity – ecology relationship, but not a major determinant. It seemed appropriate to handle their contribution by first developing recommendations for the Trinity and San Jacinto, then allocating the coastal stream flow by subtracting the Trinity and San Jacinto from the total bay requirements. Using total bay flow analyses for *Rangia* and oysters, total flow recommendations for coastal streams in spring, summer and fall can be derived.

Figure 43 shows a very strong logistic regression for total spring inflows to Galveston Bay and the area of designated *Rangia* habitat with suitable salinity. The analysis for the oyster health indicator in summer is shown in Figure 44. The inflection in the logistic regression is not as strong, but the lower threshold provides a reasonable estimate of the flow needed to maintain the health of oysters in the central part of the bay. Figure 45 shows the very problematic regression analysis of fall flows when the antecedent conditions have been suitable and area of the *Rangia* habitat covered by suitable salinity. A better relationship exists for fall flows and *Rangia* habitat when using high salinity antecedent conditions, but that analysis yields a higher recommended flow for a relatively low priority indicator.

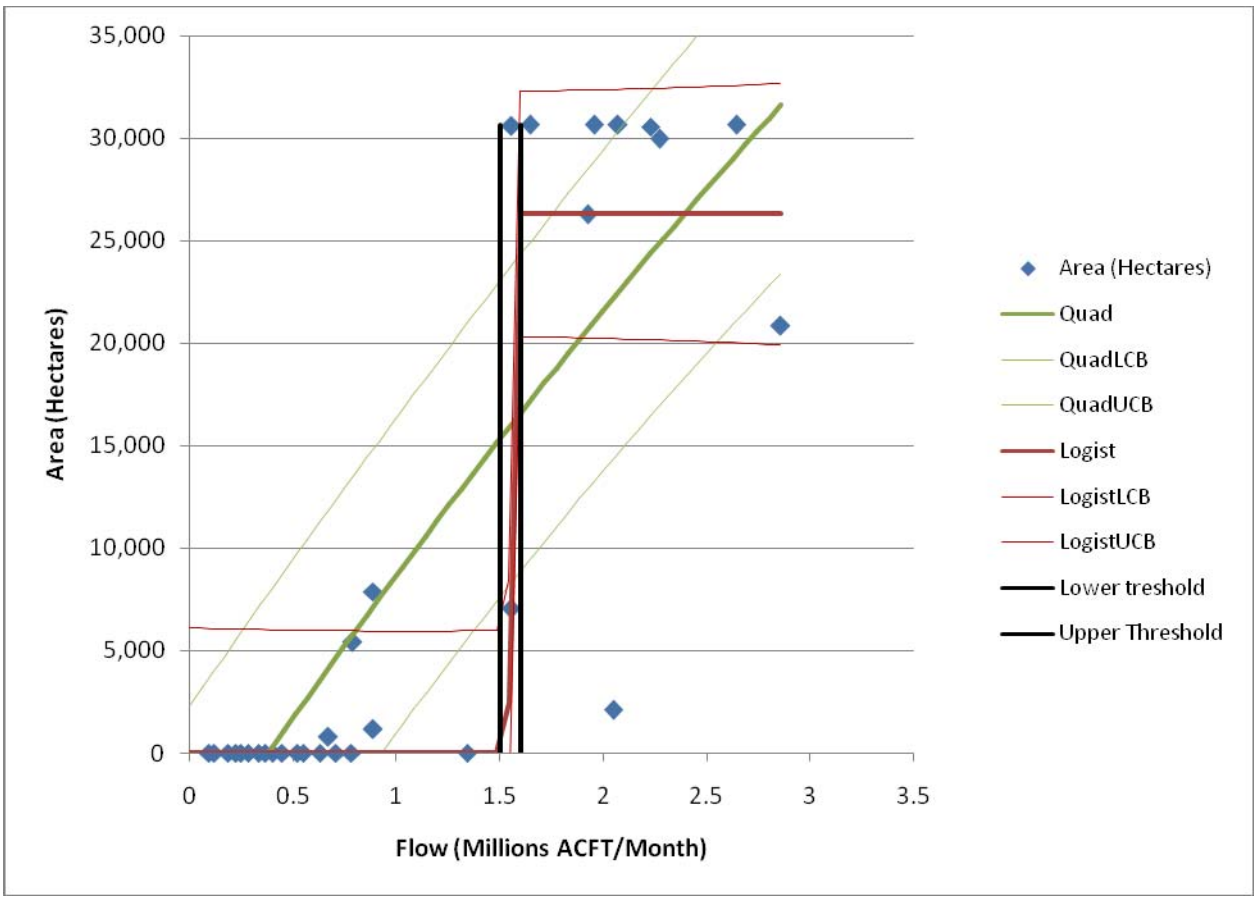

Figure 43 Plots of logistic and polynomial regressions based on spring flows for the entire bay when the preceding conditions have been high salinity and the amount of the area of the bay assigned to the *Rangia* spawning indicator with a suitable salinity.

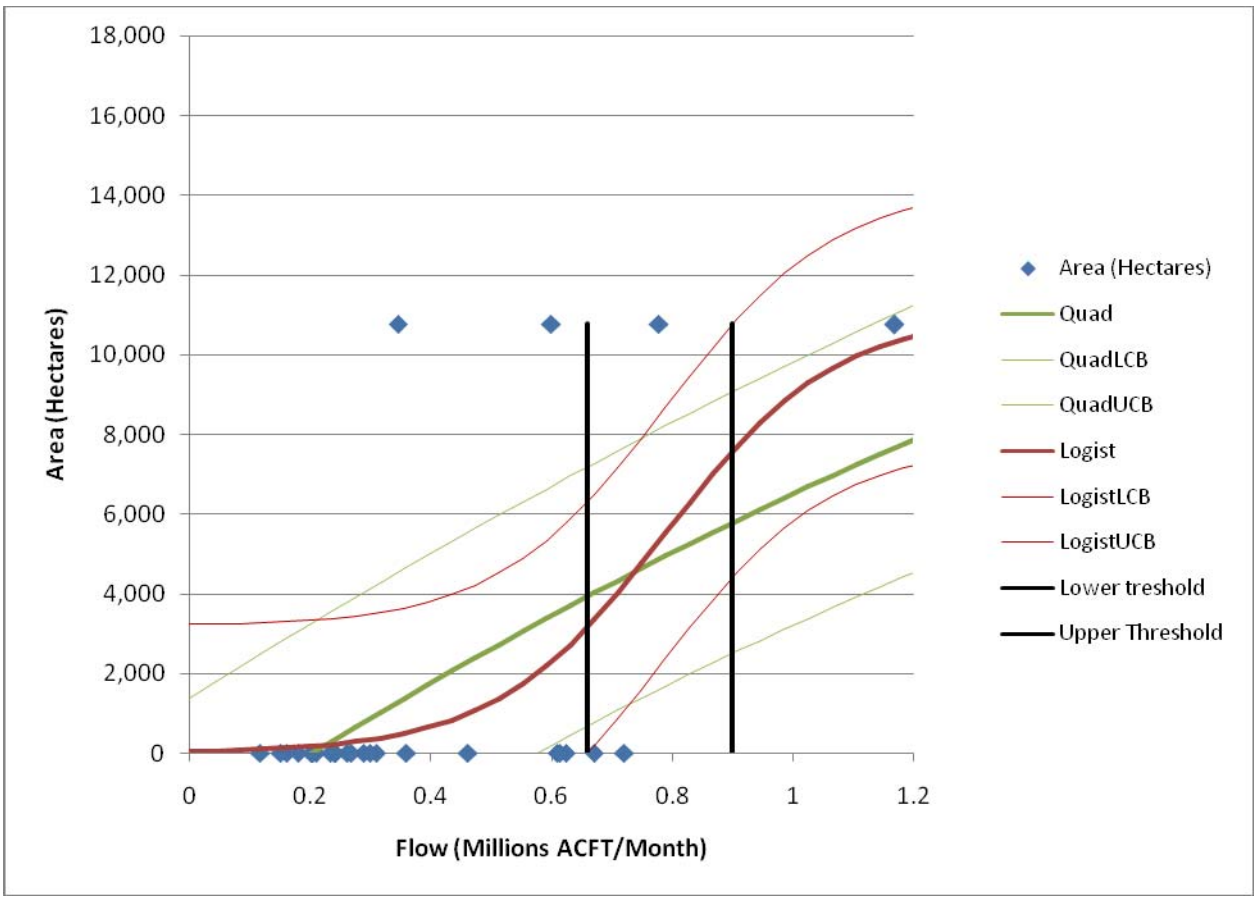

Figure 44 Plots of logistic and polynomial regressions of summer month flows for the entire bay when the preceding conditions have been high salinity and the area of the oyster health indicator with a suitable salinity.

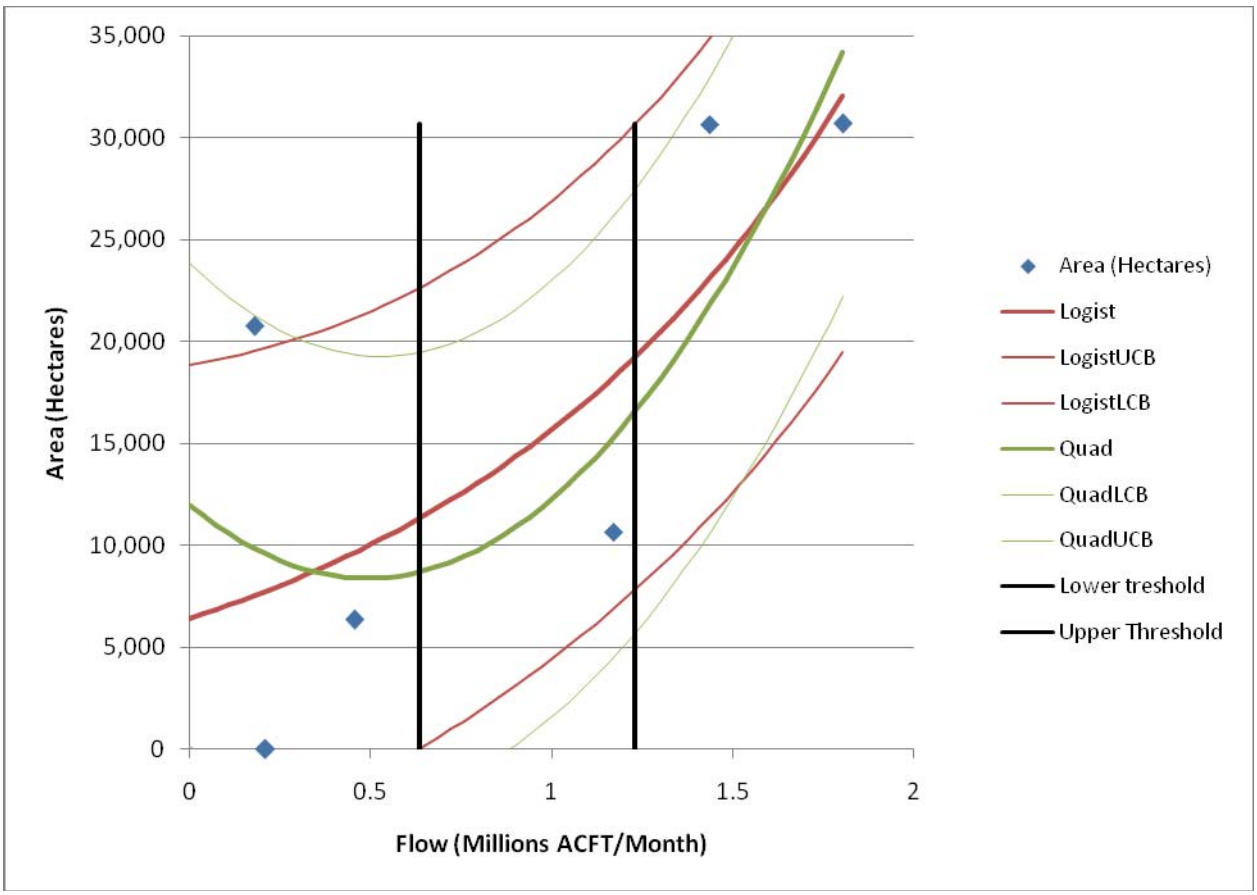

Figure 45 Plots of logistic and polynomial regressions based on fall flows for the entire bay when the preceding conditions have been suitable and the area of the *Rangia* spawning indicator with a suitable salinity. Note that this antecedent condition is rare and the logistic regression does not provide a good fit.

Recommended flows from the coastal streams can be estimated for spring, summer and fall by subtracting the recommendations for the Trinity and San Jacinto in that season from the total flow value explained above. The sessile indicator organisms used in the above analyses have specific temporal requirements for the salinity range that can be applied to the recommendations derived in this way. Spring and fall values should be maintained for one month to facilitate spawning of clams in the mouths of the streams. The larger coastal streams feeding Galveston Bay are on the western shore and make additive contributions to the flow of the San Jacinto in determining the salinity of western Galveston Bay, which is a major portion of the area assigned to the oyster indicator organism. Thus summer flows from coastal streams should be maintained for two months to provide conditions suitable for oyster survival.

The total bay flows employed based on these analyses are 1,500,000 ac-ft for spring, 659,000 ac-ft for summer, and 635,000 ac-ft for fall. After subtracting the flow recommendations for the Trinity River and San Jacinto River for a given season from the total bay flows for that season, the remainders can be assigned to the coastal streams. The resultant values are shown in Table 37.

Table 37 The seasonal flow recommendations for the coastal streams, their recommended periodicity, the historical annual occurrence and the recommended future annual occurrence periods are shown. There is no recommendation for winter.

Season	Spring	Summer	Fall	Winter
Flow	455,000	196,000	244,000	
Periodicity	1 of 3 months	2 of 3	1 of 3	
Annual Occurrence	17 of 23	7 of 23	6 of 23	
Recommended Annual Frequency	1 in 2	1 in 4	1 in 4	

3.4. Winter Flow Recommendation

The BBEST discussed in its last meeting how to develop a winter season flow. The estimates by flow source obtained from use of Gulf menhaden did not receive consensus, but this is the only biological indicator that offers a reasonable basis for a winter flow recommendation. Suggestions for the use of hydrological models were made, but employing these would be inconsistent with the approach of basing flow recommendations on biological indicators. Therefore, a suggested winter flow recommendation is presented based on a flow – salinity – Gulf menhaden relationship using a total bay flow to produce suitable salinity over most of the menhaden area. The analysis is based on the same regression approach shown for all of the recommendations presented above.

Figure 46 shows the standard analysis of flow and habitat area covered by suitable salinity. In this case the habitat area is so large that the desired salinity seldom covers even 90% of the entire area. Despite this difference with the other biological indicators, the regression analysis shows a strong relationship between flow and achievement of the criterion in large areas on habitat. The lower threshold on this regression is 469,000 ac-ft, which seems a reasonable value for a winter flow requirement from the combined flow sources. This flow recommendation could be allocated to the three sources using proportional contributions to historical flows, e.g. 54% from the Trinity River, 28% from the San Jacinto and 18% from the coastal streams.

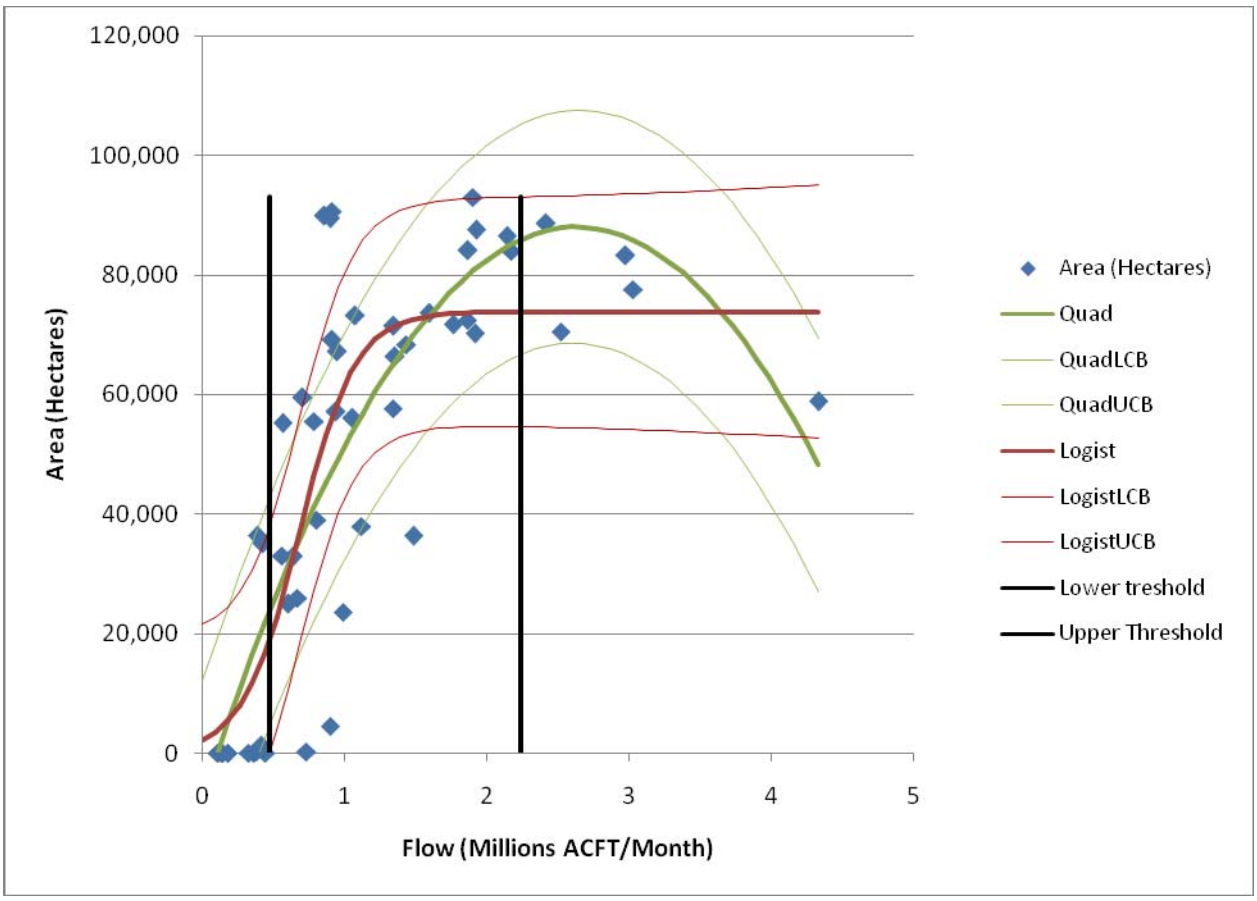

Figure 46 Regression analysis of winter flows following high salinity conditions and the area of Gulf menhaden habitat in suitable salinity conditions. The area assigned as menhaden habitat is so large that the desired salinity condition seldom covers the entire area.

Another indicator organism that was not employed in the seasonal recommendations covered above is blue catfish. It is primarily associated with pulses of low salinity conditions in the upper bay and at the mouths of tributaries. Winter high flow pulses are important to obtain salinity conditions suitable for the occurrence of the biological indicator blue catfish.

Flood Flow Recommendation

Scientific studies have shown that the health of the oyster population can be enhanced by periodic flood events. Specifically a two week period of salinity below 5 psu will significantly reduce the level of infection by *Perkinsus* (LaPeyrie et al 2009). An additional recommendation is that a high flow event should occur at least once per decade. This event should lower the salinity in the area assigned to the oyster health indicator to less than 5 psu for a period of two weeks.

4. ADAPTIVE MANAGEMENT TO ENHANCE BEST AVAILABLE SCIENCE

4.1. Introduction

The SB 3 requirements to establish environmental flow regimes recognize that individual river basins and estuarine areas have unique characteristics. These unique characteristics are important in establishing flow and ecological/biology relationships. The SB 3 also recognized that there is probably limited flow and ecological/biology relationship information available for specific water bodies for which flow regimes are to be established. In this respect, comprehensive searches were performed to gather and review available ecological information for the Trinity and San Jacinto River basins. These searches concluded that there is limited information and data available to define flow and ecological/biology relationships for the basins. Also of relevance is recognizing that the SB 2 investigation is in the process of identifying information needed to assess flow and ecological/biology relationships. It is important to note that it is anticipated that development of the scientific information to facilitate making decisions based on sound science and technology will probably take several years. However, there may be an opportunity for the SB 3 process to identify some priority needs of information that could be beneficial to the TCEQ permitting process. In this regards, the BBEST includes individuals with unique expertise and knowledge of the basins and coastal areas gained through the SB 3 process and / or their professional careers that provide a unique opportunity to define priority needs at this time. Considering these discussion points emphasizes the value and need to go forward with identifying Trinity and San Jacinto River basins specific information that should be developed for future use in refining and expanding the suite of initially identified flow regimes.

The SB 3 includes provisions to apply an adaptive management process to facilitate the development of information to address uncertainties and to enhance the science available to refine and/or to expand flow regimens. The application of the Adaptive Management process should not be used to avoid taking any action but should be an action oriented approach in the face of uncertainty when dealing with complex ecological problems. This approach provides an opportunity for individual advocates that support different initial starting points to work together in a collaborative manner to advance the decision making process based on enhanced available science. Based on these considerations, it is proposed that the recommendations for Flow Regimes be accompanied by recommendations of path forward actions involving focused research and studies for developing information beneficial to refining and expanding the suite of recommended flow regimes.

4.2. SAC and BBEST Process

The Science Advisory Committee (SAC) has developed methodologies for various overlays (e.g. nutrient and water quality overlay, biological overlay, etc.). Unfortunately,

due to time constraints and / or lack of data needed to employ the methodologies there has been limited opportunity to apply the methodologies. However, the methodologies provide valuable insights regarding the type of information needed and procedures for applying the overlays. The charge to the BBEST is to develop flow regimes giving consideration to the available best science and to the guidance methodologies provided by SAC. The BBESTs members' expertise and knowledge of the Trinity and San Jacinto River basins and coastal area is extremely valuable in identifying the specific information needed for application of sound ecological condition general concepts. Additionally, the SAC methodologies identify water body specific information that would facilitate adapting these general concepts to the determination of recommended flow regimes.

4.3. Research and Data Gathering

A program to perform research and data gathering should be developed in collaboration with SAC and the SB 2 process. Development of this program would involve identifying basin specific information that would be valuable in the application of the SAC methodologies and in providing information that would aid in the adaptation of generally recognized concepts to the Trinity and San Jacinto River basins and coastal areas. Of particular interest will be to identify information that could be relatively easy to develop in a short timeframe that would not be excessively costly. This could involve gathering physical and water quality data, and confirmation of the biology present. Also, of interest will be to identify additional information needed that could require a longer timeframe such as the response of biology to different flow regimes. The program should also include recommendations regarding how it should be implemented as part of the SB 2 process and/or by some other approach.

The following list of issues, adapted from Richter et. al. 2006, could be used as a reference in identifying information needed.

Hydrology

1. Do stream gauges exist along the river, and if so, where are they located, who maintains them, and how long have they been in operation?
2. What are/were the typical seasonal patterns of natural river flow variation (e.g. when do higher flows tend to occur, when do the lowest flows occur)?
3. To what extent have the low, high pulse, and flood flows in the river changed over time in response to human influences? Have extreme low flows become more frequent or extreme? How do hydrographs from recent years compare to predevelopment hydrographs?
4. What are the primary human influences on the flow regime, and where do these impacts occur? Do certain human impacts appear to dominate over other human influences?
5. What types of water development activities are planned for the future, and how might those developments influence river flows?

6. How important are ground water contributions to base flows? What is the nature of hydraulic connections between river stage and alluvial water table levels? How might these connections be altered by future water developments?

Suggested approaches:

- Prepare a schematic drawing of the drainage network, noting the mean annual flow and drainage basin area at all available stream gauge stations.
- Provide a tabular summary of water uses and water structures, at the finest level of detail available.
- Prepare "typical" hydrographs (both annual and decadal hydrographs) for undeveloped and developed conditions at all river and lake monitoring stations.
- Categorize the natural hydrologic regime into ecological flow components: subsistence flows, base flows, high pulse flows, overbank flows. Using the IHA software, estimate quantitative values for each of these components under natural, historic, present, and future conditions (if hydrologic simulation data are available). Assess changes in the magnitude, duration, timing, and frequency of each flow component.
- Prepare flow duration curves for undeveloped and developed conditions at all stream gauges.
- Characterize typical groundwater-surface water interactions using monitoring well data or other sources of information.

Hydraulics

7. Has any hydraulic modeling been performed for the river? Has any flood hazard mapping been undertaken?
8. How well are relationships between river stages (water elevations) and river flow levels understood?
9. How well are relationships between river flow and the distribution of velocities and depths in the river channel understood?
10. Is there longitudinal (upstream to downstream) connectivity in flow or are there major discontinuities (i.e. diversion dams), and if so where?
11. Has the lateral connectivity between the river and its floodplain been altered in any way?

Suggested approaches:

- Develop river stage-discharge relationships (e.g., at flow monitoring stations or from hydraulics models).
- Plot the relationship between flow and estimated percent floodplain inundated at representative river transects (e.g., at stream gauges or from aerial photos).
- Develop flow depth and velocity estimates across river transects (e.g., at stream gauges or using hydraulics models).

Geomorphology

13. Have any topographical surveys been conducted of the river channel or floodplain (including any surveying for bridges, roads, floodplain mapping, etc.)?
14. Is the channel and floodplain system in dynamic equilibrium or disequilibrium? Is the sediment input to each segment in equilibrium with the capacity of the channel to transport it through the segment? Are there detectable trends in the elevation of the river bed or lake bottom, indicating degradation or aggradation? Has the river's longitudinal profile changed over time?
15. Has the channel or floodplain width changed over time?
16. Has the channel's planform changed over time, such as between meandering and braided forms?
17. Has the size distribution of stream bed sediments changed over time?
18. Has the availability of in-stream physical habitats changed over time (e.g. changes in availability of pools or riffles)?
19. Is lateral channel migration or bar formation important ecologically (e.g. to support riparian plant communities)?
20. Has human activity and land use significantly altered the stream channel and floodplain morphology and processes?

Suggested approaches:

- Plot the river's present-day longitudinal profile from topographic maps or field survey information.
- Characterize historical changes in longitudinal river slope, if adequate data are available (e.g., at multiple river flow monitoring station locations).
- Review historical aerial photographs to assess changes in river plan form and floodplain over time.
- Assess changes in channel cross-sectional shape, if data are available (e.g., at stream gauges).
- Develop sediment budget estimates for appropriate representative time periods, such as historic, pre-dam agricultural, and post-dam periods.
- Estimate flows necessary to entrain river sediments (to maintain desired streambed composition or move sediment downstream to lake).
- Estimate channel forming flows necessary to maintain desired channel geometry.
- Estimate channel migration flows needed to sustain floodplain development and riparian ecosystem.

Water quality

21. Have water quality data been collected for the river, and if so, by whom, where, for how long, and of what type?
22. How do water quality conditions vary spatially in the river?

23. What is known about water quality problems in the river?
24. Is wastewater discharged into the river? Where, and how much? What proportion of the low flows in the river arises from upstream wastewater discharges?
25. What is known about daily, seasonal, annual fluctuations in key parameters such as dissolved oxygen or temperature in the river?
26. How do human activities affect water chemistry, temperature or dissolved oxygen in the river?
27. What water quality components are of greatest concern to the target organisms, life stages or riverine processes (e.g. dissolved oxygen, suspended sediment, temperature, chemical elements, nutrients)? Are species distributions or abundances thought to be affected by water pollution?
28. Is large woody debris an important component of the aquatic ecosystem?
29. Are any invasive plant species an issue of concern?

Suggested approaches:

- Characterize natural and post-development patterns of water temperature, including seasonal and diurnal fluctuations.
- Characterize natural and post-development patterns of dissolved oxygen in the water, including seasonal and diurnal fluctuations.
- Identify known relationships between reservoir releases and discharge of contaminants present in the reservoir.

Freshwater ecology

30. What type of biological data have been collected for the river? Who collected these data, over what time frame, and how often?
31. Has the abundance or distribution of certain species changed over time? Are these changes thought to be linked to changes in river flow or water quality? Are data available to document these trends?
32. What species (fish, birds, mammals, invertebrates, aquatic plants or riparian vegetation) are of greatest concern from either ecological or socio-economic or recreational standpoints?
33. What is known about the linkages between river flow and life histories of aquatic species? What times of year are most critical for indicator species, life stages or species assemblages?
34. Can the flow needs of certain indicator species be used to represent the flow needs of assemblages of organisms (e.g. fish communities, riparian vegetation)?
35. If the river flow regime has been altered by human influences, are necessary flow conditions still properly sequenced to enable successful life cycle completion for indicator species?
36. Which habitats are most limiting, and what is the importance of drought, flooding and intermediate flow conditions for developing and maintaining these habitats?

37. Are aquatic floodplain habitats critical for maintaining fish populations in rivers?
38. Is the aquatic ecosystem dependent upon energy subsidies (e.g. detrital matter) that are brought into the river from the floodplain during floods?
39. Do certain species require particular flow levels to facilitate movements in the river?
40. If reservoir releases are proposed in order to provide recommended flows, could there be effects on the ecology and fisheries in the reservoir?

Suggested approaches:

- Define life history stages for a diverse cross-section of species, such as aquatic plants, invertebrates, and resident and anadromous fishes, along with any known relationships to flow components and their seasonality. Specific life history aspects to consider include adult foraging, survival, and gonadal development; spawning migration and activity; egg, larva, and juvenile development; juvenile growth and survival.
- Define relationships between flow components and maintenance or access to critical habitats for completion of life history stages for key species.
- Describe ways in which flow components will influence primary productivity, decomposition processes, and nutrient dynamics.

Riparian ecology

41. Have the riparian plant communities or distributions of riparian plant or animal species been surveyed or characterized?
42. Have they changed over time?
43. What is known about relationships between river flows, alluvial water table levels, floodplain inundation patterns, and the influence of these hydrologic conditions on riparian plants or animals?
44. Do certain riparian plants or animals depend upon physical habitat conditions that are shaped by river flows? Is lateral channel migration or bar formation important in forming these physical habitats?

Suggested approaches:

- Define life history stages for a diverse cross-section of riparian obligate flora and fauna species, along with known relationships to flow components and the seasons in which they occur.
- Define relationships between flow components and maintenance or access to riparian habitat conditions.
- Describe relationships between flow components and vulnerability to disturbances such as fire or introduced species invasions.
- Describe ways in which flow components will influence primary productivity, decomposition processes, and nutrient dynamics.

Examples of information and data that could be gathered include:

- Cross-section data for selected streams
- Flow velocities
- Grain size information
- River slopes
- Topography between the river channels and off channel oxbows (etc) to help assess lateral conductivity.
- Precipitation-based metric to help determine watershed moisture levels
- Winter season flow and biological information

4.4. Path Forward Action

It is proposed that a workshop be held between the BBEST and SAC to identify focused research and information needs. The workshop should be coordinated with TPWD, TCEQ, and TWDB.

The path forward to apply Adaptive Management would involve:

- Defining and documenting the science and assumptions that served as a basis for SB 3 analysis

- Defining a research and data gathering agenda based on input from the workshop described above

- Developing and / or gathering relatively easy to obtain information (cross-section, velocities, wetted perimeters, sediment grain size, etc.)

- Monitoring flow conditions, water quality, and biological parameters to achieve Adaptive Management purposes

- Performing focused research and studies for enhancing available science needed for the Trinity and San Jacinto River basins and coastal areas

- Providing input into refining initial decisions based on the enhanced science and site specific data

The intent of this recommended Path Forward plan is to take advantage of the expertise and knowledge of the BBEST members in advancing the decision making process for the Trinity and San Jacinto River basins and coastal areas. The Path Forward actions should be closely coordinated with the SB 2 process.

5. COMMENTS BY TRINITY-SAN JACINTO BBEST COMMITTEE MEMBERS

Submitted within this chapter are comments provided by various committee members on various aspects of the approaches, theories, investigations, studies, and interpretations utilized within this document. These are submitted to provide an open forum to air alternative opinions and professional judgments on the subject matter herein.

5.1. Instream Flow

5.1.1. William H. Espey, Jr., Ph.D., P.E., D.WRE, Alan H. Plummer, P.E., Richard Browning, Ph.D., Woody Frossard, Tony L. Smith, P.E., and Michael Reedy, P.E.

Consolidated Comments on "Science-Based Environmental Flow Regime" (Section 2.2)

These Comments Endorsed by:

William H. Espey, Jr. Ph.D., P.E., D.WRE.
Richard Browning, Ph.D.
Alan Plummer, Jr., P.E., B.C.E.E.
Woody Frossard
Tony L. Smith, P.E.
Mike Reedy, P.E.

As there have been a number of similar concerns between several of the Trinity-San Jacinto BBEST members in regards to the adequacy of the "Science-Based Environmental Flow Regime" approach proposed discussed in Section 2.2 of this report, for convenience comments regarding this proposed approach have been consolidated herein. The following is a discussion on the merits of specific technical aspects of the proposed recommendation incorporated within that discussion.

The recommendations associated with the "Science-Based Environmental flow Regime" proposal are based on fundamental biological principals that, while are useful in establishing a methodology, do not provide evidence for setting specific criteria at known locations. The Trinity River is unlike many of the streams under which these principals are developed, at least for the flow components of subsistence and base flows. As can be seen in Figure 4, Page 11, the Trinity at Rosser has increased in flow (7Q) from less than 100 cfs in 1939 to over 700cfs in 2007. This trend is throughout the Trinity Basin. The application of specific scientific studies developed in other river basins should be used as a check, but due to the differences in hydrology, geology, topography, and biological communities that develop around these specific components, the flow

recommendations from these studies cannot be applied without site specific data for the recommended site.

The concepts for establishing ecologically-based flows apply where there are habitats that represent the conditions that are trying to be protected, e.g. Riffles. Due to the increase in flow from upstream waste water discharges, it is not known if these habitats still exist and therefore, until data is collected that establishes these habitats and their locations, flow rates should not be established to maintain a habitat that may not exist.

In regards to high pulse flows, while the flow regime may be needed, there is no scientific data for determining what specific magnitudes, durations, or frequencies are required. The only methodology that was available was a statistical analysis of hydrology without any additional specific ecological data to apply to determine flow rates or duration at any gauge for environmental needs. Without specific biological function data, these flow criteria are arbitrary and can be defined by any user based on their preference anywhere in the State and therefore, negate the importance of developing river basin based knowledge (BBEST).

With respect to overbank flows, it is recognized that overbank pulses (e.g. 1 per year, 1 per-2 years) are essential for the long-term maintenance of biota and ecosystem productivity. While these flows may provide ecological functions in the Trinity and San Jacinto basins, they are also the cause of significant movement of bed materials, a process that creates both instream and floodplain aquatic habitat structure. To maintain seasonal connectivity with floodplain lakes and oxbows in order to provide necessary velocity refuge areas for spawning, nesting, and rearing, historical overbank flow values have been identified. Similar to the approach adopted by the Sabine-Neches BBEST, it is recognized that the frequency and duration of such flow events are naturally driven by rainfall runoff events, and there could be variable degrees of risk to certain economic activities in the floodplains, property, and public safety. For this reason, the BBEST recognizes the ecological functions and benefits of these higher flow pulse categories, but does not recommend actions be taken to produce such flows, nor should overbank flows be included as an environmental flow standard or future permit condition.

SB3 has required the Trinity-San Jacinto BBEST to develop a flow regime that could be shown to support a sound ecological environment and maintain the productivity, extent and persistence of key aquatic habitats. SB3 did not instruct the BBEST to use HEFR or apply all the components of HEFR. The use of HEFR alone without applying additional environmental overlays does not equate to “best available science”. Such an application only accomplishes one overlay of the environmental flow recommendation, the hydrologic flow component, which is insufficient to identify ecological needs. Nowhere is it noted within the “Science-Based Environmental Flow Regime” approach that site-specific data needs to be collected. This ignores the most critical component for

establishing science-based instream flow recommendations for protection of a sound ecological environment now, or in the future, through adaptive management.

The Trinity-San Jacinto BBEST's charge was to use the best available science, review the adequacy of the information, determine the degree of uncertainty in the available science, and ultimately submit a responsible recommendation for an environmental flow regime. Included in that charge was a responsibility to provide guidance under Adaptive Management to recommend additional work needs to improve or add to our recommendations.

The aforementioned endorsements apply for the comments above, as well as the "Science Based Conditional Phased Approach" referred to in Section 2.1. That approach meets the mandates as set forth by Senate Bill 3, speaks to the level of scientific certainty, and speaks to addressing future science in the framework of adaptive management.

INDIVIDUAL COMMENTS

The following are additional comments provided by the following individuals.

William H. Espey, Jr., Ph.D., P.E., D.WRE
The precision of the fifteen (15) suggested base flow targets for a given station within the "Science-Based Environmental Flow Regime for the Trinity River, San Jacinto River, and Galveston Bay" discussion on pgs. 101-109 is a manipulation of hydrologic data beyond any reasonable ecological justification. There must be some level of ecological information specific to the Trinity (or San Jacinto) rivers to support such a comprehensive level of detail. This same comment is appropriate for the characterization of high flow pulses as well.

The hydrologic data that have been utilized within the HEFR analyses have been changing due to man's historic impacts. These flows will continue to vary due to importations to the Trinity River basin and the full utilization of currently permitted water rights. The historical record, as utilized, does not reflect the full utilization of currently legally permitted water rights or the somewhat recent trend of permitting the reuse of return flows, which are at a minimum as much as a 0.5 million acre-feet of water annually. The establishment of hydrologic criteria based on flows that are already legally permitted to be used will by definition change from the historical condition. This is a fundamental issue that has been previously discussed at the Trinity-San Jacinto BBEST and SAC levels, but has yet to be addressed by any means.

Alan Plummer, P.E.

As indicated by the approaches presented in Sections 2.1 and 2.2 (Draft - November 19, 2009), stream flow variation is important to achieve a sound ecological condition. There

are differences in opinion regarding the availability of Trinity and San Jacinto (TSJ) river basin data needed to support a full compliment of flow regime recommendations. Valuable data have been collected in both basins; however, due to limited data and basin-specific information and/or limited time to analyze the data, specific flow and biological relationships have not been developed. The advocates of the approaches appear to agree that the performance of research would be of value and is needed to develop relationships between biology and flow representatives of the TSJ Basins. The overlays developed by Science Advisory Committee (SAC) and the scientific information and conditional candidate flow values developed by BBEST provide an excellent basis to define focused research and data gathering for enhancing the science applicable to the TSJ Basins.

A phased approach, as proposed in Section 2.1, provides an opportunity to advance the environmental flow decision making process. An area of apparent agreement between the two approaches involves establishing values for subsistence and base (dry) flow regimes. Although recommended flow values proposed by the advocates of the two approaches differ, there may be an opportunity to resolve the differences. The flow quantities presented for other flow regime components could be recognized as conditional flow candidates, which could serve to provide the basis for future research and data gathering exercises. As indicated in the Section 4 - Adaptive Management to Enhance Best Available Science, there is an opportunity to define TSJ river basin specific information (e.g., cross sections, sediment grain size, etc.) that could be developed in a relatively short time period. Such information would be beneficial in applying some of the generally recognized flow and biological relationships to the TSJ Basin. Of particular interest to the research efforts would be to determine the need and ability to confirm the benefits of establishing an extensive number (e.g., up to 50 flow values per station) to maintain sound ecological condition.

The recommended phased approach proposes a method utilizing information developed by the BBEST Team activities that would greatly benefit the refining and expanding of environmental flow regimes based on sound science and technology.

Richard Browning, Ph.D.

Overall comments:

- When SB3 was enacted and when the BBEST began, there had not been any work focused on environmental instream flows in the Trinity or San Jacinto Basins, and thus the BBEST effort was the first on instream flows in these watersheds.

- There is a comprehensive record of streamflows, some of it for 50-100 years, and a comprehensive record of water quality for over 30 years. Quantitative geomorphologic data is very limited. Biologic data included various reports,

some dating back several decades, but limited to lists of species collected, sometimes including numbers of individuals and some data about those individuals.

- There no data relating specific flows to biological/ecological function in these basins.

Science Based Conditional Phased Approach

- I endorse this approach and recommendation for use in the SB3 process
    - It includes a regime of specific flows at four locations, two on the main stem of each river. These include four seasonal base flows, and overbank flow, and four seasonal subsistence flows and each site. Given the lack of information relating any specific flows to ecological function, these regimes stretch the limit of what can be recommended based on available science. It provides a basis for the TCEQ, stakeholders, and others to develop flow standards under SB3.
    - It also includes some 'candidate' flows and sites for consideration for consideration through adaptive management under SB3. I emphasize that these candidate flows are only for consideration through adaptive management and are not recommended as flow standards in this initial round of SB3 recommendations or rulemaking.
    - This approach and recommendation is the best that can be made using the best available science.

Science Based Environmental Flow Regime for the Trinity River, San Jacinto, and Galveston Bay

- I do not endorse this approach or recommendations
    - The report on this approach includes a long background section. It is a good general discussion. However, and there are a number of points on which it does not apply, at least in the Trinity Basin. Some of those have been discussed at length by the BBEST members. This is not the place to go over those differences, except to note that they exist.
    - As for the specific recommendations, I have a number of concerns, but mention here just three:
        - The recommendations are too detailed. The recommendations for each site include 24 to 26 specific flow levels, plus frequency, duration, and volume specifications for 8 to 10 of the higher flow levels, a total of 48 to 56 specifications for each site. That goes beyond the best available science, considering that there is no corroborating data at any of the sites.

- It is also too detailed from a hydrologic point of view. It is too prescriptive and does not respect the unpredictability of the stream flows.
- The recommendations use the wet, dry and average conditions concept that has not been defined except in arbitrary statistical terms. Those three conditions have the effect of creating three different regimes for each site. It is not justified.

5.1.2. Mike Turco

Thank you for the opportunity to participate in the Trinity-San Jacinto Basin and Bay Expert Science Team (BBEST) over the last 12 months. I want to take this opportunity to thank Joe Trungale and Tony Smith for their outstanding effort on this team, much of the "heavy-lifting" for this effort came at the "expense" of their shoulders. The discussions between all the members of the team have been thought-provoking and very informative. Although it is obvious from the report that consensus was an aggressive goal on our part, I feel that we have pulled together the best available scientific data and interpretations available to take a first cut a flow regime that supports a sound ecological environment. I have outlined my major comments below:

1. Section 2.1 does a good job laying out the foundation of the problem and identifying the limitations of the data sets for both basins. Several times throughout the document it is mentioned that the hydrology of the basins have changed over the last several decades, with most of the systematic change coming from impoundments and anthropogenic induced return flow of various sources. Al that being said, the sites associated with this recommendation are currently a sound ecological environment, which is a fundamental assumption to the rest of the document and my comments that follow.

2. Table 3 page 25: Consider listing all sites considered in the analysis, including those that have a recommendation of flow regime and those that have only conditional flow regimes. The table could then denote at least which gaging station's were investigated, which were chosen, and which carry what level of recommendation or condition. Also, gages should be listed in downstream order (increasing station ID number).

3. Page 28: I agree that natural variation in base flow is beneficial for the in stream and riparian ecology, however, data is insufficient to designate a specific flow for each. An appropriate approach is to take the minimum base flow as a lower threshold and specify in the table that "variation in base flow is beneficial to the ecosystems at these locations" regardless of the output from HEFR - the adaptive management process should be able to provide more information and validation to a wet and dry and average discharge value should it be added at some time in the future.

4. FLOW Recommendations for 2.1.##: Consider in the flow regime table for each site and providing both the conditional and recommended flows in one table, adjustments in font and color should allow for the user to know what is recommended and what is conditional based on future data and analysis. This may make it too busy but there is an advantage to having the whole "story" for each site in one picture.

5. Section 2.2 overall includes a wealth of background information on the importance of flow to the loic community. The term best available science is certainly open to interpretation, and although there are statements in this section that suggest to me that best available science could be "professional opinion," in the context of this exercise I believe that that is a recipe for non-consensus as all of us have a professional opinion based on our experience and background and my limit of best available science maybe more or less rigorous than others. The discussion of uncertainty in the ecological information on page 51 is the type of information that leads me to favor a less complex approach to the in stream flow recommendation.

6. There are numerous occasions within section 2.2. where the same statement is repeated, consider a more in depth editorial review of the section to thin out some of the redundant information. Additionally, there are many references cited in the section that are not listed in the references section of the document and could not be verified. DOUBLE CHECK TO INCLUDE ALL REFERENCES CITED ARE LISTED.

7. Typo on Dry Base Flow in Table 16.

8. The study conducted by Bio-West on the Lower Colorado River is mentioned several times in section 2.2 as representative data set of the hydrology, water-quality, and biological community of the Trinity and San Jacinto rivers. In my experience in studying streams in Iowa, Nebraska, and Texas, every stream has its own "character" and in this part of the state of Texas that certainly holds true. Urban verses rural hydrology, return flow variation, and sediment and water-quality concentration all vary dramatically across the area, making the comparison to the Lower Colorado uncertain. Since there is little biologic data in the Trinity and San Jacinto basin, no data to data comparison can be completed to ascertain the validity and limitations of testing the Bio-West conclusions in the Trinity or San Jacinto Rivers.

9. Section 2.2.6 second half of paragraph: I agree that the hydrology of these systems is very complex. However, with the absence of any independent variable to correlate to the complexity a priori, we must not fall into the trap of adding complexity where it can not be defended. One could make a very complex model and nail down the hydrograph to the daily level and predict the response of the ecosystem to that estimated hydrograph, however, without the data to verify those necessary flows, the recommendations are unusable. Identifying the uncertainty and the translating the limitations to the recommendation is an important if not vital part of this exercise.

10. SIGNIFICANT FIGURES: Please adjust all discharge values to include two significant figures and round appropriately.

11. Section 2.2.9.2: Frequencies associated with these overbank recommendations should not be averaged over the period of record, use the period of record frequency (i.e. 5 per 10 years not 1 per 2 years). The annual cycles of wet verses

dry years is important to preserve, but should also be noted in the recommendation that the overbank flows should not be anthropologically induced.

12. Section 2.2.9.2: There is no definition of what a wet, dry or average year is at each of these gages, it is possible for one gage in the Dallas area to have a dry year and gages at the lower end having a wet year in the same year. Base-flow is base flow, and the wet and dry base flows are more associated with lead or trailing leg of an event. Breaking out baseflow without an associated data set to validated each discharge is more complexity than our data set provides.

13. The adaptive management and proposed future data collection and research suggestions are well thought out for both sections 2.1 and 2.2. Once the foundation is set with this recommendation, future data sets will allow planners to better refine the recommended flow regime provided in the document and possibly account for more complexity at locations where it is needed to insure a sound ecological environment.

It is obvious to me that I have a fundamental disagreement on how best to approach the determination of the flow regime based on the availability of the site specific data at our selected gages. My experience in hydrology and, in particular, modeling leads me to the conclusion that at this time, for these basins, the "less complex" approach is the appropriate course of action. Although HEFR model will provide a multitude of different base flows and high flow pulses; I do not feel the a priori data on Trinity or San Jacinto supports that level of complexity outlined in section 2.2. There is no question that in other streams in other areas, like the Lower Colorado River in Texas and the other rivers elsewhere in the US mentioned in section 2.2 of the report, variability in base flow and high flow pulses is important, however, assigning a specific flow rate and a frequency without much of any information about the site is premature. Based on these comments I feel comfortable endorsing the less complex approach of section 2.1.

It is unfortunate that the BBEST Team was unable to come to a consensus on the best approach to a flow regime, however this document does provide a wealth of information that will assist the stakeholders as they take-on the further refinement of these recommendations.

5.1.3. Dave Buzan

Comments on the "Science Base Conditional Phased Approach"

Prior to passage of SB 3, stakeholders argued appropriately and successfully that they had not had adequate input into the scientific basis for the state's water quantity evaluations and management. SB 3 is designed to provide stakeholders and a broad range of science experts, other than only scientists working for state agencies, the opportunity to evaluate the best science currently available and provide flow regime recommendations based on that evaluation. SB 3 did not recommend deferral of flow recommendations based upon the lack of information. It acknowledged there would not be enough information and encouraged stakeholders and scientists to identify future work needed to address uncertainty. It allowed adjustment of flow requirements in future permits.

The "Science-Based Conditional Phased Approach" discusses concerns about, and recommendations for the manner in which a flow regime should be considered and implemented in several portions of the document. The "Science-Based Conditional Phased Approach" also advocates future work to address uncertainty in the current science.

Uncertainty about implementation of a recommended environmental flow regime is shared by all members of the BBEST. However the BBEST's charge is to ensure that the stakeholders, the Environmental Flows Advisory Group, and the TCEQ have the best, most complete, environmental flow regime recommendations possible within the time allotted and with the information available. The state will continue to issue water rights permits with or without a scientifically-based environmental flow recommendation from the BBEST.

The "Science-Based Conditional Phased Approach" emphasizes the ability of future research and investigation through adaptive management to clarify the relationships between flow and environmental health. However resources have not been allocated or identified for that work and there is no certainty that resources will ever be available for future investigation. If resources are available, there is no certainty that resources will be adequate to provide the desired information.

Although the concerns regarding implementation described in "Science-Based Conditional Phased Approach" are understood, the recommendations provided do not appear to recommend complete environmental flow regimes nor do the recommendations appear to use all sources of information and data may available.

Specific comments

P 24 To clarify for the reader, the statement, “As noted in Guillen 2009 and Espey 2009, no collection of data is available within the Trinity nor San Jacinto basins;….” may be interpreted as meaning there literally are no data available to evaluate environmental flows. It is clear in the citations mentioned that there are hundreds of studies and over 100 years of data describing flow, water quality, biology, and geomorphology of these systems which can be considered for the purpose of determining environmental flow regimes. The authors recognize the existence of usable information for these systems on p. 26, “The hydrology of all four stations is very similar and the available geomorphologic, water quality, and biologic information also indicates no differentiation between them.” And again on p. 28, in stating “Based on application of the best available science (i.e., extensive flow data, a significant amount of dissolved oxygen data, fishery conditions relative to dissolved oxygen conditions, and a calibrated QUALTX water quality model for the assessment of dissolved oxygen), the recommendation for the Trinity River near Oakwood gage is as shown in Table 4 below:”

5.1.4. Jarrett (Woody) Olen Woodrow, Jr.

I am providing technical comments to our report: Environmental Flows Recommendations Report. Thank you for leading this group and I sincerely hope that my contributions have been meaningful.

Global comment: All references and/or citations should be included with each section of the report. These are the scientific and technical foundations for the various recommendations and statements provided in the report and it should be apparent to the readers what recommendations are using what information.

Section 1.0
I endorse this Section of the report and offer the following comments.

1.3 Sound Ecological Environment
The statement that the BBEST reached consensus that the current status of the ecosystem is healthy and sound is a true statement. This member having agreed to the statement considers his opinion at the time an error and therefore retracts his agreement. The two biological overlays do provide substantial information regarding the occurrence and distribution of species, particularly aquatic species. They do not however make an assessment of the "health or soundness" of the ecosystem which under SB3 considers not only the rivers, streams and bays but their immediate and associated habitats such as floodplain forests, sloughs, meander scars, sandflats, and marshes. The Galveston Bay Estuary Program has documented significant impairments over time to the Galveston Bay system including the loss of 30,000 acres of wetlands (GBNEP-31) and recent wetland losses (State of Bay), significant water quality issues (TMDLs), and reductions in certain species populations over time (State of the Bay). While the ecosystem is nowhere near collapse and is very resilient, it would however be difficult to say that it meets the definition provided by SAC (2009a) and the TIFP Technical Overview Document. There is much less information on the status of the river basins and there have been no studies to this member's knowledge that evaluate their ecosystem integrity. There are several indicators that suggest the integrity of the river ecosystems is at risk.

The Trinity River is considered one of the most impacted river basins in Texas (Chin, et al, 2008). Reservoirs do have effects on the physical and biological components of the ecosystem (Richter et al. 2003). Changes in flow regimes have detrimental effects on the sustainability of floodplain forests (Ward and Stanford 1995, Hughes and Rood 2006, Jungwirth et al 2002). Changes in the geomorphology of the river result that have long-term consequences to habitats (physical and biological) associated with morphological evolution of a river (Hupp, et al. 2009, Hodges 1997) and delta formation in the bay. Texas has lost 63% of its bottomland forests and this only further elevates the importance of what remains. Many migratory and resident songbirds are in decline that depend on these floodplain forests (Moore, et al. 1992, Rich et al. 2004). Changes in

flow regimes have been shown to affect mussels, floodplain forest, and breeding birds (Rypel et al. 2009, Hoover 2009). There are several species of mussels and birds that are at risk of extirpation from the ecosystem if current trends of habitat loss and disruption continue (Rich et al. 2004, Howells et al. 1997). These are impacts and data that contradict the definitions provided by the SAC (2009a) and the TIFP Technical Overview document. There has been no data or assessment that indicates that all the conditions as defined exist in the basins and bay. There are data and information that indicate that these ecosystems do not meet the definition.

Section 1.4.2

Galveston bay was not inland during the last ice age. During the ice age, the bay was then the river valleys of the Trinity and San Jacinto Rivers. As the earth warmed and the sea levels rose, the river valleys became what is now Galveston Bay (Galveston Bay Estuary Report GBNEP-44).

1.5.2 page 17 last paragraph

The BBEST did not arrive at consensus on a complete set of recommended freshwater inflow values. I suggest this paragraph be inserted instead:

"A set of values for three seasons were developed using the methods approved by the BBEST. The tables therein present flow recommendations stated in acre-feet per month for three flow sources: Trinity River, San Jacinto River, and coastal streams. No winter indicator organism comparable to the others that were used was identified. Some members were satisfied to leave a winter flow value out of the recommendation and other members were not. The report elaborates on this issue and the Bay Committee members did seek alternative ways to identify an inflow winter value. This however remains unresolved."

Section 2.1

I do not endorse this Section of the Report because it fails to meet the charge of SB-3.

The authors claim in several locations in their report that insufficient data exists to make flow regime recommendations that are protective of the riverine ecosystem. Despite that declarative, they make recommendations for select flow categories. It is unclear what the purpose of these recommendations are, if, as the authors claim there is insufficient information to make recommendations. There is a reference to Guillen (2009), page 28 regarding the need for minimum base flows to protect mussel populations. However, other than relationships to dissolved oxygen (Qualtux), there is little to indicate that the recommendation is an "environmental flow regime recommendation".

I encourage the readers to the Section 2.2 of the Environmental Flows Recommendations Report and its associated citations for scientific support for making flow recommendations. Additional citations are summarized below.

Lytle and Poff (2004) provide a review of how organisms are adapted to natural flow regimes. They outline the costs and benefits for particular species and/or groups for floods, droughts and pulse events, timing, seasonality, duration, etc. Recent work by Rypel et. al. (2009) demonstrates the need for variable flow regimes that replicate natural flow patterns including low pulse flow events, timing, reversals of hydrograph are important for mussels populations of different species to prosper. Rypel (2009) et al also found that the inverse relationship from those found for mussels for bald cypress growth demonstrating that variable flow regimes are necessary for different species to thrive. Recent research in river restoration and our understanding of river ecosystem integrity has demonstrated that flow, flow pulses, its seasonality and variability are important factors in determining the integrity of the river ecosystem (King et al 2009, Naiman, et al. 2005, Jungwirth et al. 2002). Rood et al. (2003) found that variable flow and pulse events are important to the recruitment of riparian tree species and that timing, duration and volume all played important roles in sustaining a sound ecosystem. Hoover (2006 and 2009) found that hydrologic restoration of floodplain forest is important to the nesting success of birds. Several researchers demonstrate that groundwater and surface water have important relationships (Sophocleous, 2002, Malard, et al., 2002) not only with each other but the instream and adjacent biological and chemical environment. Hupp et al.(2009) found that coastal plain rivers in the U. S. changes in natural flow regimes disrupt the geomorphological process that maintain stability in riverine systems leading to increased erosion rates, head-cutting, aggredation and bank slope failure.

Section 2.2

I endorse this section of the report because it provide environmentally based flow recommendations using best available science.

Section 2.2.9.1 Page 100
This should be included at the end of the text for this section:

There was insufficient time or resources to inspect and assess each site in person by members of the BBEST. Therefore, aerial photograph imagery of each site and topographic maps were reviewed for each gage site and its adjoining river reach. Imagery reviewed was provided by Google Earth. Recent 2008 and 2009 USGS aerial coverage now was not available when the Google Earth imagery was reviewed. A brief summary of that review is provided after each base flow recommendation. A significant limitation of this review is the lack of elevation data for specific features.

5.1.5. L. James, Lester, Ph.D.

It is disappointing that no consensus could be reached on instream flow recommendations. In my opinion, the "Science Based Environmental Flow Regime for the Trinity River, San Jacinto River and Galveston Bay" represents the best available science in more ways than the "Science Based Conditional Phased Approach." In the former, there is an implication of more certainty than I have about multiple flow regimes in years that differ by some determinant of "base" flow. The complexity of the recommendations at all of the gages based on the IHA/HEFR analysis suggests a level of understanding of the ecologies of these rivers that I think would be extremely difficult to obtain. However, there are clear biological justifications for a subsistence flow, a single base flow, periodic high flow pulses and less frequent overbank flows. In the latter "Conditional" recommendations, there is the initial omission of high flow pulses, which I consider to be ecologically essential, but there is also an emphasis on adaptive management, which will be absolutely necessary to provide a more solid foundation for the next iteration of environmental flow recommendations.

I endorse the "Freshwater Inflow Recommendations for Galveston Bay" and the "Science Based Environmental Flow Regime for the Trinity River, San Jacinto River and Galveston Bay," and commend all of my colleagues on the BBEST for their dedication to the process and their commitment to outcomes that match their perception of what is best for the people and the nature of the State of Texas.

5.1.6. Joseph F. Trungale, P.E.

Endorsements

"Science Base Conditional Phased Approach" - I do not endorse this proposed recommendation
"Science Based Environmental Flow Regime for the Trinity River, San Jacinto River, and Galveston Bay" - I endorse this proposed recommendation
"Freshwater Inflow Recommendation for Galveston Bay" - I endorse this proposed recommendation

Comments on the "Science Base Conditional Phased Approach"

It is my professional opinion that the instream flow proposal entitled "Science Based Conditional Phased Approach" fails to meet the mandate set forth in Senate Bill 3 in fundamental ways. Rather than define a quantitative schedule of flows necessary to protect a sound ecological environment based on best available science, this proposal presents incomplete recommendations and puts off difficult decisions with the promise of additional studies to be completed in adaptive management. Adaptive management was included in the legislation to allow for refinements to the recommendations as greater understanding of the flow – ecological relationship is developed with the collection of new data. The Legislature understood that data are limited (as evidenced by the passage of Senate Bill 2 in 2001) and yet passed Senate Bill 3, mandating the identification of environmental flow regimes prior to the completion of SB 2 studies. Adaptive management was included to provide a mechanism for refinements, it was not included as a substitute to identifying flow regimes.

This proposal is based on an extremely narrow interpretation of the best available science. With the possible exception of an undocumented water quality analysis, the authors do not believe that science exists that can be applied to develop flow recommendations. Contrary to the application of best available science this proposal is a refutation of decades of studies in instream flow science. The overwhelming consensus of published research concludes that the safest and most certain way to maintain a healthy ecosystem is to mimic components of a natural flow regime. While there may be legitimate concerns about this basic paradigm that might be scientifically questioned (e.g., though publishing a study and subjecting it to peer review through the scientific literature), the authors simply deny the existence of this accumulated science.

What is offered herein is a flow recommendation resulting from a misunderstanding of basic concepts (e.g. the ecological purpose of base flows) and misapplication of hydrologic analysis tools (IHA/HEFR). The result is a recommendation which largely dismisses SAC guidance. While much is made of the need to clearly articulate the level of uncertainty associated with instream flow recommendations, it is my professional opinion that there is a very high level of uncertainty that the recommendations put

forward in this document would protect a sound environment. I think it more likely that the implementation of these recommendations would produce the opposite result.

Specific comments

P 20 "Fundamental to the analyses employed in deriving a flow regime recommendation is the acknowledgment that the Trinity and San Jacinto rivers, at the locations considered by the BBEST, are currently a sound ecological environment."

If this is the case why then are the recommendations for flows that have not occurred since the drought of the 1950s? A comparison of the base flows recommended for Oakwood reveals that these flows have not occurred since Jan 23, 1957. How can we be confident that the "currently sound environment" would be maintained by these very low and fairly static values?

Ultimately, the problem with these recommendations is that the authors selectively extracted concepts from the natural flow paradigm, i.e. those parts that would result in the lowest flows, and then misapplied tools used to create a flow separation, in which most of the base flows are partitioned into the high flow categories. Finally, with no clear explanation, the authors concluded that there was only enough confidence in estimates of the "dry" base flows to merit their inclusion in the recommendation, other levels of base flows, which are commonly identified in the literature, were deemed too uncertain to include.

P 20 The proposal cites a section from the draft SAC Discussion Paper: Moving from Instream Flow Regime Matrix to Environmental Flow Standard Recommendations (SAC 2009c). This document is very much in draft form. In the version that was reviewed at the SAC meeting in November, 2009, the entire section that is cited had been commented out of the document. This is not to suggest that some of these ideas will not make it back into the final document, just that it may not be prudent to cite (as a "thorough" discussion) a document that is still undergoing significant modifications. As to the specifics of the citation, the authors of this proposal appear to be implying that historical target frequencies may not be necessary and perhaps they could be significantly lowered. Given that the values in these recommendations are more closely representative of drought condition flows and are not a "sufficiently close representation of key elements of the historical hydrology," it is my opinion that the authors have incorrectly carried the draft SAC discussion too far.

P 21-22 Section 2.1.1 concludes with two paragraphs on the history of return flows and some discussion of potential plans for the use of this water. While it is clear that some historical flows had been legally appropriated but left in the river, the legal status of historical flows makes no difference to habitat, sediment transport, or any other important aspect of the existing sound ecological environment. The legal status of flows is certainly important to future implementation, but this is not the charge of the BBEST which is to define instream flow recommendations "without regard for other uses of water." Perhaps the more salient point to consider with respect to reuse is the acknowledgement that as

water reuse projects are implemented, water managers will be confronted with decisions that will affect future flow conditions. It is therefore critical that they have access to the best available science so as to make informed decisions. The North American Waterfowl Management Plan Implementation Framework (2004) provides some guidance on this issue that might be applicable to the discussion of instream flows.

> "Uncertainty is and will remain a prevalent facet of the management and conservation of biological systems. In the face of making decisions when the outcomes are uncertain, wildlife conservation planners and managers have only two options. The first is to defer decisions until understanding of the managed system improves. Continued and possibly escalating human-caused and naturally occurring change in biological systems—and the likelihood that research will offer no short-term solution to management dilemmas—are factors which render this option largely unacceptable and risk irreparable damage to the wildlife resource. The second, more prudent response is to base conservation resource allocations on current scientific understanding supplemented with educated guesses. Managers should proceed with conservation programs while maintaining the explicit goal of reducing uncertainties and improving future conservation strategies."

The latter option is consistent with the framework established by SB 3. Unfortunately the "Science Based Conditional Phased Approach" proposal appears to follow the former, less prudent, option.

P. 22 The last paragraph includes a discussion of the Bio-West instream flow study in the lower Colorado River and includes the following: "As can be seen from the findings in that report, the variations in habitat areas are significantly diverse at different locations within the Colorado watershed." As they do not refer to any specifics in that report upon which they base this finding, it is difficult to fully respond to this interpretation. Clearly the Colorado, like all rivers, contains varied habitats, however the flow recommendations developed to protect a sound ecological environment in that study were very consistent throughout the river. The same flow percentiles were recommended for a range of base and subsistence level flows at all five sites with the notable exception of subsistence flows at Wharton (in part because that site is outside the range of the state threatened Blue Sucker). The high flow pulses, channel maintenance and overbank flows were identical for the entire river stretch. All of the recommendations in that study are reasonably consistent with the recommendations included in the other riverine proposal "Science Based Environmental Flow Regime for the Trinity River, San Jacinto River, and Galveston Bay."

P 23 with reference to Table 2 the authors of this proposal argue that "Given the limited data sources and information available on the Trinity and San Jacinto River basins, it is readily apparent that any approach that may be utilized by the Trinity-San Jacinto BBEST will likely fall on the far left of Table 2, as there is great uncertainty given the lack of available data." Dr. Kirk Winemiller, a member of the panel established by National Academy of Sciences to review the Texas Instream Flow Program and the original author of Table 2,

attended the final Trinity San Jacinto BBEST meeting. At the meeting he informed the authors of this proposal that they had misinterpreted this table. The correct interpretation, at least from the perspective of its author, is that while there are different levels of information, decisions can be made based on a range of different types of analysis. A more considered reading of the table than the one presented by the proponents of this proposal suggests that different approaches are appropriate for different contexts. These contexts have a lot to do with the questions being addressed and the scale at which they are to be applied. The approaches on the right are not necessarily better than the approaches on the left. In fact it is arguable and I believe wrong to assume that even if information was available to conduct "Individual based models" that this would be the best approach to address the mandate of SB 3. Finally, the supposition that "any approach that may be utilized by the Trinity-San Jacinto BBEST will likely fall on the far left" deserves a little more consideration. The biological overlay reports prepared under SB 3 for the Trinity and San Jacinto would probably not be characterized as "Coarse Ecological Indicators" by the majority of fluvial ecologists. At least some if not most of this analysis would better be characterized as "Habitat Guild Analysis" and they also include some review of "Species HSC." These approaches are right in the middle of Table 2.

P 23 The paragraph under table 2 repeats the author's opinion that professional judgment is excluded from the definition of "best available science." The authors of this proposal brought this argument before the SAC on October 7, 2009 - where it was thoroughly rejected.

P 24 "The scientific method also requires reproducible results." The literature on the topic of holism verses reductionism in ecosystem studies is extensive (Wiegert 1988, Bergandi and Blandin 1998) and review of it is beyond the scope of what can be presented here. However this comment, along with the Webster's definition of the scientific method, begs the question: is it the position of advocates of this proposal that instream flow recommendations should not be developed until site specific ecosystems experiments are conducted and shown to produce reproducible results? I don't know of a case for which this standard has been applied to instream flow studies. This type of ecosystem level manipulation was clearly not envisioned in the SB 3 legislation.

P 24 With regards to the comments that hydrologic analysis by themselves are "insufficient to develop and instream flow relationship" and "Unless additional information is available to help establish the percentiles for each flow component, there is no environmental connection with the resulting flow regime." While it is hard to imagine that any BBEST members would disagree that the application of more overlay information is beneficial, it should be pointed out that hydrologic analysis, with far less supporting information than has been available to the BBEST, has been used in dozens if not hundreds of evaluations to develop flow recommendations. This should not be meant to imply that I believe that only hydrologic data is available in the Trinity and San Jacinto (the other riverine proposal includes an extensive discussion of the biological basis for the recommendations present therein. If, however it is true that there is not sufficient biology and hydrology is insufficient by itself, then how do the authors justify the inclusion of anything, with the possible

exception of subsistence flows supported by an undocumented water quantity analysis, to be worthy of the designation of recommended flows?

P 26 I do not believe it is "imperative" that the BBEST require "that TCEQ recognize the contributions of downstream water deliveries, hydropower releases, and inflow passage to honor downstream water rights towards maintenance of recommended flow regimes supportive of a sound ecological environment." Clearly, these flows, where/when they exist, do contribute to a sound ecological environment. It may be more relevant to the BBEST charge to point out that if there are changes to how these water rights are managed (e.g. the transfer of water rights from the lower basin to the upper basin or some other water transfer scheme) then these "protections" vanish.

P 26 "The Trinity-San Jacinto BBEST recommends that the TCEQ develop appropriate methods for interpolation of flow conditions applicable to future permits and amendments from reference locations for which flow regimes supporting a sound ecological environment are established." This proposal includes two locations in the lower Trinity and two in the San Jacinto (on different streams). It is not at all clear how interpolation might be achieved with such a limited number of points.

P 28 The mention I saw with reference to the water quality analysis is "An assessment has been performed on subsistence flow levels established through a HEFR analysis at the Oakwood gage (Recommended Flows). This assessment utilizing the QUALTX model provides a reasonable level of confidence that the selected flow regime should be supportive of a sound ecological condition represented by achieving stream standards for dissolved oxygen that support fishery conditions." Given that this essentially represents the entirety of the scientific basis for the recommendations put forward in this proposal, it would be helpful to provide some detail and description of the analysis performed.

P 29 Table 4 (and Tables 5-7). These tables include definitions and purposes for the various components of a flow regime. These "purposes" are not synonymous with the purposes as described in the SAC guidance, the TIFP technical overview or any other references that I could locate. What is labeled "purpose" in these tables would more accurately be described as a hydrologic description, although these hydrologic descriptions are not consistent with the actual purposes of these flows, namely that they provide for specific ecological functions. These functions are thoroughly discussed in the documents mentioned above.

P 30 The last sentence in the first paragraph highlights the inherent conflict in the proposal. Throughout the proposal it is argued that there is insufficient science to develop recommendations and that flow regimes cannot be developed based solely on hydrology. However, on this page the authors write "a flow regime based solely on historical hydrology is proffered for two gages in the watershed." It is unclear throughout the document why some locations and flow components were deemed acceptable for inclusion in the flow recommendations, but other were not, and also why hydrology alone was sufficient in some locations, but not others.

P 31 The sentence “As indicated previously, this flow regime is based solely on hydrologic data, and is provided as a means of investigation of a less-impacted stream in the future through adaptive management.” is confusing. Are the values in Tables 6 and 7 SB 3 recommendations as their captions state or do they fit into the category variously called “Candidate” or “Conditional” recommendation?

P 32 It should be pointed out that SB 3 never mentions or even suggests the terms or concepts “Candidate” or “Conditional” recommendation. These ideas were invented by the proponents of this recommendation as way to acknowledge that there are likely flows that are needed to support a sound ecological environment, but which they are unable or unwilling to identify.

5.1.7. George Guillen, Ph.D.

I appreciate the opportunity to review and provide technical comments on the draft **Review of Environmental Flow Recommendations Report**, prepared by the Trinity San Jacinto Galveston Bay BBEST. I have tried to limit my comments to major areas deserving clarification or where I felt additional narrative may be needed to clarify a topic for future readers of this report.

Overall I feel that this report represents a significant technical achievement in furthering our knowledge about instream and estuarine environmental flow needs within the two basins. As pointed out there is still disagreement between various members on the best approach to deal with environmental uncertainty. This is unfortunate because this may imply that there is some flaw in this report when in fact it represents normal healthy scientific debate that characterizes much of environmental science including equally challenging issues that defy traditional experimental approaches including global warming, loss of biodiversity, and emerging contaminants. My specific recommendations and comments are listed below. I have also attached a few editorial comments.

I do not endorse the *Science Based Conditional Phased Approach.*

I believe that this approach fails to meet the full intent of SB3 responsibilities set forth for the BBEST. SB 3 was designed to provide stakeholders and a broad range of non-agency scientists familiar with river and estuarine ecosystems the opportunity to evaluate the best available science and develop flow regime recommendations based on that evaluation. Deferral of recommendations based upon the lack of information was not considered an option by SB3. Instead it addresses current uncertainty by encouraging scientists to identify future work needed to address data gaps with allowance for adjustment of future water rights permits. In addition, in my opinion, it does not utilize the available biological and hydrological data provided by the San Jacinto and Trinity River Biological Overlay Support Documents in developing the recommended instream environmental flow regime. I do however agree in principle with portions of the adaptive management approach that advocates additional research to fill in data gaps and address uncertainty. This future research would help refine and enhance the flow recommendations made as part of the BBEST recommendations. This uncertainty about implementation of a recommended environmental flow regime is shared by all members of the BBEST. However the charge of the BBEST committee was not to wait for this research to be completed but rather to utilize best available science to develop an environmental flow regime that best support a healthy river within the time (approximately 1 year) allotted. The major weakness of the *Science-Based Conditional Phased Approach* relies on the ability of future research and investigation through adaptive management to further clarify the relationships between flow and environmental health. Adaptive management was included in the legislation not to defer recommendations but to allow for further refinements as additional research and

knowledge regarding the understanding of the relationship of ecological needs of the river and flow are developed through the collection of new data specific to the San Jacinto and Trinity River systems.

I do endorse the *Science Based Environmental Flow Regime for the Trinity River, San Jacinto River and Galveston Bay* approach. I believe that it meets all the criteria set forth by SB3 and subsequent SAC guidance documents by recognizing the importance of natural variability in riverine systems and their relationship with the health of lotic ecosystems and geomorphology and its use of best available science. The approach used is well documented with scientific literature as to the importance of individual flow components and the rationale of having wet, average and dry conditions. In addition, this approach provides a framework for future studies to test existing hypotheses and data on the functioning of the Trinity and San Jacinto River systems to facilitate adaptive management.

Specific Comments:

Page 4. Section 1.3

Although I agree that the Trinity River can support a healthy population of fish and invertebrates it is important to note that the Trinity has undergone major changes in the basin that influence sediment transport, fish migration etc. Similar arguments can be made for SJR, which to a lesser extent has undergone habitat fragmentation including increased wastewater loading and habitat fragmentation. Effected species most likely include sensitive invertebrates (e.g. unionid clams vs. ammonia, hypoxia) and migratory species, e.g. freshwater shrimp, paddlefish. Lake Livingston has reduced downstream sediment and nutrient transport.

Suggest adding: "However, many features of the natural system that previously existed have been altered. For example, the Trinity River Basin is the most fragmented watershed within Texas in terms of reservoirs per river mile. This has the effect of limiting migration of several river species including paddlefish, river prawn, and anadromous American eel. In addition, various dams along the river such as Lake Livingston have likely reduced downstream sediment and nutrient transport. In addition, pre-1980 fish assemblages were seriously impacted by poor water quality (low oxygen, high ammonia) from at least the late 1950s to the 1970s in portions of the Trinity River below Dallas and in the several coastal bayous in the San Jacinto River and coastal watersheds. For example, numerous fish kills have occurred in the Dickinson Bayou and the Houston Ship Channel over the last 30 years. Attainment of dissolved oxygen standards is still problematic in many watershed segments near Dallas Fort Worth and greater Houston area. It is difficult to ascertain how these levels impacted stream biota since few historical monitoring data exist from before the 1970s."

Page 12. Section 1.5.1

The reader is currently left with the impression that there is not enough information to make a decision. The text should read such that the reader is aware that although this is not the ideal case a decision was made using the *best available science*. A sentence should be added at the end of this paragraph that reads. "Since no site specific or river basin specific studies have been conducted, this represents the best available science for development of environmental flow regimes". BBEST had to rely on this data exclusively along with biological data provided by the Biological Overlay support documents".

Based on the discussion given it is unclear why you would not use all the hydrological information available for developing a flow regime at this time. On one hand the author advocates a "plan to establish a more comprehensive coverage of monitoring stations and flow regime values if needed, which would be more complex, as scientific data is developed that supports Trinity and San Jacinto River basin flow and biological/ecological relationships." However, at this time they want to limit use of pre-selected gage sites to a few sites in each basin, even though the IHA/HEFR analysis can easily handle additional sites. This is confusing to the reader. It is highly unlikely that any new sites would help in establishing the historical hydrology, since all historical gage and monitoring sites have been identified during the BBEST review process. Additional sites would likely only help provided some additional information on spatial patterns, not historical flows.

Page 13. Section 1.5.1.1

Some explanation should be made as to why the original 13 sites that were selected for hydrological review were not used in the analysis. These sites were initially selected based on a review of their historical hydrological record and location in their respective basins from the entire universe of much larger number of sites, using many of the criteria listed in this section. There were also used by the Crespo analysis. Some rationale needs to be given for NOT using these data.

Page 20. The proposal cites a section from the draft SAC Discussion Paper: Moving from Instream Flow Regime Matrix to Environmental Flow Standard Recommendations (SAC 2009c). This document is still in draft from and I would caution the authors for including this.

Page 23. The paragraph under table 2 appears to suggest that *best professional judgment* is not part of what is considered *best available science.* As discussed under *section 2.2.3 Best Available Science* of this report and supported by various federal and state guidance documents “best professional judgment” is often acceptable and falls within the definition of “best available science”. This interpretation is applicable here since the best professional judgment provided is from several biologists with a cumulative experience of over 75 man-years in the field of aquatic and riparian biology

as further informed by a thorough literature review of both basins and analysis of the most current instream flow needs for target focal species and guilds within the basin.

page 24. The authors state that "As noted in Guillen 2009 and Espey 2009, no collection of data is available within the Trinity nor San Jacinto basins;…." and that this in turn eliminates the possibility of employing the scientific method. I agree with this if we were planning a new study or were limited in our decision to *best science possible*. This would be the ideal situation in an ideal world. However, we are not. The authors of this portion of the report (section 2.1) have confused the use of best available science for rendering opinions and recommendations with the use of "best science" for formulating new studies, which includes hypothesis testing, experimental design etc. The fact is there is literally 100's of studies that are cited by both Guillen 2009, Espey 2009 and the included section 2.2 Science Based Environmental Flow Regime for the Trinity River….Galveston Bay, that provided the technical basis for the recommended flow regime in section 2.2.

page 24. The authors state that hydrologic analysis by themselves are "insufficient to develop an instream flow relationship" and "Unless additional information is available to help establish the percentiles for each flow component, there is no environmental connection with the resulting flow regime." However, the use of IHA has increased substantially and there is a rich literature on its use. Recent river restoration projects on the West Coast (e.g. Trinity River) have relied primarily on recreating something as close as possible to the natural flow regime as possible recognizing the need for adaptive management to deal with uncertainties during implementation.

Section 4.0 Adaptive Management

Recommended Additions: Page 157 on, mostly under biology

1. Develop information on floodplain forests and habitats that can be geo-referenced against varying flow regimes to estimate percentage of overbank flooding within these areas and relationship to plant and animal communities, including critical riparian species (Neotropical migratory birds, wading birds, and river turtles).

2. Develop an inventory of riffle habitat and develop relationships to extent and depth with varying flows.

3. Map and evaluate mussel bed distribution and mussel density within each watershed in relation to flow regime

4. Conduct PHABSIM type studies to relate focal species distributions and responses to varying flow regimes. Focus on fluvial specialists.

5. Conduct additional geomorphological studies to evaluate the relationship of stream flows and channel formation and sediment transport.

6. Measure and collect data on cross-section depths, cover, and stream velocities at critical points including riffles.

7. Map the occurrence of tributary and oxbow connectivity at varying flows.

General Comments:

Literature Cited Format

Since each section of this report has been produced be separate authors as in the case of a chapter in a technical book, I recommend that the scientific references used in production of that section or cited by that section be listed immediately after the section of the report and associated with it. This will provide for a more concise chapter format.

5.2. Freshwater Inflows

5.2.1. William H. Espey, Jr., Ph.D., P.E., D.WRE, Alan H. Plummer, P.E., Richard Browning, Ph.D., Woody Frossard, Tony L. Smith, P.E., and Michael Reedy, P.E.

Consolidated Comments on Freshwater Inflow Recommendations for Galveston Bay (Chapter 3)

These Comments Endorsed by:
William H. Espey, Jr. Ph.D., P.E., D.WRE.
Richard Browning, Ph.D.
Alan Plummer, P.E.
Woody Frossard
Tony L. Smith, P.E.
Mike Reedy, P.E.

The Trinity-San Jacinto BBEST has, in the interest of time and resources, focused upon the most direct measure available, salinity, noted by the SAC as the "quintessential estuary parameter" (SAC 2009a). As further noted by the SAC, "the presence, or absence, of salts in water is a mediator in its biological function…" As inflow has a direct role in the variation of salinity gradients within an estuary, as well as roles in delivering sediments and nutrients to the system, it is recognized that the effects of inflow are one of several dominant factors controlling ecological processes. It is the analysis of these effects which the BBEST has attempted to address utilizing the conceptual model proffered by the SAC. It is acknowledged that such a representation is a greatly simplified, data-driven conceptual model of a highly dynamic system relating freshwater inflow to "biology", with salinity as a "keystone habitat attribute".

The Trinity-San Jacinto BBEST's identification of a suite of indicator organisms has been a significant step in the process of identifying flows necessary to support a sound ecological environment. While the salinity-zonation approach holds a potentially viable method, the salinity-zonation approach as utilized in Chapter 3 has many limitations that unfortunately do not allow for the identification of freshwater inflow requirements that can be shown to be necessary to support a sound ecological environment for Galveston Bay in its entirety.

The recommendations for freshwater inflows for the Galveston Bay system submitted in Chapter 3 of this report are not endorsed by the authors of these comments. As there have been a number of similar concerns between several of the Trinity-San Jacinto BBEST members, for convenience comments regarding the Freshwater Inflow Approach discussed in Chapter 3 have been consolidated. The following is a discussion on the

merits of specific technical aspects of the proposed recommendation incorporated within Chapter 3 of this report.

A substantial difficulty with developing relations of freshwater inflow to estuarine "health" has been the notion of competing needs for multiple species (i.e. what is good for one organism may not be beneficial to another). This was spoken to within the TWDB's State Methodology through the application of an optimization model (detailed in Longley 1994) in an attempt to address the multiple management targets, including harvest, focused upon within that study. Constraints were utilized within the optimization model to maintain the historical proportions of the various species when compared to total harvest amounts. Within the present effort, it appears that, with respect to the Trinity River and its impacts on Galveston Bay, *vallisneria* alone has been deemed sufficient to represent a sound ecological environment for the entire estuary. A thorough discussion is warranted on the scientific rationale behind *vallisneria's* identification as the single indicator of estuarine health for the Trinity River flows to Galveston Bay.

As is noted in the discussion regarding Figure 39 for Atlantic Rangia, the lower threshold for flows necessary to foster suitable salinity conditions for Rangia is in fact higher than the 141,000 ac-ft. amount necessary for a suitable condition for *vallisneria*. While it is noted that a second spawning season is not critical for Rangia, no discussion has been provided on the remaining suite of indicator organisms selected by the Trinity-San Jacinto BBEST as representative of the Galveston Bay ecosystem. Considering this is no evidence supporting the assertion that *vallisneria* alone are representative of a sound ecological environment for Galveston Bay when related to the Trinity River, there is a large amount of uncertainty that such flows "maintain the productivity extent, and persistence of key aquatic habitats" for the Galveston Bay system, as is required by Senate Bill 3.

This holds true for the utilization of rangia and oyster for the San Jacinto as well. As the flows asserted to protect Rangia and oyster for the San Jacinto River and Total Galveston Bay watershed are not demonstrated to maintain the productivity, extent, and persistence of any other identified key habitats or organisms, there is a great amount of uncertainty regarding these flow amounts representing a sound ecological environment for the Galveston Bay system.

While sessile organisms were preliminarily selected for their utility in identifying freshwater inflow targets, the Trinity-San Jacinto BBEST B&E Subcommittee indicated it is necessary to ensure these results work within the context of the needs of the remaining indicator organisms identified by the subcommittee. As no such work has been performed, the assertion that the flows incorporated within the proposed recommendation are necessary for a sound ecological environment should be limited to only those organisms studied (i.e. *vallisneria*, Rangia, and oyster), and not suggested as representing a healthy Galveston Bay ecosystem in its entirety.

The Trinity-San Jacinto B&E Subcommittee never issued a formal opinion on species associated with recreational and commercial fisheries. The committee identified species with specific sensitivities to salinity in particular locations within Galveston Bay, which led to the subcommittee's selection of that suite of species as indicators of Galveston Bay's estuarine "health".

No documentation is provided identifying the specific sources utilized to select how specific salinity niche parameters for particular life stages were obtained, nor where the professional judgment of the subcommittee was exercised. As this is one of the critical parameters upon which all of the freshwater inflow recommendations are based, thorough documentation is warranted. As it currently stands the process utilized to arrive at specific salinity niches is unclear, not reproducible, and contributes to the uncertainty surrounding the proposed recommendations.

The assertion that a HEFR analysis of the flow regime for the Romayor gage could be used to determine a recommended flow from the Trinity River to Galveston Bay for any months not covered by a recommended flow level has never been formally adopted by the Trinity-San Jacinto BBEST. A HEFR analysis is solely a statistical assessment of the hydrology at a particular location, and carries with it no ecological underpinnings that could be interpreted as providing for a sound estuarine environment. All that could be indicated is that flows identified as necessary for a sound ecological environment at the Romayor gage may reflect a pattern of flows the Galveston Bay system have experienced, and the system is currently a sound ecological environment. Given the presently available information to the BBEST, no interpretation can be made given to assert that the flow regime is necessary for a sound ecological environment in Galveston Bay.

It is stated that any of the base flows in an approved flow regime could be used to calculate a monthly flow for months not covered by the Trinity recommendation. It must be made clear that while such a calculation may be possible, this should not be interpreted as a suggested method to determine necessary flows for the periods not covered by a recommended flow. There has been little discussion amongst the BBEST as to a method of identifying such flows during periods which are not prescribed, how such amounts should/could be interpreted, nor how they might be presented for consideration.

The calculated amounts presented are not correct representations of the historical frequencies of occurrence of the proposed freshwater inflow targets. An analysis has been performed and presented investigating flow frequencies over the period of record upon which the flow targets for Trinity, San Jacinto, and the Coastal watershed were based, as well as Total Galveston Bay inflows over the same period, specifically 1983-2005. These are presented in Table 1 below.

Table 1
Historic Frequencies of Occurrence over 1983-2005 period

Watershed	Identification	Spring	Summer	Fall
Trinity	Criterion	742,000	205,000	141,000
	Periodicity	1 of 3 months	2 of 3 months	2 of 3 months
	Historic Count out of 23 years	18 of 23 years	17 of 23 years	8 of 23 years
	Historic Maximum Annual Duration between Events	3 years	2 years	8 years
San Jacinto	Criterion	302,000	257,000	250,000
	Periodicity	1 of 3 months	2 of 3 months	1 of 3 months
	Count out of 23 years	17 of 23 years	10 of 23 years	10 of 23 years
	Maximum Annual Duration between Events	4 years	7 years	8 years
Coastal	Criterion	455,000	196,000	244,000
	Periodicity	1 of 3 months	2 of 3 months	1 of 3 months
	Count out of 23 years	4 of 23 years	9 of 23 years	14 of 23 years
	Maximum Annual Duration between Events	8 years	5 years	3 years
Total Galveston Bay	Criterion	1,499,000	658,000	635,000
	Periodicity	1 of 3 months	2 of 3 months	2 of 3 months
	Count out of 23 years	16 of 23 years	17 of 23 years	6 of 23 years
	Maximum Annual Duration between Events	3 years	2 years	13 years

Historic flow amounts for the Total Galveston Bay watershed are available from the Texas Water Development Board (TWDB) going as far back as 1941. A comparative analysis has been performed to assess the historic frequencies of occurrence of the recent period against the frequencies of the identified flows for the Total Galveston Bay watershed over the longer period of record (i.e. 1941-2005). To compile the longer period of record, the TWDB reported historic data has been utilized for 1941-1982, and hydrologic data extracted from the TWDB's TxBLEND hydrodynamic salinity model for Galveston Bay were used to represent 1983-2005. This combination was necessary as concerns have arisen regarding the accuracy of the reported amounts on the TWDB website (http://midgewater.twdb.state.tx.us/bays_estuaries/hydrology/galvestonsum.txt). As can be seen from the comparison in Table 2, frequencies of occurrence of the proposed amounts identified for the Total Galveston Bay watershed decrease by approximately 17% in the spring, 17% in the summer, and 5% in the fall, when considered over the 1941-2005 time period.

These differences are likely due to the extended period including the 1950's drought of record. While the B&E workgroup arrived at an estimated adjustment factor from an approximately **6%** difference in Total Galveston Bay flows to account for this fact through a comparison of preliminary results at an early workgroup meeting, it appears from this more relevant comparison that **the adjustment factor needs to be refined by 17%, 17%, and 5% for the spring, summer, and fall seasons, respectively**.

Table 2
Comparison of Occurrences for Total Galveston Bay Watershed
over Recent Period (1983-2005) and Total Period of Record (1941-2005)

Total Galveston Bay	Criterion	1,499,000	658,000	635,000
	Periodicity	1 of 3 months	2 of 3 months	2 of 3 months
	Count out of 23 years	16 of 23 years	17 of 23 years	6 of 23 years
	Maximum Annual Duration between Events	3 years	2 years	13 years
Total Galveston Bay - 1941-2005	Criterion	1,499,000	658,000	635,000
	Periodicity	1 of 3 months	2 of 3 months	2 of 3 months
	Count out of 65 years	34 of 65 years	37 of 65 years	14 of 65 years
	Maximum Annual Duration between Events	7 years	7 years	13 years

With the adjustments applied to account for the difference in time periods, the resulting historic frequencies of occurrence are presented in Table 3 below. It must be noted that translation of seasonal freshwater inflow recommendations into environmental flow standards and permit conditions may result in more frequent occurrence of flows less than or equal to the recommended seasonal freshwater inflow values as a result of the issuance of new surface water appropriations or amendments. Furthermore, there is insufficient data to conclude that future seasonal flow frequencies representative of infrastructure consistent with meeting water needs for human uses in the foreseeable future would result in loss of a sound ecological environment. No information is provided within the proposed B&E recommendation document (in its present state) supporting the recommended annual frequencies. Hence, it should be noted that a recommended attainment frequency associated with each seasonal freshwater inflow value would certainly be less than that based on the historical frequency of occurrence shown in Table 3. As an aside, this is similar to the approach taken by the S&N BBEST within its instream flow analyses.

Table 3
Adjusted Historical Flow Frequencies of Proposed Freshwater Inflow Targets for the Trinity, San Jacinto, and Coastal Watersheds

Watershed	Identification	Spring	Summer	Fall
Trinity	Criterion	742,000	205,000	141,000
	Periodicity	1 of 3 months	2 of 3 months	2 of 3 months
	Historic Count out of 23 years	14 of 23 years	13 of 23 years	7 of 23 years
	Historic Maximum Annual Duration between Events	3 years	2 years	8 years
San Jacinto	Criterion	302,000	257,000	182,000
	Periodicity	1 of 3 months	2 of 3 months	1 of 3 months
	Count out of 23 years	13 of 23 years	6 of 23 years	9 of 23 years
	Maximum Annual Duration between Events	4 years	7 years	4 years
Coastal	Criterion	455,000	196,000	244,000
	Periodicity	1 of 3 months	2 of 3 months	1 of 3 months
	Count out of 23 years	1 of 23 years	5 of 23 years	13 of 23 years
	Maximum Annual Duration between Events	8 years	5 years	3 years

The assertion that coastal flows are not a major determinant is misleading. During certain conditions coastal flows may be a significant contributor to freshwater inflows to Galveston Bay. Further, no scientific rationale is provided as to why Coastal flow recommendations are developed differently from the Trinity and San Jacinto (i.e. via subtraction from Total Galveston Bay recommended amounts). It is not clear that if the recommendations for each of the components (Trinity, San Jacinto, and Coastal flows) do not sum to the recommended flows for the Total Galveston Bay system, such a scenario is necessarily incorrect. Instead, such a difference may in fact reflect the uncertainty in the derived relations and the variability of the constituent hydroclimatologies contributing to the system. It is not clear that the coastal flow recommendations are valid utilizing this differential approach, and this uncertainty should be considered carefully if they are to be implemented.

A more thorough discussion on the derivation of recommended flows for the Total Galveston Bay watershed is necessary. The Trinity-San Jacinto BBEST never formally identified these two organisms as the sole indicators of the soundness of the Galveston Bay system. The derivation of these flow amounts have a significant effect upon the resulting recommended flows for the coastal watershed, yet no documentation is provided as to how Rangia and oysters were identified as suitable indicators for the soundness of the entire Galveston Bay system.

There is a low level of confidence associated with the science utilized to identify the proposed recommended flow amounts necessary for a sound ecological environment. For example, the relation for Trinity flows in the fall to vallisneria area (Figure 14) has a mere 11 points of data, which likely contribute to a great amount of uncertainty in any interpretation of a derived relation from such data. Further, the area of vallisneria under study are at the outer fringe of the hydrodynamic modeled area, where precision has been noted to be less than other locations within the bay. Flow alone, as measured through USGS gaging stations, may be inaccurate by 5-10%. Within the current document it is not addressed how such uncertainties should be utilized in the interpretation of the resultant flow recommendations.

As suggested within the document, the use of Gulf menhaden did not receive consensus, nor is any rationale provided for the “reasonableness” of it as the single indicator species for the entirety of Galveston Bay in the winter season. Further, it must be noted that the preferred salinity niche, identified as an area within a range of salinity within Galveston Bay, is not only moving temporally, but spatially within the large area identified by the workgroup for menhaden. It is not clear that the way the BBEST has been interpreting the logistic regressions for sessile organisms in small areas of the system is applicable for mobile organisms in larger areas. No scientific rationale is provided as to why the resultant flow magnitude from the winter menhaden regression is a “reasonable” number, nor is any scientific justification provided as to the apportionment of a total bay inflow amount to its constituent sources through their historically average proportional contributions is appropriate. If such a method had

been found to be scientifically valid, it would have been found to be valid by the BBEST to employ such a technique for all of Galveston Bay's constituent watersheds. Individual derivations of flow recommendations for the Trinity and San Jacinto watersheds would have been unnecessary. It should be stated that the Trinity-San Jacinto BBEST has been unable to identify biological indicators that correlate with a flow requirement for the Winter season for individual watersheds. Through adaptive management additional scientific/ecologic/biologic information should be developed to inform upon a recommendation for freshwater inflows during the winter season.

With regard to a flood flow recommendation, it must be noted that it is recognized that the magnitude, frequency, and duration of such flow events are naturally driven by rainfall runoff events, and there could be variable degrees of risk to certain economic activities in the floodplains, property, and public safety. For this reason, the BBEST recognizes the ecological functions and benefits of these flood flows, but does not recommend actions be taken to produce such flows, nor should overbank flows be included as an environmental flow standard or future permit condition.

It should be noted that during some of the BBEST meetings there were comments that stated that the higher of two recommended flows (either freshwater inflows or instream flows) will ultimately dictate the required flows for the system. This is arbitrary and not consistent with sound biological principles. The bay receives flows from the Trinity, San Jacinto, and coastal watersheds, and responds accordingly. The ecology of the bay reflects the flows that it has received, and as was determined by the Trinity-San Jacinto BBEST, is currently representative of a sound ecological environment.

Early within the Trinity-San Jacinto BBEST process a pre-existing approach to adopting available science towards identifying environmental water needs of streams and freshwater inflows into the Galveston Bay system was proffered and considered by the BBEST. The Region H Water Planning Group (RHWPG) has promoted the utilization of management strategies to ensure freshwater inflows to Galveston Bay proposed by the Galveston Bay Freshwater Inflows Group (GBFIG). Texas Parks and Wildlife Department has recommended 5.2 million acre-feet per year as the freshwater inflow needed to achieve maximum productivity of the bay. GBFIG has recommended a schedule of targets, shown in Table 4, which includes meeting the maximum productivity target in at least 50% of future years. The RHWPG has endorsed GBFIG's recommendation, and has supported further efforts to develop strategies for meeting the freshwater needs of both humans and the bay.

These targets, displayed in Table 4, are recommended as a Freshwater Inflows approach for the Galveston Bay system.

Table 4
Alternative Recommendation for Freshwater Inflows for the Galveston Bay System

Inflow Scenario	Quantity Needed (acre-feet/year)	Historical Frequency	Target Frequency
Max H	5.2 million	66%	50%
Min Q	4.2 million	70%	60%
Min Q-Sal	2.5 million	82%	75%
Min Historic	1.8 million	98%	90%

- **Scenario Descriptions:**
  - Max H: Modeled inflows recommended for maximum bay and estuary fisheries harvest by Texas Parks & Wildlife Department.
  - Min Q: Minimum modeled inflow recommended to maintain the bay and estuary fisheries harvest.
  - Min Q-Sal: Estimated minimum acceptable inflow recommended to maintain the salinity needed for bay and estuary fisheries viability.
  - Min Historic: Minimum annual inflow calculated for Galveston Bay over the period of record (1941-1990).

As noted by Region H, the health and productivity of Galveston Bay must consider the quantity, quality, seasonality (monthly inflows), and location of inflows. It is anticipated that the inflow needs projections will continue to be refined over time. As has been noted by the SAC, there are significant weaknesses to the State Methodology in regards to its application in a Senate Bill 3 process, particularly in its identification of an optimum flow regime. While there is a significant amount of uncertainty that 5.2 million ac-ft/yr would produce the maximum productivity within the system, it is recommended that these flow amounts be met at the noted frequencies over future years. It is anticipated that more science will be developed and applied to refine the identification of flows that can be shown to be necessary to support a sound ecological environment for the entirety of the Galveston Bay ecosystem.

INDIVIDUAL COMMENTS

The following are additional comments provided by the following individuals.

William H. Espey, Jr., Ph.D., P.E., D.WRE:
The salinity-zonation approach suggested by the SAC I believed had the potential to be a reasonable technical approach for the Trinity-San Jacinto BBEST, given the limited amount of time and resources available to the BBEST. As the salinity-zonation approach was adopted and developed by the BBEST, it evolved into a complicated picture of indicator organisms at varying locations within the system considering antecedent salinity conditions. I believe that this complicated approach progressed to a point that the complexity of the results compounded significant issues, such as a scientifically defensible representation of the ecological health of the Galveston Bay system, incorporation of statistical uncertainty for a reasonable interpretation of the results, and the determination of attainment frequencies reflecting historic and current conditions.

The salinity-zonation approach suggested in Chapter 3 grew in complexity to where it remains incomplete, as indicative of email traffic regarding substantive unresolved issues during the final weeks in preparation of this document. As noted throughout the comments in Section 5, the proposed approach is still a work in progress, and cannot be utilized for the development of a scientifically defensible representation of what is to be maintained to support a sound ecological environment for the Galveston Bay system.

Richard Browning:

At the beginning of the BBEST work, I presented to the full BBEST several approaches that I recommended for the work. One of those was that the estuary inflow recommendation adopted by the Region H Planning Group was a reasonable approach. It covers a range of flows from low to high and recognizes inter-annual variability. It is not very detailed and in that respect is consistent with the inability to find correlation between inflow and species abundance in extensive analyses that have been conducted. I also emphasized that any quantified inflow recommendation must quantify the uncertainty in the recommendation. Since then, BBEST has considered other methods of making inflow recommendations, with the latest attempt focusing on a salinity based approach. That approach has some strengths, but during its development in several meetings I objected to some particular steps in the way it was being done. These included the reliance on just three sessile species (two mollusks and one plant) in three limited geographic areas of the bay, and the concentration of those areas at the mouth of the Trinity River. The completed version of that approach (Section 3 of the BBEST report) still relies on the same three species in the same three limited areas, and it includes no quantification of uncertainty. Moreover, during the course of BBEST work, several presentations were made that confirmed by various methods the difficulty of correlating inflow to species abundance. For these reasons I must decline to endorse the recommendation in section 3. The Region H approach still deserves consideration as

a reasonable scientific approach given the manifest uncertainties and in all aspects of the system and the numerous other powerful, uncorrelated factors that affect bay health, including tides, temperature, wind, land modification, and water quality.

Woody Frossard:

BBEST established a process by which we would review the salinity requirement of certain selected species. Once reviewed, the impacts of fresh water inflows by sub-basin on the salinity would be reviewed for making recommendations. Included in this process was a selected list of sessile organisms to reflect different areas of the bay. Once flow was reviewed for these organisms, an additional list of mobile organisms would be reviewed to determine the adequacy of flows to represent the total ecology of the bay. This was not accomplished due to time constraints. The proposed flows are developed only for the sessile organisms that represent specific areas of the bay and not the whole bay system. Therefore, the recommended seasonal flows do not represent total bay health.

There has not been any verification that the recommendations in Tables 34, 35, 36 or 37 are statistically accurate or significant. In any case, these flows cannot be taken in the aggregate as they used independent seasonal analysis e.g. Spring only, as opposed to annual analysis or all seasons. These flows represent what is recommended seasonally and not added together to represent an annual recommendation.

The use of the instream flow outputs for applying to the freshwater inflows for the bay should not be applied. The development of these flows for each system was performed on a different time scale. The freshwater inflow period of record was from 1983 to 2005 to represent mostly existing conditions. The BBEST agreed that the existing condition of the bay was that it was in good health. The instream flow period of record that was agreed upon by the BBEST was defined as the “Pre-Impact” period and for Romayor, this was from 1925 to 1968.

Since the purpose for choosing the flow periods was different, the ability to use the flow outputs from the instream flow for the bay freshwater inflow would only apply if one were to develop flows for pre-impact analysis.

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5.2.2. Mike Turco

Section 3. is an excellent example of the complexity in this system and the difficulty in using only inflow as a driver for bay "health". Through the course of the deliberations, both Dr. McFarlane and Dr. Ray provided passionate interpretations on the driving parameters of the ecosystem in Galveston bay. Temperature, nutrients, and GOM interactions are just a few of the other parameters that can effect the productivity of the ecosystem in Galveston Bay. There is a general lack of discussion regarding the uncertainty of the relation between freshwater inflow and the sessile organism productivity (in the report reported as area). In order for this document to be a useful tool for the stakeholders and future planners, a more detailed discussion, beyond the upper and lower limits on the regression plots, needs to developed, reviewed, and included in the report.

14. There is a general lack of discussion of the GBFIG and Region H's approach to determining the necessary freshwater inflow to the Galveston Bay Estuary. More information is needed to compare this recent work with the work of the BBEST.

15. Vallisneria's area is located along the model boundary in a generally small portion of Trinity Bay. Although it occurs only at the mouth of the Trinity River, more information is needed to translate that to an overall health of Galveston Bay.

16. Based on the sessile species chosen for this analysis there is no significant statistical relation between inflows and the sessile organisms in the winter, the use of mobile organisms to come up with any flow recommendation for Galveston bay comes with a great deal of uncertainty. Although it is listed in table 34 that the HEFR table is used as the recommended inflow from the Trinity River to the bay, the time scales of the HEFR analysis and Galveston Bay analysis are different. The reference to the HEFR table should be removed from the winter recommendation as no data has been presented that shows a significant relation between winter flows and productivity of any of the selected organisms. Delete section 3.4 and move to section 4.#.

Before I can endorse the recommended flows for Galevston Bay in Section 3, I would like to see a more detailed discussion of the uncertainty of the approach and additional detailed information on how the recommendation of the BBEST compares with previous discussions and determinations by the Galveston Bay Freshwater Inflows Group (GBFIG) and Region H.

5.2.3. Dave Buzan

Comments on Freshwater Inflow Recommendations for Galveston Bay

P. 146, Table 34. The recommended annual frequency for the spring is "1 in 2 years". The recommended flow has occurred in 18 of 23 years. I recommend that the recommended annual frequency be "2 of 3" years which better reflects its annual occurrence over the period-of-record evaluated.

p. 146, Table 35 and its preceding paragraph should be deleted from the report. The values in Table 35 and the preceding paragraph discussing those values do not reflect previous consensus on the adjustment of flow values. The difference of 6% is not intended to represent a flow value that should be lowered by 6%.

p. 154, Although the report does not include winter inflow recommendations, this part of the report describes 469,000 ac-ft as a reasonable value for a winter flow requirement from the combined flow sources. This value is slightly higher than the 10th percentile winter inflow (1941-2005) of 435,000 ac-ft for Galveston Bay and therefore seems relatively low. If the stakeholders and/or TCEQ consider 469,000 ac-ft for a winter flow requirement, I recommend that it be used with a frequency of occurrence that states that 469,000 ac-ft should be exceeded 4 out of 5 years.

Additional recommendations:

The "Freshwater Inflow Recommendations for Galveston Bay" does not address the appropriate flows for other months in the flow regime. For example, in Table 34 on p. 146, The recommendation for spring is that 1 of 3 months have a total flow of 742,000 ac-ft but does not identify appropriate flows for the other 2 months of the spring. I recommend that the flow for the other months in tables 34, 36, and 37 be set at 50% of the designated flows with a frequency of occurrence of 2 in 3 years. Using the example from Table 34, if one month in the spring should have a flow of 742,000 ac-ft, the other two months in the spring should each have a flow of 371,000 ac-ft (50% of 742,000). This makes it clear to the reader that freshwater inflows are needed in every month and that the BBEST is not stating that there can be months without freshwater inflow. Use of these flow values increases the total annual inflow recommendation to the bay to about 5.4 million ac-ft. This flow has been exceeded 80% of the years from 1941-2005.

The "Freshwater Inflow Recommendations for Galveston Bay" does not address sediment or nutrient loading to Galveston Bay. Data indicate that loading of both nutrients and sediments have decreased in the recent past. It should be noted that the flow recommendations described in this section are relatively low compared to historical inflows. These flow recommendations address the possible relationship between salinity and biological health but they do not address the relationships between nutrients, sediments, and biological health which are also very important to estuarine health. Biological communities that are already stressed because of lower than normal nutrient regimes may

be more susceptible to salinity regimes near the extremes of salinity/inflow that have occurred in the past.

5.2.4. Jarrett (Woody) Olen Woodrow, Jr.

Section 3.0

I endorse this Section. It should however include a winter flow recommendation. I do believe had BBEST more time this could have been resolved to most member's satisfaction.

Section 3.1 Page 145

The reader should be referred to Section 3.4 at the end of the last paragraph.

Section 4.0

While I disagree with two declarative statements in the text regarding the sufficiency of data and understood limitations, I endorse this section and suggest the following be consider by readers to further the goal of adaptive management.

There is little in this report and its sections to provide specific recommendations that can be used for adaptive management. The answers to questions provided by Richter (2006) are a good general starting place for enhancing our understanding flow relationships and the environment. Provided below are some specific recommendations for readers to consider that may enhance our understanding of the recommended flow regimes and how the basin and bay ecosystem may respond to changes in flow patterns. Many of these do not require that flow recommendations be established prior to initiation as any these information sets will be helpful as soon as they are gathered and assessed. Additionally, some long-term monitoring of biological, chemical, and physical parameters is needed to establish how changes in flow may affect resources not documented in Section 2.2 and 3.0 of this report. Some of these efforts may require substantial investment of resources while others may not. It should be recognized that without monitoring and assessment, the current integrity of the basins and bay are in jeopardy. If the recommendations are too low to sustain the riverine ecosystem, future changes in water allocations may affect the environment negatively. Conversely, if they are higher than what is required reduced water supplies may affect human activities during droughts. Having information to inform stakeholders that conditions continue to present a sound and healthy environment is critical to the SB3 process.

Floodplain Forests and Habitats

In order to prioritize efforts, specific sites should be monitored to assess how flow conditions behave with the geomorphology and associated floodplain habitats. For example, areas that contain significant public investment such as parks, Recreation Areas, Wildlife Management Areas and National Wildlife Refuges (private lands could be used as well provided landowners have granted permission) that contain significant

floodplain forests could be monitored for several parameters. Water level recorders can be placed within specific riparian banks, meander scars, sloughs and other adjacent features to relate inundation patterns with flows in the rivers. Additionally, plant community assessments can be made to relate the distribution of species assemblages with different flow events. Measure of forest integrity can also be taken and related to historic flow patterns, tree species regeneration, and maintenance of community structure.

North American songbirds that use the Gulf of Mexico as a migratory route are very dependent on the Texas floodplain forests. This is a significant proportion of the North American populations whom may travel to Canada to nest and then back to tropics of Mexico, Central America, and South America to winter. Understanding how floodplain forest integrity and connectivity affects not only migratory stopover habitat quality but also for resident birds and other important vertebrates.

Gage Interpolation

Specific gages were utilized to determine flow recommendations primarily based on length of record from 1924 to 1964. Based on discussions within the BBEST 13 priority gage stations were chosen for making recommendations. In most cases, one gage is used to characterize a significant stretch of river reach. For example the Romayor Gage characterizes most of the reach between Lake Livingston and the Wallisville Salt Water Barrier. To refine recommended flows for the basin rivers and streams, an analysis of recommended flows for each priority station should be interpolated to other stations and their respective reaches of each basin. This analysis should be comparative for the period of record overlap and include additional or reduced watershed contributions. An assessment should be made as to the environmental resources that are affected including instream and floodplain habitats. With regard to the Romayor Gage for example an analysis can be made to determine how recommended flows might behave at 4 gage stations further downstream (or upstream) Specific habitat features associated with a particular tributary may be significantly different downstream or upstream of the priority gage site as well as tributaries to the main stem.

Remote Sensing Tools

Light Detection and Ranging (LiDAR) Data. There may be existing datasets for elevation derived from LiDAR techniques. These provide more precise (although not as accurate) elevation data of geomorphic features that exist within and along river ecosystems than are readily available. Most 15 minute topographic maps are divided into 10-foot intervals which is too coarse for relating flow patterns to adjacent geomorphology. Additionally, LiDAR data would be taken at a specific time and water elevation will be highly accurate. Therefore , these data can be related to gage data. There are some LiDAR data sets available. The Center for Space Research at the University of Texas at Austin has developed approaches integrating STRM, aerial photography, and LiDAR information.

A technique used for assessing flood events and connectivity to floodplains has been used by National Wildlife Federation on sites within the Sabine Neches basin (Johns 2009 Unpublished data). In addition, the Oakwood Gage for the Trinity River was assessed. The study used satellite and aerial imagery to delineate flood inundation patterns within the floodplain. Recent work done by Texas Parks and Wildlife Department mapping vegetation associations was used for the Sabine Neches sites to examine inundation patterns and vegetation community assemblages. The imagery can be related to flow levels for that particular day.

Weather and Climate

There is a need to develop a precipitation-based metric to provide a way to determine watershed moisture level and its relation to instream and freshwater inflows. There are metrics such as the Palmer Drought Index but these are focused on drought episodes. Flow recommendations are based on a historic period of record. While there is some certainty that historic conditions will be approximated in the future, it is also recognized that climates can change and that any given hydrologic year will likely not be replicated in same volume or pattern the following year due to weather patterns. Environmental Flow Recommendations are balanced against water needs and how water is conserved. There are limited methods to determine whether any current year or month is in a dry, normal or wet period. Having a reliable metric which can be used to evaluate watershed moisture would ensure that balances between environmental needs and human needs are met with limited burden on all users. Recent development by the National Weather Service with Doppler radar and precipitation as well as runoff models developed by the USGS may provide a basis to develop a metric.

There is no certainty how our changing climate may affect flow conditions in the San Jacinto and Trinity Rivers and Galveston Bay. Some forecasting models suggest dryer conditions while others suggest wetter conditions. Recent work by Ward (2009) indicate that dryer watershed conditions of only 5% in the watershed could lead to a reduction in bay inflows of approximating 30% based on 1950s drought conditions, 2050 water demands and climate change.

Tributaries

There is a need for more information on tributaries to the main stems of the the San Jacninto and Trinity Rivers. These tributaries often have substantial resources associated with them including a full range of biological resources and process of geomorphology. Cooperative partnerships between stakeholders can be developed to support efforts to collect and monitor for select resources within these tributaries.

Estuarine Indicators

Water Celery, *Vallisneria americana* in the Trinity River delta should be mapped, ground-truthed and assessed and then monitored to with salinity and other water quality parameters to enhance the understanding of its distribution within the delta and its relationship to freshwater inflow.

Further monitoring of *Rangia cuneata* distribution and its response to salinities regimes is important if we are to gain increased knowledge between the inflow recommendation and its response to different salinity conditions. Current monitoring of this species may not be temporally or spatially resolute to ascertain relationships with salinity.

Current monitoring of nearshore fauna may not be at the resolution to determine relationships between salinity and juvenile and larval estuarine species. The purpose of the monitoring done by Texas Parks and Wildlife Department is not to establish relationships between habitat and fisheries resources but to monitor the status and trends of populations. There may be a need for a special study to ascertain if increased temporal and spatial resolution will yield a greater understanding between nearshore fauna and freshwater inflows.

Additional effort evaluating how winter flows affect the bay ecosystem is needed. The current recommendation using menhaden as an indicator may be to low based on past historical winter flows. Changes in detrital input, nutrient, sediment dynamics and antecedent conditions may have detrimental effects on the bay productivity. Winter flow regime may be relevant in distinguishing the character of Galveston bay from other Texas Bays and provide important cues for changes in migration and movement patterns of fisheries resources that use the bay for a particular part of their life cycle.

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5.2.5. L. James Lester, Ph.D.

I am strongly supportive of the estuary recommendations. The relationships obtained for flow – salinity – biological indicators appear satisfactory as bases for the recommendations made. The methodology could be improved by getting more precise information about responses to salinity changes by the selected species and other potential indicators. Better information on flows from coastal streams would be useful. More information on sessile benthic organisms would be very helpful. A methodology needs to be developed to provide flow guidance for months not currently covered by the recommendation. However, as a first iteration, these recommendations should satisfy the requirements of SB 3.

I endorse the "Freshwater Inflow Recommendations for Galveston Bay" and the "Science Based Environmental Flow Regime for the Trinity River, San Jacinto River and Galveston Bay," and commend all of my colleagues on the BBEST for their dedication to the process and their commitment to outcomes that match their perception of what is best for the people and the nature of the State of Texas.

The document has several shortcomings in the section I drafted on freshwater inflow to Galveston Bay that should have been corrected. First, the recommendations for the Trinity River do not need to be adjusted down by 6%. The flow – salinity – biological indicator relationships should be independent of the alteration in flow amounts observed between the early and recent records. Suggesting an adjustment was an error in logic. Second, the logistic regression graphs on which the recommendations are based should have received more explanation. The logistic function is used to fit a sigmoid curve, which was observed in many of the plots of suitable habitat area to flow amount. The y axis can be interpreted as the probability that the habitat of the indicator organism will be completely suitable. The threshold lines are set by using the 90% confidence bounds determined by the regression analysis. The lower threshold is the flow amount at which the lower confidence bound intersects the x axis, i.e. when the habitat starts to become suitable. The upper threshold is the flow at which the upper confidence bound intersects the total amount of habitat, i.e. when the entire area of habitat is suitable. Given the importance of these analyses, the graphs deserved more explanation. Third, multiple references were consulted in deciding on the salinity niches of the various indicator organisms. I regret the omission of these references because it weakens the case for the significance of the indicators. I can provide these on requests from future readers of the document.

5.2.6. Joseph F. Trungale, P.E.

Endorsements

"Science Base Conditional Phased Approach" - I do not endorse this proposed recommendation
"Science Based Environmental Flow Regime for the Trinity River, San Jacinto River, and Galveston Bay" - I endorse this proposed recommendation
"Freshwater Inflow Recommendation for Galveston Bay" - I endorse this proposed recommendation

Comments on the "Freshwater Inflow Recommendation for Galveston Bay"

Unfortunately time has became short at the conclusion of the BBEST one year effort to develop flow regime recommendations for both the Trinity and San Jacinto as well as Galveston. I support the recommendation put forward in this document however believe the issue of what to do with respect to months or seasons for which no flow recommendation is included remains unresolved. While it would be impossible to reach consensus on these issues I feel it necessary to at least comment on them.

However before addressing this issues, there is one specific issue that to my understanding had been resolved yet it remains in the draft document. If this is an oversight, I would ask that this paragraph be removed from my comments. The recommended in flows for the Trinity River have been adjusted downward by 6% to account for the fact that flows during the more recent period appear to be wetter than the long term condition. While never particularly happy with this bit of "hand waving," it was a compromise that I could live with if it had been applied in the way that was discussed at the Freshwater Inflow subcommittee meeting October 17, 2009. At that time it was agreed that the reporting of the historical attainment frequency for these flows would be reduced by 6 percentile points however the flow magnitudes that produce areas of preferred salinity conditions were estimated via logistic regression and should not have been adjusted. On November 18, 2009 I discussed this misinterpretation with Tony Smith, and I believe were in agreement on this issue. On the 19th I sent an email to the principal author of this section, Jim Lester, describing this issue and my discussion with Mr. Smith. Mr. Lester then sent a message to the full BBEST informing all that barring objections this adjusted table would be removed. As there were several responses in agreement and non opposed, I expected that it would be removed. Table 34 and the paragraph immediately preceding it on page 146 should thus be removed from the final document. I hope this is simply a clerical error.

It is unclear if the Winter flow targets are included as recommendations or as considerations. As they appear to be somewhat reasonable, though on the very low end of historical flows about 10th percentile, I support their inclusion in the recommendation.

It is unclear if the document recommends the use of HEFR flows for the months in which the targets do not apply. This includes both the winter months and months in the other seasons that are not the one out of three or two out of three for which flows have been recommended. On page 146 the report states " A HEFR analysis of the flow regime for the Romayor gauge could be used to determine a recommended flow from the Trinity River to Galveston Bay for any months not covered by a recommended flow level. Any of the base flows in an approved flow regime could be used to calculate a monthly flow for months not covered by the recommendation above." This statement captures some of the discussion that had been taking place surrounding this unresolved issue. Earlier versions of the Freshwater Inflow document from as late as November 15th included language that stated "Winter high flow pulses are important to obtain salinity conditions suitable for the occurrence of the biological indicator blue catfish. This suggests that the HEFR analysis employed should include high flow pulses, not simply base flows." I was not privy to the discussion that resulted in the removal of pulses from this recommendation. Given the internal BBEST disagreements regarding the HEFR analysis for the instream flow requirements, there was no time or opportunity to adequately vet this issue. My own position is that the flow recommendation for the months for which no value is provides should not be interpreted to mean that the flow can be zero at those times. I believe a HEFR analysis is an appropriate surrogate for the flow need for those periods however given that the there is insufficient gage coverage for the bay, I believe the appropriate flow data to develop these HEFR values is the flow data that was used to develop the salinity modeling namely the TxBLEND inflows. I also believe that the flows recommended in the State's freshwater inflow studies should be given some consideration. The table below presents subsistence and Base Dry with pulses HEFR output volumes based on the HEFR approach presented in the " Science Based Environmental Flow Regime for the Trinity River, San Jacinto River, and Galveston Bay."

		Subsitence			Base - Dry with Pulses		
Season	Month	Trinity	San Jacinto	Costal	Trinity	San Jacinto	Costal
	Dec	25,244	46,103	9,346	270,536	149,174	60,802
Winter	Jan	25,244	46,103	9,346	611,119	336,369	135,470
	Feb	22,801	41,642	8,442	262,383	143,110	59,660
	Mar	61,039	47,674	8,362	160,117	135,344	60,958
Spring	Apr	61,039	47,674	8,362	785,758	307,828	136,088
	May	55,132	43,061	7,553	151,447	129,726	59,881
	Jun	40,628	47,511	9,777	83,550	99,766	40,700
Summer	Jul	40,628	47,511	9,777	202,548	173,616	126,966
	Aug	36,696	42,914	8,830	76,612	94,351	39,528
	Sep	11,738	39,905	8,608	91,851	104,372	72,011
Fall	Oct	11,738	39,905	8,608	268,456	195,062	192,544
	Nov	10,602	36,044	7,775	86,781	99,022	70,910
	Total	402,528	526,049	104,787	3,051,158	1,967,739	1,055,517

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5.2.7. George Guillen, Ph.D.

I endorse the Freshwater Inflow Recommendations for Galveston Bay

However, I strongly recommend adding the recommended flow regime listed below for current "blank months".

Section 3.1- 3.2 Recommendations:

The "Freshwater Inflow Recommendations for Galveston Bay" does not address the appropriate flows for other months in the flow regime. I recommend that the flow for the other months in tables 34, 36, and 37 (pages 146-154) be set at 50% of the designated flows with a frequency of occurrence of 2 in 3 years. This value is more biologically reasonable and falls at the lower end of the cumulative frequency distribution for freshwater flows. It also recognizes the year long use of the watershed by various life stages of estuarine organisms.

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Report to BBEST on Results of Salinity – Ecology Workshop

August 14, 2009 held at USGS Offices, The Woodlands, Texas

The agenda and a list of potential indicators species compiled by a subcommittee of the Sabine-Neches BBEST were distributed before the workshop. The meeting began with a presentation of the progress made by Joe Trungale and Tony Smith in describing the historical relationship between flow and salinity patterns. Joe showed the results of TXBlend modeling by month since 1983. Tony discussed the issues associated with using regression equations to provide point to point relationships for salinity to flow relationships.

The group decided to proceed with development of ecological indicators on which to base flow recommendations. It was also decided that habitat indicators would be appropriate. Several habitats were discussed. Seagrass meadows were rejected. *Vallisneria* in the Trinity delta and cypress swamp in the lower Trinity and San Jacinto were determined to be worthy of further consideration. Jamie Schubert has provided a map of *Vallisneria* distribution and suggested salinity ranges for establishment and survival. Establishment could be related to a spring freshet <5 psu and survival relates to <10 psu. We do not yet have a salinity tolerance for cypress.

Indicator species were discussed in two groups: one for high flow-low salinity conditions and a second for low flow-high salinity conditions. The group agreed that our charge related to maintaining an ecologically characteristic salinity regime, which relates to avoiding transitions toward Sabine Lake or Laguna Madre. Various proposals were made and checked against data provided via Lisa Gonzalez from TPWD and TCEQ monitoring databases.

High flow-low salinity indicators that will be considered further are Rangia, menhaden and blue catfish. Rangia will be used to indicate an appropriate salinity in Trinity and Upper Galveston Bays. (2 – 10 psu was stated to be a necessary range for larval survival and recruitment.) Gulf menhaden in trawls show a preference for all of Galveston Bay except West Bay. The proposed salinity range associated with menhaden abundance is 5 – 15 psu. Blue catfish show an association with the spring freshet in Trinity Bay and primarily occur at <10 psu.

Low flow-high salinity indicators that survived the discussion were pinfish, mantis shrimp and brittle stars. Unfortunately a later examination of data on brittle star occurrence will not allow us to provide a map to guide the analysis of historical salinity patterns in the area occupied by brittle stars. The records are too few and too dispersed (e.g. one sampling point in West Bay). Pinfish have a distinct preference for West and Christmas Bays. We are using a salinity >20 psu as the range for pinfish. Mantis shrimp have fewer records and have been collected into Upper Galveston Bay, but they are usually collected at salinities >20 psu.

Two more indicators were discussed that would be based on oysters. Sammy Ray recommended an indicator that would simply focus on maintaining a salinity between 10 and 20 psu in the area of Redfish

Bar (the waist of Upper and Lower Galveston Bay). The group agreed that this salinity is beneficial to the growth and survival of oysters. We are going to examine the historical pattern of how often this condition has been met in the past. The second oyster indicator is based on the desirability of reducing oyster parasite loads periodically. A recent publication provided experimental evidence that a salinity <5 psu for two weeks would significantly reduce the incidence of dermo in an oyster population. The suggested periodicity is every ten years. We will find out from Joe and Tony how often this condition has occurred in the period being modeled.

Participants: Jim Lester, Bill Espey, Tony Smith, Joe Trungale, Richard Browning, Woody Frossard, Sammy Ray, Woody Woodrow, Carla Guthrie, Cindy Loeffler, Lance Robinson, Bill Balboa, Jamie Schubert, Paul Montagna, Jennifer Pollack, Mike Turco, Norman Johns, Lisa Gonzalez, and George Guillen. Several observers were also present, but did not comment or vote.

Summary of Results from the Second Salinity-Ecology Workshop
Sponsored by the Trinity-San Jacinto Basin and Bay Expert Science Team
Held August 26, 2009 at SJRA Offices

Preliminary results were presented by Joe Trungale and Tony Smith under a contract to Espey Consultants for hydrological analyses in support of our potential freshwater inflow recommendations at a workshop, held August 26, 2009. The analyses were based on indicators proposed by the workshop participants who met at the first Salinity-Ecology Workshop held August 14th at the USGS offices. Hydrological analyses based upon TXBlend modeling, the identified preliminary biological indicator species and their regions of distribution in the estuary were explained. (The output of these preliminary analyses was distributed by Cory Horan with the agenda to the workshop.) Most of the discussion focused on graphs of the proportion of historical monthly flows that exceeded a criterion salinity value over a particular area of interest. These graphs were accompanied by graphs that translated the salinity relationships into flow relationships.

The discussion of preliminary results by Trungale and Smith was followed by a presentation by Dr. Robert McFarlane in which he argued that salinity has a minor effect on the biological community in the estuary and the SB 3 process should focus on a larger geographic pattern of estuarine salinity along the Texas coast. He suggested that the mobile indicator organisms, particularly Gulf menhaden and pinfish, did a poor job of demonstrating a requirement for a specific salinity regime. He also criticized the oyster indicator based on the observed distribution of oysters across areas and bays with very different salinity patterns. The discussion that followed this presentation showed that there was a consensus among the rest of the BBEST that the approach being followed was viable and should be pursued.

Based upon the considerations at this meeting, the following modifications were made to the methodological approach:

- Seasons were selected to be characterized and investigated as displayed in Table 2,
- The regions of characterization for Atlantic Rangia and American Oyster were modified (concave Trinity Bay, and “tilt the egg” for American Oyster. The oyster area will cover Redfish Bar and extend into the mouth of East Bay.
- The seasonal characterizations for each organism were identified as displayed in Table 1.
- Cypress swamp and Brittlestar were removed from consideration at this time. Cypress swamp is problematic due to the performance of the TXBlend model upstream from the river mouths. Too little data on brittle star abundance and distribution has been obtained so far. George Guillen is trying to obtain more. The oyster indicator’s salinity range was determined to be related to susceptibility to parasite infection, i.e. Dermo. The infection process is a function of salinity and temperature, which was incorporated by limiting the seasons of concern to summer and fall.
- Relations of organism salinity zone areas to flows for the Trinity and San Jacinto watersheds were identified to be investigated and evaluated. In the case of indicators with areas of concern solely or principally in Trinity Bay, some felt that flow from the Trinity River should be our primary concern and it should be distinguished from total flow.

Others argued that San Jacinto and other flow sources contribute to low salinity in Trinity Bay. More investigation and discussion will follow on this topic.

- The frequency of occurrence of the initiation of the maximum salinity zone area, (i.e. the breakpoint in salinity zone area frequency curves for each season on the ogive curve) was identified as that to be maintained. In other words, the analysis will be based on the conditions when the total area of concern for a given indicator meets the salinity requirements.
- The flow range representing +/- one standard deviation about the modeled monthly flow/area regression for each season will be presented along with the flow representing the mean predicted relation to this salinity zone area. There was debate about how to incorporate the uncertainty in the model into a desirable flow. The historical frequency of occurrence of each of these flows during the given seasons would also be presented.
- The resultant flow matrix generated through the aggregation of these flows, by season, for each species under analysis in this study would constitute the basic information upon which a flow recommendation will be considered by the Trinity-San Jacinto BBEST.

The contract for support from Trungale and Smith ends on August 31 and a final report will be distributed, which will describe their methodology and results. A third Salinity-Ecology workshop will be scheduled in September decide on how the relationships among indicator organisms, salinity and freshwater inflow should be translated into flow regime recommendations to be presented to the Trinity-San Jacinto BBEST.

Please address corrections or questions to the entire group.

Table 1
Preliminary Identified Biological Indicators for Galveston Bay

Indicator Species/Type	Taxonomic Classification	Salinity Range	Seasonality
Habitat Indicator			
Wild celery	*Vallisneria americana*	<5 psu for establishment	Spring – Summer - Fall
High Flow-Low Salinity Indicators			
Atlantic Rangia	*Rangia cuneata,*	2-10 psu for larval survival	Spring – Fall
Gulf Menhaden	*Brevoortia patronus*	5-15 psu for common occurence	Winter-Spring (Confirmed in TPWD trawl data. Bag seine occurence is spring.)
Blue Catfish	*Ictalurus furcatus*	<10 psu in single freshet during seasons	Winter- Spring
Low Flow-High Salinity Indicators			
Mantis shrimp	*Squilla empusa*	>25 psu	Summer – Fall
Pinfish	*Lagodon rhomboids*	>25 psu	Summer – Fall
Oyster Indicators			
American Oyster	*Crassostrea virginica*	10-20 psu	Summer - Fall

Table 2
Seasonal Assignment of Months

Month	Season
March	Spring
April	
May	
June	Summer
July	
August	
September	Fall
October	
November	
December	Winter
January	
February	

Report on Salinity Ecology Workshop III

Of the Trinity – San Jacinto BBEST

Held on September 9, 2009 at TCEQ in Austin

Tony Smith and Joe Trungale went over the highlights of their final report on modeling the salinity regime of Galveston Bay using TXBlend and relating the monthly model results to the salinity niche ranges of selected species and to historical flows from the Trinity and San Jacinto Rivers. If you have not had a chance to read the report and review the appendices, please access them at the ftp site provided in the last e-mail.

A variety of issues were discussed in the workshop. I will try to summarize the discussion and indicate those topics that yielded some actionable decision.

- The suggestion that sessile organisms be our primary focus received general agreement with the understanding that the impact on mobile species of meeting the salinity requirements of the sessile indicators be assessed and the mobile indicator species be used in justifying the recommendations.
- The Vallisneria indicator was originally specified as the criterion for establishment in spring, < 5 psu. It was decided that maintenance of Vallisneria habitat is a useful indicator, which has already been employed for a similar purpose in Florida. Dave Buzan suggested that we use a higher salinity range, <10 psu, for maintenance of Vallisneria populations in the Trinity delta in summer and fall. Joe and Tony will develop the analyses that permit a flow estimation based on this criterion.
- There was a discussion about whether some indicators, particularly Vallisneria and blue catfish, should be based on seasonal flows of more than one month. There were objections to using combined periods of flows. So no change was made in the temporal unit used for the analyses.
- Atlantic Rangia larvae are the basis for the salinity niche in the Rangia indicator. Spawning occurs in spring and fall so the summer season was dropped. The occurrence region and the salinity range remain the same.
- In the final report, the ellipse defining the oyster indicator (10 – 20 psu, Summer and Fall) was shifted to cover Redfish Bar and the northwestern part of East Bay. No discussion suggested any change to this indicator.
- There was a discussion about how to deal with those indicators that had ogive charts on which the maximum area was not reached or reached only once. If there are not multiple occurrences of the salinity criterion over the entire region of the indicator organism, then the methodology of using a quadratic regression and standard deviation is not appropriate. Menhaden was the organism considered in this discussion. Two options were suggested: designate a smaller range in the bay for the species or accept less than 100% of the designated area as the target. No

agreement could be reached on this issue. It is of secondary importance because this problem was only observed when analyzing the mobile indicator organisms.

- Flow estimates for meeting salinity criteria were provided in the final report for the Trinity and San Jacinto Rivers. This differentiation between the river flows implies independence that does not exist, with the exception of the salinity regime in the occurrence region for Vallisneria. There was a discussion about how to allocate contributions to salinity conditions among the rivers and other watershed sources. This would require a significant level of effort by the contractors for which no funding is available so no information will be available to address this issue beyond the historical record and TXBlend inputs.
- The final report includes a discussion of the potential to use a step regression analysis to specify the flow at which the salinity regime is triggered. Most of the people present felt that a step function was not an appropriate representation of the relationship between flow and salinity under most circumstances. However, there was general agreement that some salinity conditions might be associated only with flood flows that could be represented as a step function. There was general agreement to retain the quadratic regression approach.
- In the final report, there is no analysis of the proposed multi -year oyster-dermo indicator: salinity <5 psu for two weeks in the ellipse around Redfish Bar once every 10 years. Based on a cursory examination, this condition was met 7 times in the 23 year period of record. The temporal period of this indicator might deserve adjustment, but no determination was made at the workshop.
- There was some discussion of the use of blue catfish as an indicator of a freshet condition. Some of those present object to the inclusion of blue catfish as an indicator of estuarine salinity conditions, but others countered with information on the common occurrence of this organism in the bay. No agreement could be reached on the temporal extent of a freshet. So this indicator remains as simply an indicator of high flow pulses.

This list exhausts my memory of the discussion. I would like others to make comments to the entire e-mail list about deficiencies and errors.

The people present agreed that at least one more meeting of the workshop group should be held. Mike Turco agreed to provide a conference room at the USGS offices in The Woodlands. The meeting is scheduled for October 6 starting at 10 AM.

Jim Lester

Report to BBEST on Results of Salinity – Ecology Workshop

October 6, 2009 held at USGS Offices, The Woodlands, Texas

The agenda and files describing a suggested approach for setting up inflow recommendations based on the salinity zonation analysis (by Joe Trungale and Tony Smith) were distributed before the workshop. The meeting began with a presentation of the progress made by Joe Trungale and Tony Smith.

The salinity niches for two of the three indicator species have been revised to the flowing: 1) *Rangia* - Spring and Fall, presented as Spring to Fall, but Summer is not a spawning season, and 2) *Vallisneria* - Summer and Fall, with the salinity preference revised to <10 ppt.

Joe Trungale stated that as he worked on the analysis, he realized that pre-existing salinity conditions had an impact on the resulting salinities. For example, if antecedent conditions (i.e., one month prior to the flow event) were more saline, then more inflows would be required to bring salinities within the desired range chosen for the indicator species. There was general agreement by the group that antecedent conditions should be considered in the analysis.

Flow/area relationships were graphed by Joe Trungale prior to the workshop for the sessile indicator species and three sets of preconditions (too salty, good, and too fresh). Logistic (s-curve) functions were used to set initial thresholds. A step function was apparent between flow and area in the desired salinity range when preconditions were “too salty” or “too fresh”. Trungale asked if the group thought this relationship was ecologically valid or if it was an artifact of the analysis. The group agreed that it was ecologically valid for Trinity Bay. The logistic relationship was not seen under the “good” precondition.

The flow-area relationships for mobile species were discussed. Rather than include the mobile species indicators (e.g. Gulf menhaden, pinfish and mantis shrimp) identified in previous workshops directly in the flow recommendations, their flow/area relationships will be used as a check on the flow recommendations to account for the remaining biological community.

There was a large discussion regarding how flow recommendations should be presented, i.e., as a single number or range of numbers. Woody Frossard pointed out that a single number flow regime could not be easily implemented. The group decided that recommendations should be presented as a range of flows.

The logistic regressions were used by Trungale to create lower and upper bounds of flow for each indicators species and antecedent condition (“too salty” and “good”). The lower flow regime bounds were identified as the flow volumes where the lower confidence level (-1 standard deviation) of the logistic curve crossed zero on the area axis. The upper flow regime bounds were identified as the flow volumes where the upper confidence level (+1 standard deviation) of the logistic curve crossed the maximum value on the area axis.

Based on the logistic relationship graphs, a table of flow regime bounds and attainment frequencies for each of the three sessile indicator species after “too salty” and “good” preconditions was presented.

Next, the group discussed how the flow thresholds for each indicator species should be established. Three possibilities emerged:

1. Lower flow bound of the "good" precondition and the upper bound of the "too salty" precondition;
2. Unit of central tendency (median or average) of the "good" flow range to the central tendency of the "too salty range"; or
3. Model the relationship between antecedent salinity, desired salinity, and the flow needed to produce the desired salinity.

Discussion centered on the adoption of option 1 or option 2. While the discussion leaned toward option 2 early on, by the end of the meeting consensus was reached on the adoption of option 1. The more simple range of numbers was chosen to lessen the complexity of calculations. It was believed that it might become increasingly difficult to explain them in the future. It was also agreed that Tony Smith and Joe Trungale would determine the historical frequencies of occurrence for the flow ranges in relation to "too salty" and "good" preconditions. The group decided not to consider the "too fresh" precondition as this precondition would not be countered with a management strategy to reduce flows to the bay to increase salinities if antecedent conditions were very fresh.

The seasonal frequency of flow recommendations was discussed. The group decided that the seasonal conditions to assess historic frequency should be as follows: 1) for *Vallisneria* - at least one out of three months in the spring to ensure seed germination, 2 out of 3 months in the summer, and 2 out of 3 months in the fall to ensure survival of the plant community. 2) Based on recommendations from Dr. Sammy Ray, the seasonal criteria for oysters will be 2 out of 3 summer months (July and August) and 1 out of 3 fall months (September). Dr. Ray made these recommendations to encourage inflows during times when water temperatures are warm and the prevalence of dermo is higher. 3) The seasonal conditions to assess historic frequency for Atlantic *Rangia* should be 1 out of 3 months in the spring and 1 out of three months in the fall.

The time period of the data used to calculate flow recommendations was discussed. The inflow data sets range in time from 1941 to 1976 and 1977 to 2005. The group determined that flows in the 1977-2005 time period appeared to be about 6 percentile higher than those in the 1941-1976 period (the more recent time period does not include the 1950s drought of record). To account for this difference, a correction factor of -6 percentile flow will be applied to the flow frequencies for the more current time period.

Dave Buzan suggested that a matrix be constructed to serve as a straw man for a set of flow recommendations. He also suggested that group think about how the information should be presented in the future to the full BBEST and stakeholder group. The group agreed. The matrix will include flow ranges, frequency of occurrence, and seasonal/monthly attainment criteria for each of the three indicator species and "too salty" and "good" preconditions. The matrix will be accompanied by text explaining what the recommended flow would provide in terms of a preferred salinity zone for each indicator organism. Others on the salinity-ecology workgroup will be asked to help with drafting the text. It was agreed that the matrix could be presented as a straw man to the full BBEST, but the workgroup asked that a draft be emailed to workgroup members prior to the BBEST meeting. Bob McFarlane asked that the matrix and accompanying discussion include an overview of the assumptions underlying the calculations. The group agreed this was a good idea.

There was also a discussion about whether the recommendations should be presented as a baywide set or as separate recommendations for the Trinity River Basin, San Jacinto River Basin, and Coastal Basins. While separation of the basins would be preferred, and a subtractive method was proposed, Joe Trungale was unsure if the curves would fit properly to support the method. Tony Smith suggested that the method be tried to see if it worked. Others in the group asked if the instream flow recommendations could be used to inform basin-specific bay recommendations. However, those close to the instream process suggested that it is unlikely that the instream flows information will be available in time to use for the Galveston Bay recommendations. Dave Buzan suggested that Trungale and Smith explore the development of basin-specific recommendations . The use of the historic contributions of the two river basins and the coastal basin could serve as an alternative method. This will be brought back to the group for further consideration.

The final discussion centered around the use of success criteria for the comparison of the flow thresholds to the preferred salinity ranges of the mobile species. Dave Buzan asked if success criteria should be set at a certain level, such as 50 percent of area for a given amount of time. Tony Smith replied that rather than specific success criteria, he will be looking to see if the thresholds might be detrimental to the mobile organisms.

Participants: Jim Lester, Bill Espey, Tony Smith, Joe Trungale, Mike Turco, Richard Browning, Woody Frossard, George Guillen, Bob McFarlane, Antonietta Quigg, Lisa Gonzalez, Carla Guthrie, Jan Culbertson, Dave Buzan, Cindy Loeffler, Sammy Ray, Woody Woodrow, Bill Balboa, Hong Wu, Warren Pulich, and Jamie Schubert. One observer was also present, but did not comment or vote.

Trinity and San Jacinto River Basins BBEST Instream Flow Study

Use of Hydrologic Data in the Development of Instream Flow Recommendations for the Environmental Flows Allocation Process

Prepared for:

Texas Water Development Board

Prepared by:

Crespo Consulting Services, Inc.

August 31, 2009

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Executive Summary

The objective of this project is to study the flow regime at specific locations within the Trinity/San Jacinto River Basin using tools and methodologies developed under Senate Bill 3 in conjunction with other analytic tools, and to lay the groundwork for subsequent development of the hydrologic analysis.

Conceptually, the context supporting this project work is rooted in the view of “hydrology as the master variable” (TIFP, 2008; Richter, 2006; Poff, 1997), and well-established knowledge that there are key components of hydrology that support a sound ecological environment, including flow magnitude, frequency, duration, timing, and rate of change (Poff, 1997).

An evaluation of the operations and algorithms used by the pre-processors (IHA and MBFIT) was conducted, and detailed descriptions of the meaning and procedures for parameterization are provided. The HEFR methodology and algorithms were likewise studied and evaluated, and similar descriptions of the Alternate Methodology are also included.

A relatively detailed process was employed in the separation of flows at Conroe and Oakwood, in order to investigate:

- The effect of systematic parameter adjustment on flow separation results;
- How ‘goodness of fit’ can be evaluated, ideally by quantitative means;
- The extent to which parameterization can be generalized, both into patterns of a hydrograph which point toward adjustment of a specific parameter, and in applicability of the parameterization of one gage to different record periods at the same gage or to other gages within the basin;
- Quantitative metrics and evaluation tools that might facilitate efficiency within the flow separation task;
- The extent to which correlations between flow separation results affect results of the episodic event analysis; and,
- The components of a step-wise pathway for flow separation within the context of the ongoing work of SB3: numerous gages in several different/unique basins need to be consistently and efficiently studied by multiple individuals and entities.

There are many facets revealed in such an investigation and, due to time and resource constraints, the ability to conduct the adequate testing and assessment required to fully synthesize conclusions was limited.

A pathway for engaging the hydrologic analysis was developed with the intention that the ideas, hypotheses, and recommendations for future study presented herein might stimulate productive conversation within the Expert Science Team. The Team should potentially select items which may have merit in the context of overall BBEST objectives and constraints for further pursuit. The pathway is described in four parts.

Executive Summary

A. Pre-Processing of Available Data to Support Parameterization

The recommended process for preparing to conduct hydrologic analysis includes:

1. *Gage/Site Selection*
2. *Determination of Pre-Impact and Current Condition Record Periods*
3. *Return Flow and 7-Day Low Flows*
4. *Peak Flows*
5. *Overbank Flows*

B. Flow Separation

Based on evaluation of MBFIT and IHA, the following points are offered:

1. *Appropriate categorization of flows is predicated on user understanding of the algorithms employed both in the pre-processor and post-processor in conjunction with the functional classifications utilized by the Texas Instream Flow Program. Summary documentation highlighting the key information may be useful if this work is to be conducted by multiple parties.*
2. *There are tools useful to determination of 'goodness of fit' when tuning the parameters of flow separation algorithms which are readily available. These could be codified within a procedure with information about their use.*
3. *Further study should be conducted, focused on determining whether IHA or MBFIT should be used as the exclusive pre-processor, or whether there are cases when one program performs significantly better than the other.*

C. Episodic Event Analysis

Based on investigation of HEFR, the following steps and suggestions are proposed:

1. *Consider whether all important variables affecting the soundness of the ecological environment are incorporated in current methodology, and if not, state explicitly why this is deemed appropriate and how it affects uncertainty in the recommendations.*
2. *Increase the user-friendliness of HEFR by ensuring that plots which the user is intended to evaluate provide key information and are presented at a helpful scale. There are additional plots that may be meaningful in evaluating the nature of the hydrograph on an aggregated or episodic basis, and which could be added to the computations/information synthesized by HEFR.*
3. *Consider whether the biological overlay data requisite for employing the extant HEFR methodology will in fact be available within the needed timeframe*.
4. *Key variables of interest with respect to biology could potentially be evaluated within HEFR so that flow recommendations could be further based upon observed historical events.*
5. *It may be useful to update tools for evaluating seasonality, especially in order to facilitate determination of appropriate seasonal selection.*

6. *While the Alternative Method represents significant improvement in analytical process relative to the Original Method, based on the design intention (recurrence intervals versus non-parametric characterization), there is significant room for improvement of the regression analysis used to characterize high flow events*.
7. *The functionality of subsistence calculations could be improved so that a real value for subsistence flow is returned for each month/season.*
8. *More tools could be provided for evaluating baseflow and the appropriate selection of threshold parameters*.

D. Biological Overlay

While biological overlay data which could be incorporated into model parameterization was not provided for use in this project, the methodology as it has been designed relies upon the application of key knowledge. Based upon the understanding gleaned from the literature combined with investigation of the hydrologic tools to be employed, the following thoughts are offered:

1. *Tables 4-7 from "The Essential Steps for Biological Overlays in Developing Senate Bill 3 Instream Flow Recommendations" (SAC, 2009c) provide the theory for how to step through incorporation of biologic information with hydrologic. The process outlined seems appropriate and useful if (1) the information is actually available, (2) if evaluation tools can be developed to supplement or refine existing tools so that users could actually answer the questions being posed, and (3) any evaluation tools needed to execute this process are reasonable and efficient for the user.*
2. *Because the methodology developed for HEFR relies heavily on the availability of specific types of biologic overlay data, it should be determined (as soon as possible) what information will realistically be available so that the hydrologic analysis process can be tailored to accommodate this reality*.
3. *Studies are needed in order to assess whether and how pre-impact, current conditions, or the full record should be used as the basis for hydrologic analysis and flow recommendations, based on significant species and the conditions that they are adapted to* (Poff et al, 2009).

As a byproduct of this study, preliminary flow matrices were developed for all 13 gages for pre-impact, current conditions, and the full record. These flows should absolutely not be taken as recommendations, as the focus of this study was on conceptually and contextually understanding the pre- and post-processing algorithms employed by MBFIT, IHA, and HEFR. The necessary model parameterization was not completed for each gage, and no biological overlay information was applied in the production of these flow values.

These flow matrices should not be used even as preliminary data (or only with extreme caution) because:

1. The time available for executing this project was too limited to allow for the necessary evaluation of goodness of fit for the hydrographic flow separation for Conroe and Oakwood. No evaluation of flow separation results was made for any other gages, and likewise no gage-specific parameterization was conducted.
2. Flow recurrence intervals in the episodic event analysis were not determined using any input from biological overlay, a requisite step for appropriate selection which then allows for regression results to be evaluated for goodness of fit. Recurrence intervals were randomly selected and the same frequencies used for each flow matrix presented.
3. The evaluation of seasonal behavior was limited at best, and was not conducted for each gage for pre-impact, current conditions, or full record.
4. No evaluation of current conditions was pursued—the extent of this study was limited to pre-impact conditions for the Oakwood and Conroe.
5. A key hydrologic variable, rate of change of flow, was not considered in this study outside of thresholds used in flow separation and consequently no guidance/recommendations are provided. It is believed that this is an essential component of flow that supports a sound ecological environment.
6. The default methodology for subsistence flow was utilized, which may contradict intuitive knowledge that (1) there could be a flow which is so low in any given month that organisms would not be able to recover, and (2) the historical pre-impact hydrograph should necessarily contain information about these minima.
7. Based on available information and methodology, there is an inability to adequately establish defensible thresholds or to ascertain whether a baseflow is wet, dry, or average.

Ultimately, due to limited project resources, no conclusive statements can be offered about whether IHA or MBFIT will perform better for any given hydrograph. However this study has provided a valuable opportunity for the proliferation of ideas on how process and programmatic challenges can be addressed to promote the success of the entire effort being prosecuted by the Expert Science Team. The products of this work include explanations which highlight the operations and algorithms employed by each software tool, discussion of limitations, and suggestions for improvement. Furthermore, results that are provided may enable the reader to synthesize hypotheses or conclusions which can be tested.

While the challenges of developing environmental flow recommendations that can support a ‘sound ecological environment’ are many, the Scientific Advisory Committee and Expert Science Teams have demonstrated enormous dedication to the task. This project supports that trajectory by providing explanation and assessment of modeling tools in the context of SB 3 goals and an evaluation of how well-suited the tools and processes being employed seem to be for accomplishing their intended function

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1. Introduction

The objective of this project is to study the flow regime at specific locations within the Trinity/San Jacinto River Basin using tools and methodology developed under Senate Bill 3 in conjunction with other analytic tools, and to lay the groundwork for subsequent development of the hydrologic analysis.

The Trinity/San Jacinto Basin and Bay Expert Science Team (BBEST) has specifically requested better, interpretive and quantified descriptions of how the pre-processing tools MBFIT and IHA parse flows; descriptions of how model parameters operate and how they can be adjusted to appropriately reflect hydrologic conditions; and the provision of a context for the characterization and interpretation of statistical frequencies.

This work included development of preliminary flow matrices for 13 locations (along with qualifications about the meaning, limitations, and uses thereof), and recommendations on how these preliminary flows might ultimately be developed into environmental flow recommendations using biological overlay data[1], supplemental evaluation tools, and improvements in computational methodologies.

[1] Throughout this document the term "biological overlay" is used generically to refer to multiple forms of additional information which should ideally be used in the development of an environmental flow recommendation, including information pertaining to biology, geomorphology, water quality, and geographic extent.

2. Background

This study focused on 13 locations given that information learned from these sites may inform and refine the geographic scope and extent ultimately utilized by BBEST. The 13 locations were selected generally based on quality and length of stream gage record, geographic distribution, channel/floodplain conditions, and potential biological data. The overall selection included consideration of over 100 USGS gages utilizing USGS HUCs, TCEQ Classified Stream Segments, geomorphic zonation, ecological zonation, hydrological zonation along with additional information with respect to reservoirs, subwatersheds and water availability. The Senate Bill 2 (SB2) priority study segment was also considered. One original location, Whiteoak Bayou at Houston, was determined to not be representative of the overall watershed conditions; therefore, that site was replaced by the Buffalo Bayou at Piney Point. Table 2.1 is a list of the locations and general information for the USGS stream gages at these locations (USGS, 2008).

Table 2.1: Study Site Locations and General Information

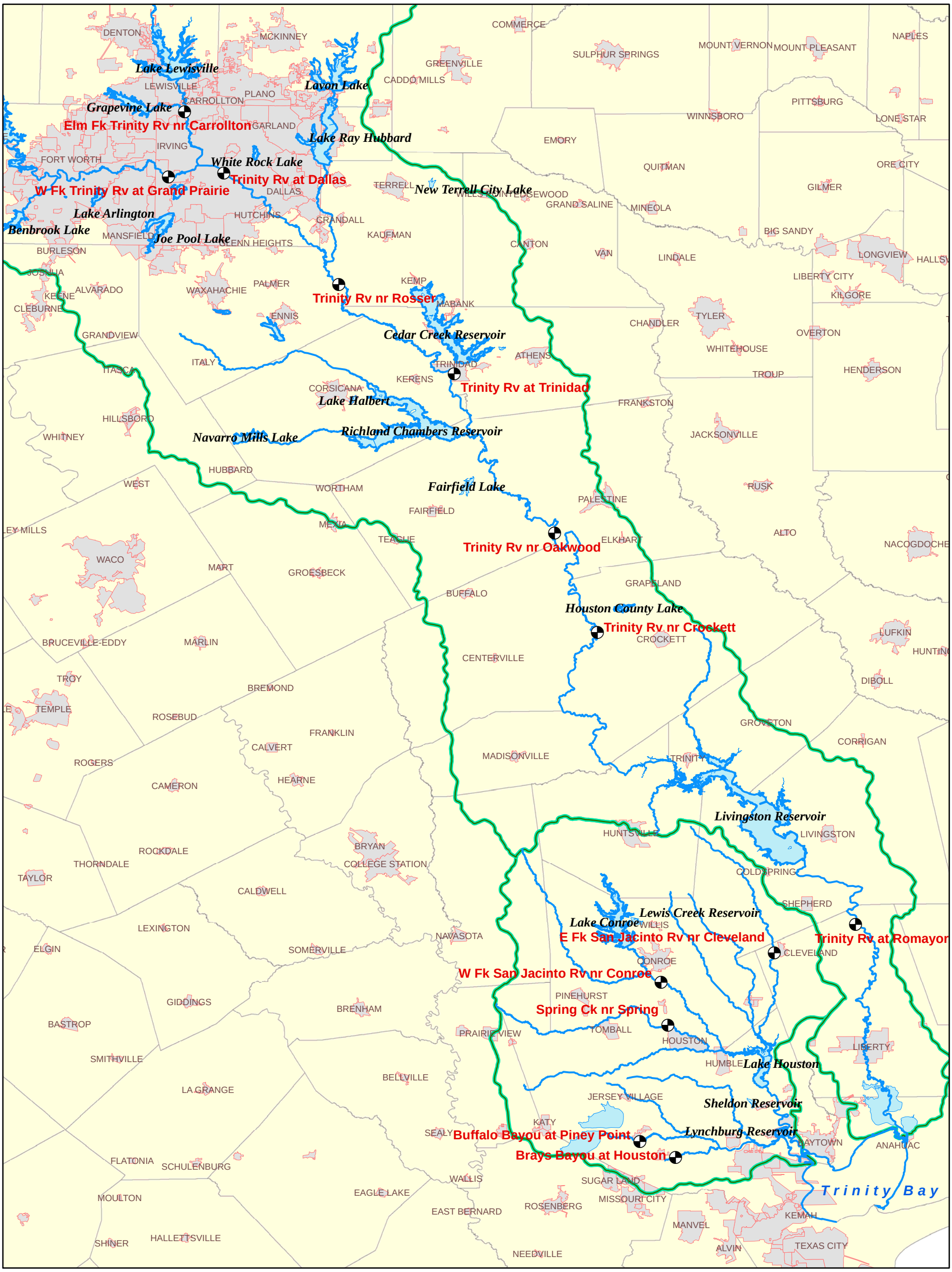
Basin	USGS Gage #	Site Name	Latitude	Longitude	River Mile	Total Contributing Basin	Flow Data	
						(Square Miles)	begin date	end date
Trinity	8049500	W Fk Trinity Rv at Grand Prairie, TX	32°45'45"	96°59'40"	514.6	3065	1926	2008
	8055500	Elm Fk Trinity Rv nr Carrollton, TX	32°57'57"	96°56'39"	18.2*	2459	1907	2008
	8057000	Trinity Rv at Dallas, TX	32°46'29"	96°49'18"	500.3	6106	1904	2008
	8062500	Trinity Rv nr Rosser, TX	32°25'35"	96°27'46"	451.4	8147	1939	2008
	8062700	Trinity Rv at Trinidad, TX	32°08'51"	96°06'08"	390.3	8538	1965	2008
	8065000	Trinity Rv nr Oakwood, TX	31°38'54"	95°47'21"	313.4	12833	1924	2008
	8065350	Trinity Rv nr Crockett, TX	31°20'18"	95°39'22"	265.4	13911	1964	2008
	8066500	Trinity Rv at Romayor, TX	30°25'30"	94°51'02"	94.3	17186	1925	2008
San Jacinto	8068000	W Fk San Jacinto Rv nr Conroe, TX	30°14'40"	95°27'25"	79	828	1940	2008
	8068500	Spring Ck nr Spring, TX	30°06'37"	95°26'10"	9.9	409	1940	2008
	8070000	E Fk San Jacinto Rv nr Cleveland, TX	30°20'11"	95°06'14"	31.4	325	1939	2008
	8073700	Buffalo Bayou at Piney Point, TX	29°44'48"	95°31'24"	24**	299	1964	2008
	8075000	Brays Bayou at Houston, TX	29°41'49"	95°24'43"	11.6	94.9	1937	2008

* River mile measured upstream from confluence with the West Fork

** From confluence with Brays Bayou

The dates shown in Table 2.1 for the gage were the analysis periods selected for this study, primarily based on the availability of data for full years and continuity of years of record.

Figure 2.1 shows the locations of the 13 study sites. There are a total of 6 sites on the Trinity mainstem, with two additional sites on two of the main forks in the Dallas-Fort Worth area. A total of three sites are in the upper Trinity in the Dallas-Fort Worth area, including Trinity River at Dallas. Four sites are along the middle Trinity River and these generally correspond to the SB2 priority study segment. One site is in the lower Trinity below Lake Livingston. These range in drainage area size from 2,459 square miles to 17,186 square miles. There are five sites in the San Jacinto River basin, with each on a separate stream or river. The San Jacinto basin sites range in drainage area size from 95 square miles to 828 square miles.



Legend

- Gaging Stations
- Major Rivers
- Trinity/San Jacinto Basins
- Reservoirs
- City Boundaries

N

20 10 0 20 Miles

1 inch equals 20 miles

Figure 2.1
Study Sites Location Map

August 31, 2009

Crespo Consulting Services, Inc.
Civil & Environmental Engineering

The Trinity River basin has 23 major (greater than 5,000 acre-foot) impoundments with approximately 7 million acre-feet of total conservation storage (TRA,2007). All of the Trinity River sites have multiple reservoirs upstream. Eight reservoirs are major flood control reservoirs, developed by the Corps of Engineers, with a total of about 1.6 million acre-feet of storage allocated for flood control. Reservoirs were constructed as early 1905. There are three main forks of the Trinity, the East, Elm and West Forks. The West Fork and Elm Fork confluence is in Dallas and is 5.2 miles above the Trinity at Dallas site. Several large reservoirs were constructed in the 1930s on the West Fork. In the 1950s, 6 major reservoirs were constructed on the three main forks.

The West Fork of the San Jacinto near Conroe site is the only San Jacinto Basin site with major reservoirs upstream and it has the largest drainage area (828 square miles). The other four San Jacinto Basin sites range from 55 to 409 square miles. Buffalo Bayou at Piney Point and Brays Bayou at Houston are in relatively more urbanized areas, and USGS reports that low flows are sustained generally by upstream effluent discharges (USGS, 2008). There are two very large floodwater detention facilities (Addicks and Barker Reservoirs) on Buffalo Bayou upstream of the Piney Point site (HCFCD, 2009).

Figure 2.2 shows the gage record period for each of the 13 sites. The light grey shading indicates when some data is available at the site.

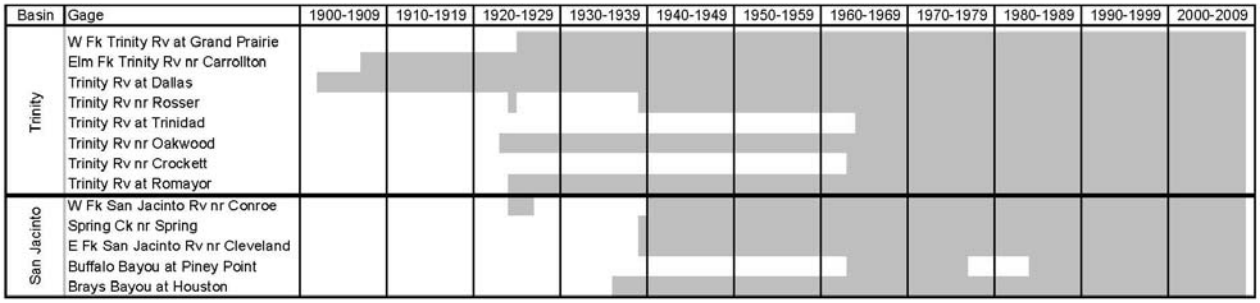


Figure 2.2: Gage Flow Records

For purposes of this study, two sites were selected for preliminary detailed analyses to test the approach and methodology. These sites are Trinity River near Oakwood (USGS Station 08065000) and West Fork of San Jacinto River near Conroe (USGS Station 08068000). These sites were selected for their long period of record and different watershed characteristics.

The Trinity River near Oakwood site is on the mainstem of middle Trinity at mile 313.4 (See Figure 2.3) and is within the SB2 priority study segment. The total drainage area is 12,833 square miles, of which 8,455 square miles (76%) is regulated by 21 major reservoirs with 5.2 million acre-feet of conservation storage along with 1.6 million acre-feet of flood storage in 8 Corps of Engineers flood control projects (TRA, 2007). The nearest reservoir is Richland-Chambers Reservoir which is 59 river miles above the site on Richland and Chambers Creeks with impoundment beginning in July of 1987. The contributing area is 1,957 square miles and

the conservation storage is 1,135,000 acre-feet. The next nearest reservoir is Cedar Creek Reservoir, with an impoundment date of 1965. Neither of these reservoirs has allocated flood control storage. The closest major tributary is Tehuacana Creek which discharges into the Trinity River about midway between the site and Richland Creek. All three of the main forks of the Trinity River are upstream of the site and the contributing watersheds include the Dallas-Fort Worth Metroplex.

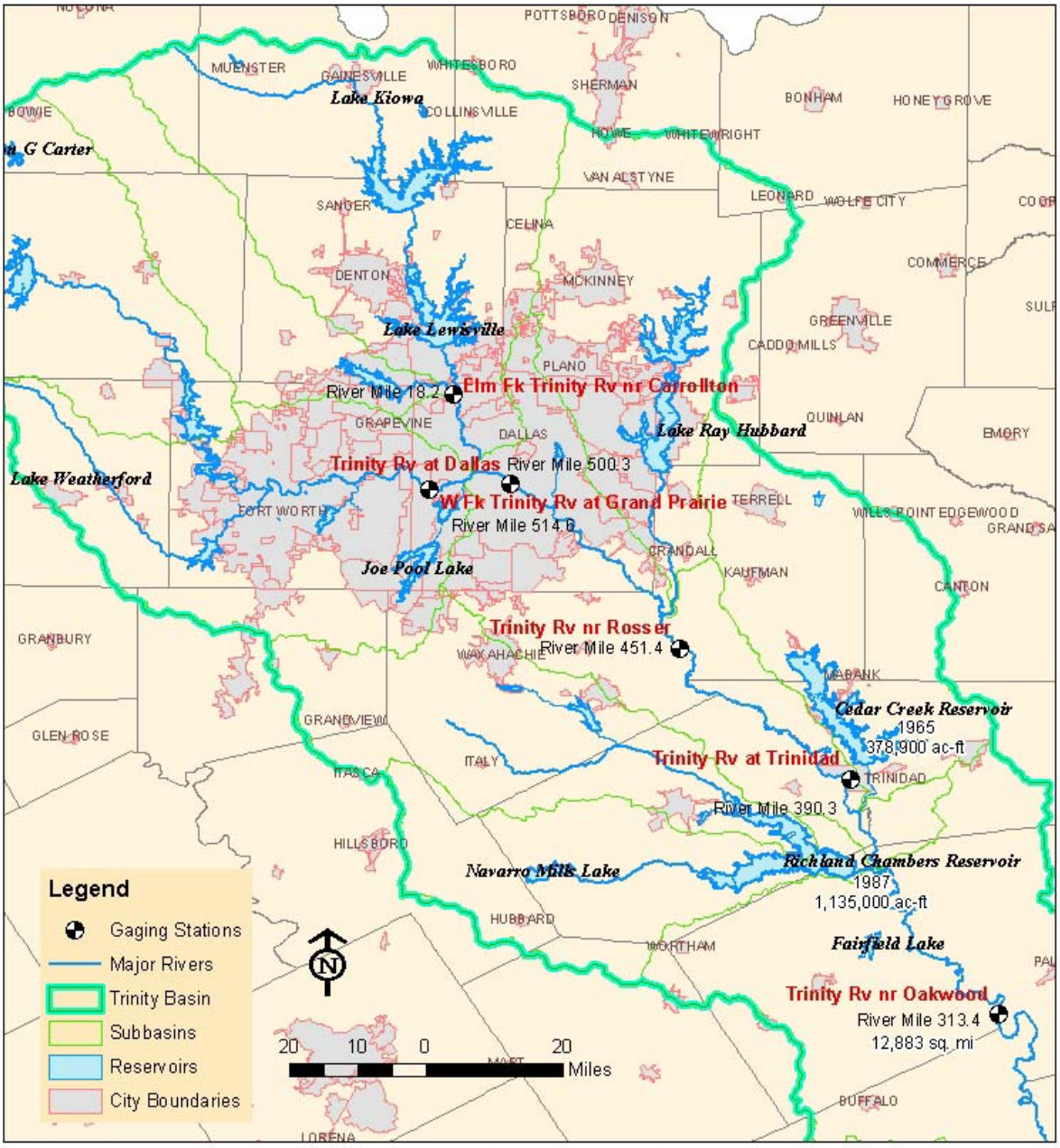


Figure 2.3: Oakwood Watershed Map

The West Fork of the San Jacinto near Conroe (See Figure 2.4) has two reservoirs upstream, including Lake Conroe with 477,260 acre-feet of storage which was impounded in 1973. Of the

809 square miles of the Conroe site contributing watershed, 445 square miles (55%) is controlled by Lake Conroe. The reservoir is only 15 miles from the site; however, Lake Creek is a relatively large tributary that enters the West Fork 3.5 miles above the site. Lake Conroe has very limited flood storage capacity. Lewis Creek reservoir is upstream of Lake Conroe with a contributing watershed of 4.4 square miles and it has 17,000 acre-feet of conservation storage. It was impounded in 1969.

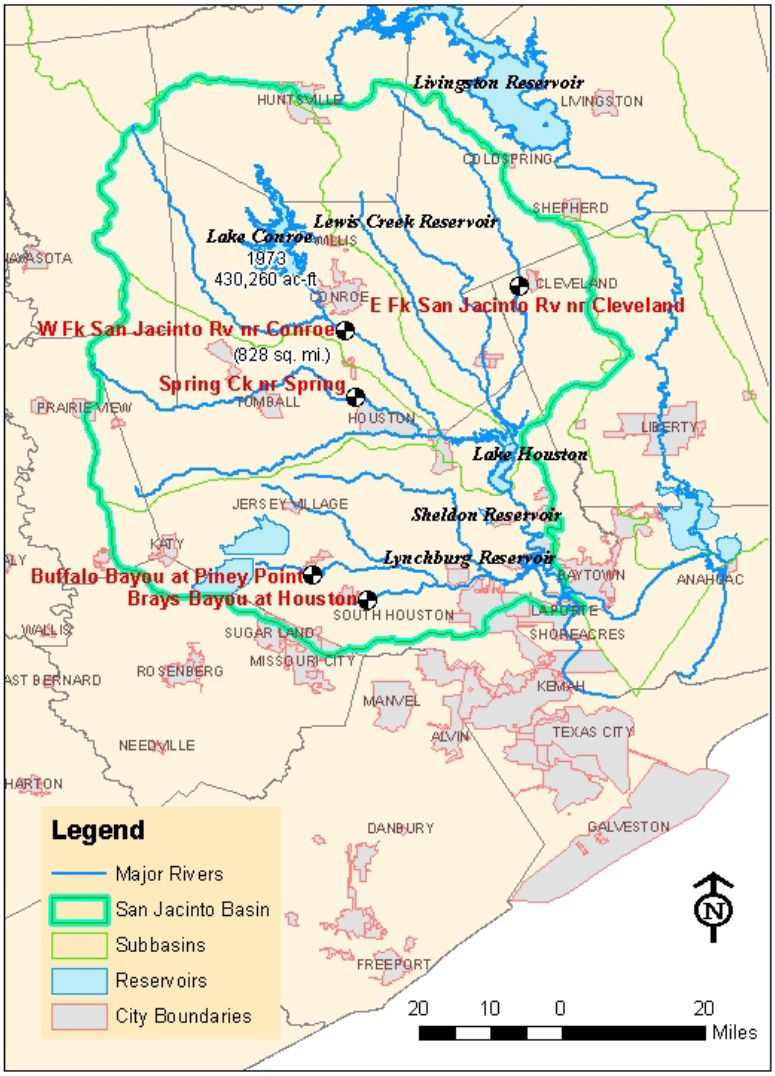


Figure 2.4: Conroe Watershed Map

Information on naturalized flow is available for all but one of the selected sites from the TCEQ Water Availability Modeling Study for both the Trinity and San Jacinto River basins (Espey, 2000, 2001a, 2001b; FNI, 1999). The naturalized flows were developed from numerous control points which were usually USGS gage sites with long-term records. The monthly gage flow data was systematically adjusted for various impacts such as, reservoir content changes, reservoir net evaporation, diversions, and return flows. Information used to perform the naturalization process and the naturalized flows were reviewed and utilized to support objectives of this study.

The Texas Water Quality Standards were reviewed primarily for consideration of the 7-day, 2-year (7Q2) low flow, which has been established in the standards (TNRCC, 2000). Although not a direct water quality standard, the 7Q2 is utilized in establishing standards, particularly the dissolved oxygen standards through water quality modeling. The 7Q2 values from the standards are available for 12 of the 13 sites and are calculated based on a relatively recent period of flow data, within the range of 1966 to 1996.

3. Project Approach

Conceptually, the context supporting this project work is rooted in the view of "hydrology as the master variable" (TIFP, 2008; Richter, 2006; Poff, 1997). There are key components of hydrology that support a sound ecological environment, including flow magnitude, frequency, duration, timing, and rate of change (Poff, 1997).

A detailed study of the flow regime was prosecuted focused on the pre-impact period for two gages: Oakwood on the Trinity River, and Conroe on the West Fork of the San Jacinto River. The pre-impact period was selected because the natural hydrograph is believed to be ideally-suited to supporting a sound ecology. In order to maximize the opportunity to evaluate each tool and methodology for flow separation and episodic event analysis within very limited time, MBFIT was selected as the primary pre-processor for the Conroe station, and subsequently used for other gages on the San Jacinto basin. IHA was used for Oakwood and all of the Trinity basin gages. (It was hoped that trends could perhaps be observed both within and across basins, however time did not permit such evaluation. Results are provided from which readers may attempt to glean some insight.) Additional studies were conducted to explore the concepts and evaluations of seasonality and subsistence flows.

Multiple MBFIT runs were systematically executed in order to understand the effect of parameter adjustments and develop an appropriate set of parameters, and these same Conroe parameters were then applied to all of the gages in the San Jacinto basin. Similarly, IHA parameters developed for the Oakwood gage were used for all flow separation runs in the Trinity basin.

Table 3.1: Analysis tools utilized for each gage.

Basin	Gage	MBFIT	IHA	HEFR
Trinity	W Fk Trinity at Grand Prairie		•	•
	Elm Fk Trinity nr Carrollton		•	•
	Trinity Rv nr Dallas		•	•
	Trinity Rv nr Rosser		•	•
	Trinity Rv nr Oakwood	•	•	•
	Trinity Rv nr Crockett		•	•
	Trinity Rv at Romayor		•	•
San Jacinto	W Fk San Jacinto nr Conroe	•		•
	Spring Ck nr Spring	•		•
	E Fk San Jacinto Rv nr Cleveland	•		•
	Buffalo Bayou at Piney Point	•		•
	Brays Bayou at Houston	•		•

The parameterized Conroe model results are presented in Appendix E and can be compared with an IHA run which used similar parameters.

Theoretically, the HEFR results for the two gages and using the two preprocessors could also compared in an attempt to evaluate the suitability of IHA versus MBFIT flow separation on end results.

The Alternate, frequency-based method of HEFR was run for Conroe and Oakwood, and for all 13 gages, the hydrographic separation (MBFIT/IHA) and episodic event analysis (HEFR) was executed for the full hydrologic record, the pre-impact, and the current conditions (Appendix E).

4. Pre- Processing to Support Parameterization of HEFR

4.1 Determination of Pre-Impact and Current Condition Record Periods

A specific facet of this study involves consideration of how, if any, the flows have changed over time. Three specific periods were identified by the scope of work:

- Flows prior to significant upstream impoundment
- Flows representative of current conditions
- Flows for the entire period of record

For purpose of this study, the first bullet is considered to be generally pre-impact, not just pre-impoundment. Current conditions were considered to be the recent period of record without rapid changes in flow or stream conditions.

The two main human influences on the river flows are:

- Reservoir impoundments (and related diversions)
- Return Flows associated with Wastewater Treatment Plant discharges.

Another human influence, that is evident mainly in the annual peak flow records, is the impact of urbanization.

The Trinity River basin has 23 major (greater than 5,000 acre-feet) impoundments with approximately 7 million acre-feet of total conservation storage. All of the Trinity River sites have multiple reservoirs upstream. For the selected San Jacinto River sites, only the West Fork of the San Jacinto near Conroe has major reservoirs upstream, including Lake Conroe with 477,260 acre-feet of storage.

The Trinity and San Jacinto reservoirs upstream of the study sites are listed in Table 4.1, along with the associated contributing drainage, size of conservation storage and other information. The size, location and impoundment dates were reviewed to determine a probable pre-impoundment condition, which would then serve as the initial estimate of a pre-impact condition.

Table 4.1: Reservoir Locations Relative to Study Control Points

Reservoir [1]	Drainage Area (square miles)	Stream	Date of Impoundment	Permitted Conservation Storage (ac-ft/yr)	Allocated Flood Storage (ac-ft/yr) [2]	Downstream Gage Number	Downstream Gage Name
Trinity River Basin							
Amon Carter	99.8	Big Sandy Creek	May 1956	20,000		8049500	W Fk Trinity Rv at Grand Prairie
Bridgeport	1,111	West Fork Trinity River	April 1932	387,000			
Eagle Mountain	1,970	West Fork Trinity River	February 1934	210,000			
Worth	2,064	West Fork Trinity River	July 1914	38,124			
Weatherford	109	Clear Fork Trinity River	March 1957	19,470			
Benbrook	429	Clear Fork Trinity River	September 1952	87,000	170,350		
Lake Arlington	143	Village Creek	March 1957	45,710			
Ray Roberts	692	Elm Fork Trinity River	June 1987	799,600	260,800	8055500	Elm Fk Trinity Rv nr Carrollton
Lewisville	1,660	Elm Fork Trinity River	November 1954	618,400	264,400		
Grapevine	695	Denton Creek	July 1952	161,250	246,950		
Joe Pool	232	Mountain Creek	January 1986	176,900	123,100	8057000	Trinity Rv at Dallas
Mountain Creek	295	Mountain Creek	March 1937	22,840			
White Rock	100	White Rock Creek	March 1905	21,345		8062500	Trinity Rv nr Rosser
Lavon	770	East Fork Trinity River	September 1953	380,000	291,700		
Ray Hubbard	1071	East Fork Trinity River	March 1978	490,000			
Terrell	14	Muddy Cedar Creek	November 1955	8,712		8065000	Trinity Rv nr Oakwood
Cedar Creek	1,007	Cedar Creek	July 1965	378,900			
Bardwell	178	Waxahachie Creek	November 1965	54,900	85,100		
Halbert	12	Elm Creek	April 1905	7,357			
Navarro Mills	320	Richland Creek	March 1963	63,300	148,900		
Richland-Chambers	1,957	Richland and Chambers Creeks	July 1987	1,135,000			
Fairfield	34	Big Brown Creek	December 1969	50,600			
Houston County Lake	44 (TWDB)	Little Elkhart Creek	November 1966	19,500		8065350	Trinity Rv nr Crockett
Livingston	16,583	Trinity River	June 1969	1,750,000		8066500	Trinity Rv at Romayor
San Jacinto River Basin							
Lewis Creek	4.4	Lewis Creek	February 1969	17,000		8068000	W Fk San Jacinto Rv nr Conroe
Conroe	445	West Fork San Jacinto	January 1973	430,260			

[1] Reservoirs are listed generally upstream to downstream for each river basin.
[2] Only stated if applicable

In addition to the reservoir impoundment dates, naturalized flow information from the TCEQ Water Availability Modeling (WAM) Studies were reviewed and analyzed for the Trinity and San Jacinto Basins (Espey, 2000, 2001a, 2001b; FNI, 1999). The purpose of the review and analysis was to try to verify the pre-impact period, which would be generally represented by the naturalize flows being approximately equal to the gage flows. Some of the WAM data utilized and analyzed included plots of the ratio of the annual natural over gage flows, monthly statistics tables, monthly statistics plots, annual bar charts and mass curves. Twelve of the thirteen sites for this study were also control points for the WAM. Buffalo Bayou at Piney Point was not a WAM control point, so the WAM control point just upstream on Buffalo Bayou near Addicks was utilized to the extent practicable.

An example of the use of the WAM naturalized flows is provided in Figure 4.1. A ratio of the annual naturalized flow to the annual gage flow was plotted for Conroe, with values of one

representing that the naturalized flow matches the gage flow. As the plot indicates, the gage flow and naturalized flow generally match, until Lake Conroe is impounded in 1973. Similar plots are provided for each site in Appendix A.

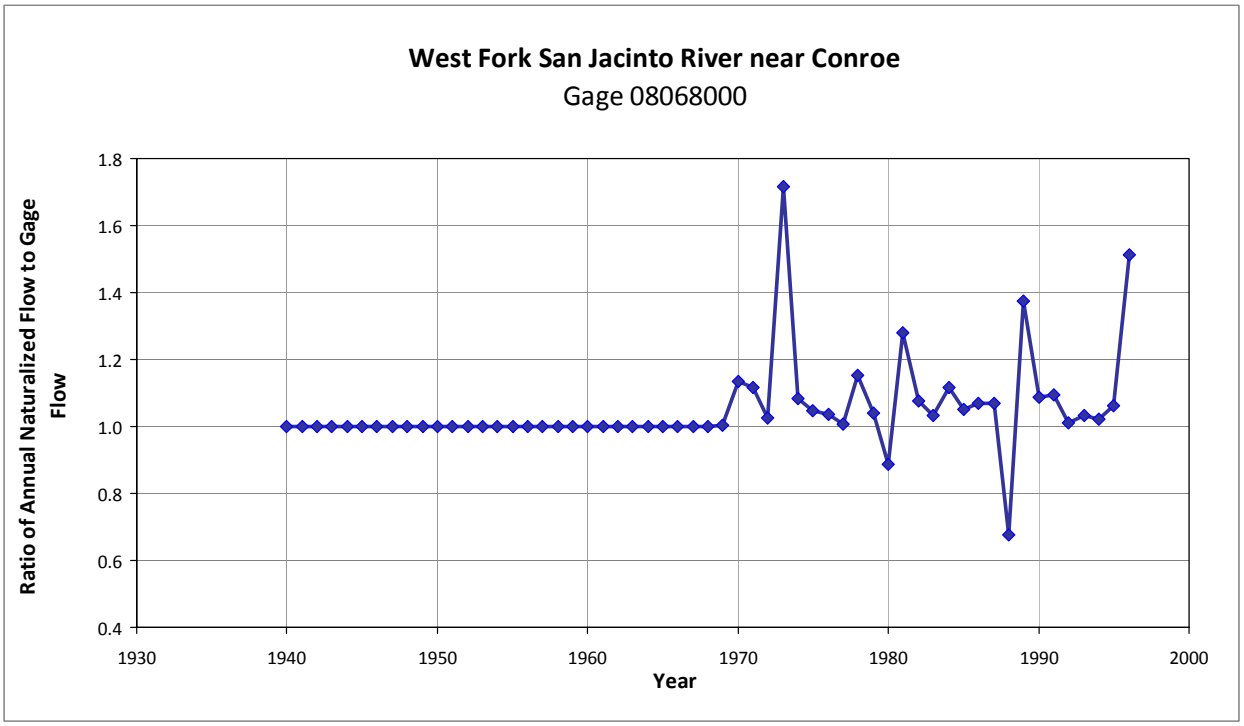


Figure 4.1: Conroe Naturalized Flow Chart

There are major return flows from the Dallas-Fort Worth area that have significantly increased over time. Figure 4.2 shows the total return flows upstream of Oakwood based on the WAM information. Return flows are significant throughout the Trinity, except for the Elm Fork near Carrollton. In the San Jacinto, return flows primarily impact Brays Bayou and Buffalo Bayou.

As shown in Figure 4.2, increasing return flows can be observed in the gage record by comparing the estimated return flows to the 7-day annual low flows. This relationship between return flows and 7-day low flows for both the pre-impact and current conditions was used to evaluate the non-stationary nature of the return flows over the period of record. Similar plots are shown for each site in Appendix B.

IHA was also run for selected gages to test potential pre-impact and current condition periods. Analysis periods were varied, selected statistics were plotted, and the pre-impact and current condition statistics were compared to assist with selection of the proposed analysis periods.

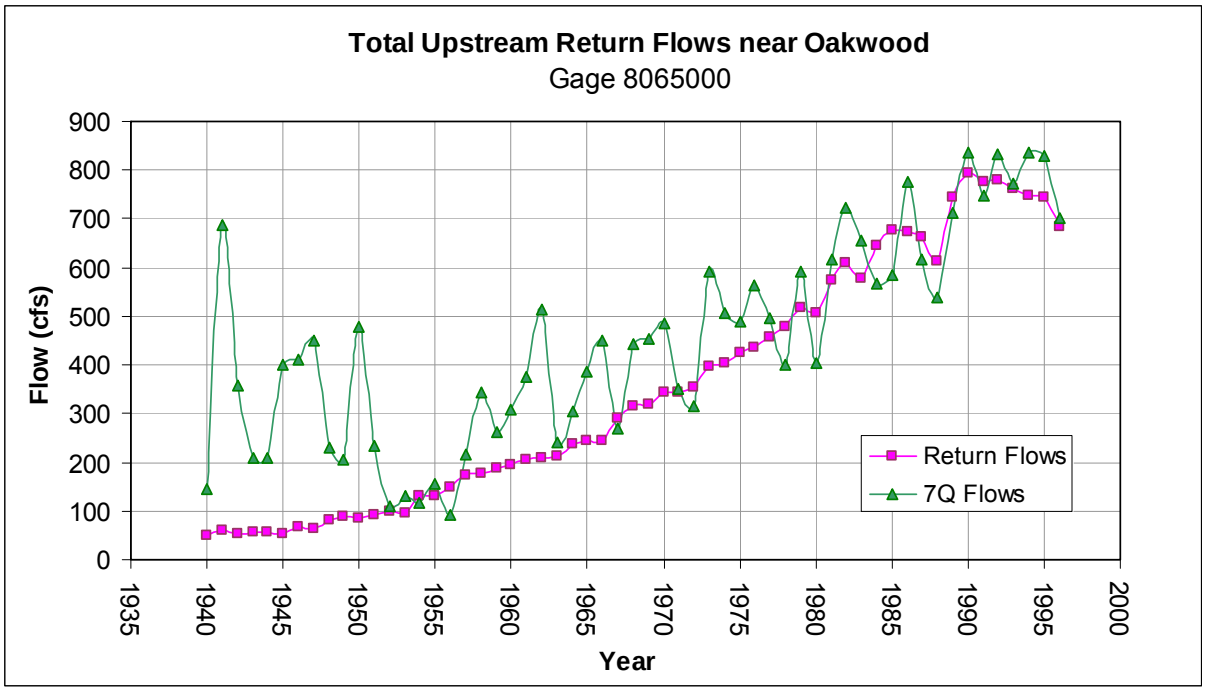


Figure 4.2: Return Flow and Annual 7-Day Low Flow Comparisons

The pre-impact periods were primarily selected to:

- Provide sufficient gage record period prior to major impoundments
- Pre-date major influences of return flows
- Match gage flows to naturalized flows

The current condition periods were primarily selected to:

- Provide sufficient gage record period after major impoundments
- Provide a period of relatively stable return flows

Generally, 20 to 30 years of record would be considered sufficient for analysis. For pre-impact conditions, the Rosser site pre-impact record is constrained by limited data before 6 major reservoirs came on line during the 1950s, including Lake Lavon in 1953. Considering the 1950s drought and increasing return flows, extending the pre-impact record did not appear to improve the data set. The 12-year pre-impact analysis period for Piney point is a result of a gap in the data set starting in 1965.

The current period for the Trinity sites was limited by the impoundment of three large reservoirs in 1986 and 1987 (Joe Pool, Ray Roberts and Richland-Chambers) with over 2 million acre-feet of conservation storage. There were also significant increases in return flows during the 1970s and 1980s.

Table 4.2 and Figure 4.3 show the selected periods for both conditions.

Table 4.2: Pre-Impact and Current Analysis Periods

Basin	Gage Station Name	Gage Number	Pre-impact analysis period	Post-impact analysis period	Start of Main Gage Record	Pre-Impoundment Date From Scope	Impoundment Date	Key Impoundment
Trinity	W Fk Trinity Rv at Grand Prairie	8049500	1926 - 1956	1989 - 2008	1926	1957	Mar-57	Arlington
	Elm Fk Trinity Rv nr Carrollton	8055500	1907 - 1952	1989 - 2008	1907	1952	Jul-52	Grapevine
	Trinity Rv at Dallas	8057000	1904 - 1953	1989 - 2008	1904	1953	Nov-54	Lewisville
	Trinity Rv nr Rosser	8062500	1939-1952	1989 - 2008	1939	1953	Sep-53	Lavon
	Trinity Rv at Trinidad	8062700	none	1989 - 2008	1965	None		None
	Trinity Rv nr Oakwood	8065000	1924 - 1964	1989 - 2008	1925	1965	Jul-65	Cedar Creek
	Trinity Rv nr Crockett	8065350	none	1989 - 2008	1964	None		None
	Trinity Rv at Romayor	8066500	1925 - 1968	1989 - 2008	1925	1968	Jun-69	Livingston
San Jacinto	W Fk San Jacinto Rv nr Conroe	8068000	1940 - 1972	1974 - 2008	1939	1973	Jan-73	Conroe
	Spring Ck nr Spring	8068500	1940 - 2008	1940 - 2008	1940	None		None
	E Fk San Jacinto Rv nr Cleveland	8070000	1940 - 2008	1940 - 2008	1939	None		None
	Brays Bayou at Houston	8075000	1937 - 1960	1984 - 2008	1937	None		None
	Buffalo Bayou at Piney Point	8074500	1964 - 1975	1988 - 2008	1964	None		None

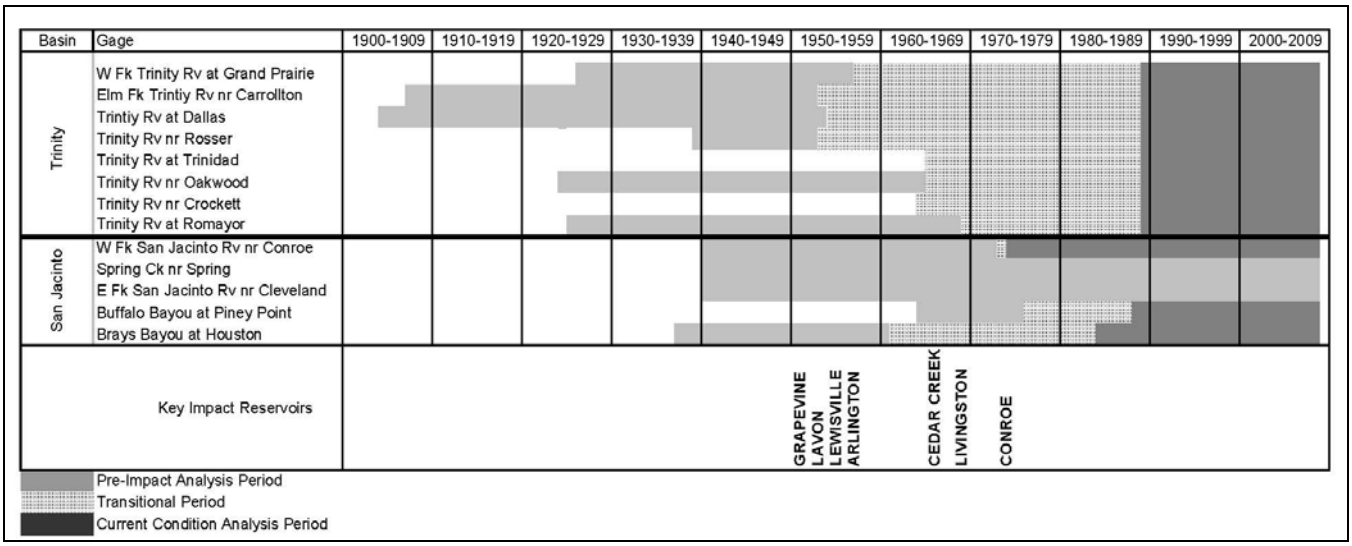


Figure 4.3: Pre-impact and Current Conditions Period

4.2 Return Flows

Return flows were estimated by compiling return flow estimates at control points using information developed for the WAM. As mentioned above, the 7-day annual low flows can generally be related to the estimated return flows. To evaluate the changes in return flows and potential change to the 7-day annual low flows, the average of these values has been estimated for both the Pre-Impact and Current periods to allow comparison to the other statistical analyses. These averages are provided in Table 4.3 and historical plots shown in Appendix B. For the Trinity River at Romayor, return flows upstream of Lake Livingston were not included in the return flow estimates after impoundment began 1969. The return flow estimates for the

WAM control point at Buffalo Bayou near Addicks were used to estimate the return flows for Buffalo Bayou at Piney Point downstream.

Table 4.3: Comparison of Return Flows and Low Gage Flows for Pre-Impact and Current Conditions

Basin	Site Name	Average Return Flow		Average 7-Day Low Flows		7-Day, 2-Year Low Flow		Flow Data	
		cfs		cfs		cfs			
		Pre-Impact	Current	Pre-Impact	Current	Pre-Impact (Calculated)	Current [1] (Published)	Pre-impact End Date	Post-impact Start Date
Trinity	W Fk Trinity Rv at Grand Prairie	28.02	192.51	63.1	187.2	36.7	107.4	1956	1989
	Elm Fk Trinity Rv nr Carrollton	n/a	n/a	103.2	34.5	21.7	15.9	1952	1989
	Trinity Rv at Dallas	30.1	402.9	134.0	355.9	32.5	221.4	1953	1989
	Trinity Rv nr Rosser	70.93	754.53	223.2	695.9	175.1	606.6	1952	1989
	Trinity Rv at Trinidad	n/a	728.6	n/a	730.2	n/a	657.3	none [2]	1989
	Trinity Rv nr Oakwood	120.57	754.12	287.4	783.2	177.4	716.7	1964	1989
	Trinity Rv nr Crockett	n/a	764.04	n/a	1004.8	n/a	810.8	none [2]	1989
	Trinity Rv at Romayor	143.18	2.55 [6]	540.6	964.4	406.8	732.3	1968	1989
San Jacinto	W Fk San Jacinto Rv nr Conroe	n/a	1.79	83.9	109.9	12.4	20.3	1972	1974
	Spring Ck nr Spring	1.85	n/a	13.5	n/a	14.1	15.4 [5]	2008	none [3]
	E Fk San Jacinto Rv nr Cleveland	n/a	n/a	15.7	n/a	14.6	18.2 [5]	2008	none [3]
	Buffalo Bayou at Piney Point	0.32	17.32	20.2	44.8	18.4	50.6	1975	1988
	Brays Bayou at Houston	1.44	102.09	5.3	97.3	4.1	92.1 [4]	1960	1984

[1] TCEQ Published current 7Q2 flow data is based on a different and variably range of dates between 1966 and 1996.
[2] Pre-impact calculations are not applicable to this gage because gage records prior to the 1960's do not exist.
[3] The entire record is pre-impact because no reservoirs or other influences exist for these gages.
[4] Brays Bayou 7-day, 2-year low flow current data was calculated for this table (a TCEQ published volume was not available)
[5] The numbers are listed in the current column although they are believed to be generally representative of the pre-impact conditions.
[6] This number (current) reflects only return flows discharged below Lake Livingston.

Through the selection of the Pre-Impact and Current conditions, the non-stationary nature of the return flows in the historical record is partially accounted for by not using the periods with the highest increases in return flows. The changes in the Pre-Impact and Current conditions return flow can be compared to averages of the 7-day low flows, the 7-day, 2-year low flows (7Q2) along with subsistence and baseflow estimates to generally evaluate the overall impact of return flows to the gage flows.

More detailed analyses or adjustment of gage flow data using return flows is limited by the estimation techniques for the WAM. Much of the return flow information is estimated from water use data and is only available by month.

No estimates were made of future return flows; however, it is considered a possibility that return flows may level off or decrease as planned re-use strategies are implemented.

4.3 7-Day 2-Year Low Flows

The impact of increasing return flows can also be seen in the increase in the 7-day, 2-year low flows (7Q2). The 7Q2 is a flow utilized in water quality standards and the associated water quality modeling. Pre-impact 7Q2s were estimated where possible for comparison to the

current published 7Q2s associated with the Texas Water Quality Standards as shown in Table 4.3 (TNRCC, 2000). A published value for 7Q2 was not available for Brays Bayou; therefore a comparable value was calculated from the available flow data. The 7Q2 information is provided since these flows are considered as a potential alternative or guide when setting subsistence flows.

4.4 Peak Flows

The PeakFQ peak flow frequency program was also run for the proposed pre-impact, current and full record. PeakFQ is an implementation of Bulletin 17-B - Guidelines for Determining Flood Flow Frequency (USGS, 1981). PeakFQ provides estimates of instantaneous annual-maximum peak flows for a range of recurrence intervals using the Log Pearson Type III distribution.

Table 4.4 shows the peak flows for each site for selected recurrence intervals for the pre-impact and current conditions. A percent change is also shown between the pre-impact and current conditions. Elm Fork of the Trinity near Carrollton dropped significantly between the pre-impact and current conditions, probably because of the proximity of three major reservoirs controlling 96% of the site watershed with a combined conservation volume of almost 1.6 million acre-feet and just over 750,000 acre-feet of flood control storage. This was the only site to drop from pre-impact to current conditions for the 1.5-year and 2-year peak flows. There did not appear to be any other definitive changes directly attributable to reservoirs. This may be a result of many of the reservoirs not having flood pools and large intervening areas below the reservoirs. Some increase in the peak flows may be attributable to urbanization. The three sites with the largest increases are Grand Prairie, Buffalo Bayou and Brays Bayou and they appear to have been impacted by urbanization in the watershed just upstream of these sites.

The full results of the pre-impact, current and full record for all calculated recurrence intervals is provided in Appendix C.

Since the values shown in Table 4.4 are based on the USGS instantaneous peak flow data set for the annual maximum series, this data may not be directly comparable to other recurrence interval analyses, such as provided in HEFR. HEFR uses daily average values and allows more than one event per year. Use of the instantaneous peak compared to the daily average values do not appear to be as significant on large river systems, such as the Trinity River, where the flood events are almost always multi-day events. However, in the San Jacinto Basin where the watersheds are much smaller, there appears to be a significant difference in the instantaneous peak and the daily average.

Table 4.4: Peak Flow Frequency Results from PeakFQ

	1.5-Year Recurrence			2-Year Recurrence			5-Year Recurrence			10-Year Recurrence		
Site Name	Pre	Current	% +/-	Pre	Current	% +/-	Pre	Current	% +/-	Pre	Current	% +/-
W Fk Trinity Rv at Grand Prairie	5,980	10,700	79%	8,210	14,100	72%	15,500	25,100	62%	21,700	34,600	59%
Elm Fk Trinity Rv nr Carrollton	12,700	5,610	-56%	18,200	6,840	-62%	37,500	10,400	-72%	55,700	13,000	-77%
Trinity Rv at Dallas	15,800	21,900	39%	22,800	27,600	21%	47,800	43,300	-9%	71,000	54,700	-23%
Trinity Rv nr Rosser	24,900	28,800	16%	34,400	35,400	3%	63,600	54,600	-14%	87,000	69,400	-20%
Trinity Rv at Trinidad	-	31,000	-	-	37,500	-	-	54,800	-	-	66,900	-
Trinity Rv nr Oakwood	24,400	34,000	39%	33,900	43,500	28%	64,300	69,300	8%	89,700	87,500	-2%
Trinity Rv nr Crockett	-	32,900	-	-	41,300	-	-	64,400	-	-	81,100	-
Trinity Rv at Romayor	30,100	45,800	52%	38,400	58,400	52%	60,400	89,200	48%	75,600	108,000	43%
W Fk San Jacinto Rv nr Conroe	6,130	6,460	5%	9,560	9,620	1%	22,400	21,400	-4%	34,500	32,700	-5%
Spring Ck nr Spring	3,950	-	-	6,270	-	-	14,300	-	-	21,200	-	-
E Fk San Jacinto Rv nr Cleveland	3,410	-	-	5,500	-	-	14,000	-	-	22,800	-	-
Buffalo Bayou at Piney Point	1,990	3,570	79%	2,420	4,160	72%	3,450	5,480	59%	4,070	6,250	54%
Brays Bayou at Houston	2,780	14,600	425%	3,800	17,300	355%	6,630	23,600	256%	8,630	27,400	217%

4.5 Overbank Flows

Bank full flows are generally considered channel forming flows and are considered very important to the geomorphology of a stream or river. Overbank flows also can serve an important ecological function. Identification of bankfull and overbank conditions can be used as a refinement of the hydrologic analyses. Although data is limited, the National Weather Service (NWS) has identified “Action Stage” and “Flood Stage” at each site. Based on the NWS description, the “Flood Stage” appears to correspond to the overbank flow stage. In most cases, the NWS reports a flow that corresponds to the overbank flow stage. For Crockett, minor overbank flooding is described for the “Action Stage”. Summary information from NWS is provided in Appendix D.

In addition the NWS information, the USGS rating curves were examined to determine when overbank flow might be occurring. The rating curves provided by USGS are provided in Appendix D. Although the rating curve is at the gage site at a bridge, the overall shape of the curve may still reflect the downstream overbank flooding condition. A single point was selected for the overbank stage from the stage-discharge curve for purposes of this study; although, a range of stage and flow could have been selected along the inflection of the curve associated with the gradual occurrence of overbank innundation.

Table 4.5 shows the overbank flow based on the NWS information, the overbank flow based on the USGS rating curve and the approximate recurrence interval based on the peak flow

frequency analysis. The result from the current frequency analysis were used to estimate the overbank recurrence intervals on the basis that the bankfull conditions based on NWS information and current USGS gage ratings would more likely be related to the recent flow record. The table also reports the pre-impact and current 1.5-year recurrence interval peak flows for comparative purposes.

Table 4.5: Overbank Flow Estimates

Category	Unit	West Fork Trinity River at Grand Prairie	Elm Fork Trinity River near Carrollton	Trinity River at Dallas	Trinity River near Rosser	Trinity River at Trinidad	Trinity River near Oakwood	Trinity River near Crockett	Trinity River at Romayor
NWS Overbank Flow[1]	cfs	20,000	6,200	11,100	40,000	17,000	24,600	31,300	94,300
RI[2] for NWS Overbank Flow[4]	yrs	2.33 to 5	1.5 to 2	<1.25	2.33 to 5	<1.25	<1.25	1.25 to 2	5 to 10
Overbank Stage from Rating Curve	ft	26	11	31	30	32	38	38	40
Overbank Flow from rating curve	cfs	12000	13000	11000	21000	17000	30000	33000	90000
RI[2] Based on Rating Curve	yrs	1.5 to 2	10	<1.25	<1.25	<1.25	1.25 to 1.5	2	5
PEAKFQ 1.5-Yr Peak Flow for Pre-Impact	cfs	5,980	12,700	15,800	24,900	-	24,400	-	31,100
PEAKFQ 1.5-Yr Peak Flow for Current	cfs	10,700	5,610	21,900	28,800	31,000	34,000	32,900	45,800

Category	Unit	West Fork San Jacinto near Conroe	Spring Creek near Spring	East Fork San Jacinto River near Cleveland	Brays Bayou at Houston	Buffalo Bayou at Piney Point
NWS Overbank Flow[1]	cfs	19,100	8,500	16,000	Not Available	3,700
RI[2] for NWS Overbank Flow[4]	yrs	2.33 to 5	2.33 to 5	5 to 10	-	1.5 to 2
Overbank Stage from Rating Curve	ft	18	NA[3]	13	NA[3]	52
Overbank Flow from rating curve	cfs	16,000	NA[3]	2,000	NA[3]	3,700
RI[2] Based on Rating Curve	yrs	2.33 to 5	-	<1.25	-	1.5 to 2
PEAKFQ 1.5-Yr Peak Flow for Pre-Impact	cfs	6,130	3,950	3,410	2,780	1,990
PEAKFQ 1.5-Yr Peak Flow for Current	cfs	6,460	-	-	14,600	3,570

[1] NWS Flood Stage appears to be the level where actual overbank flooding starts based on descriptions (No flooding is mentioned for Action Stage except for Crockett).
[2] RI - Recurrence Interval
[3] NA - Not Apparent
[4] All Recurrence Intervals based on current frequency analysis

This analysis yielded bankfull values less than the 1.25-year peak flow for several sites. Several other sites have bankfull flows near or just over the 5-year peak flow for the site. The data indicates there is some scatter of bank full conditions around the 1.5-year peak flow that is sometimes used as a typical value for bank full flow.

5. Flow Separation and Episodic Event Analysis

5.1 Flow Separation

There are four functional flow classifications utilized in the context of the Texas Instream Flow Program (TIFP, 2008), the intention of each being to fulfill unique facets of ecosystem need. These functional intentions drive the evaluation of whether a given pre-processor (MBFIT or IHA) is adequately parsing the hydrograph (categorizing flow on every day of record). It is important to note that flow categorization happens exclusively within the pre-processor, and that effectively six (IHA) or seven (MBFIT) quantitative parameters are used to perform the categorization procedure. (The parameter for defining a 'large flood event' is here discounted, as the TIFP does not use this as a functional category and the feature is effectively 'turned-off'[2].)

Default parameters have been established for IHA by the SAC (SAC, 2009b), and while no default parameters have been published for MBFIT presumably the spreadsheet tool which was programmed specifically for the BBEST contains reasonable starting values. Default parameters for IHA are shown in Figure 5.1, and the algorithms employed for assigning a flow type to each day of record are further described below.

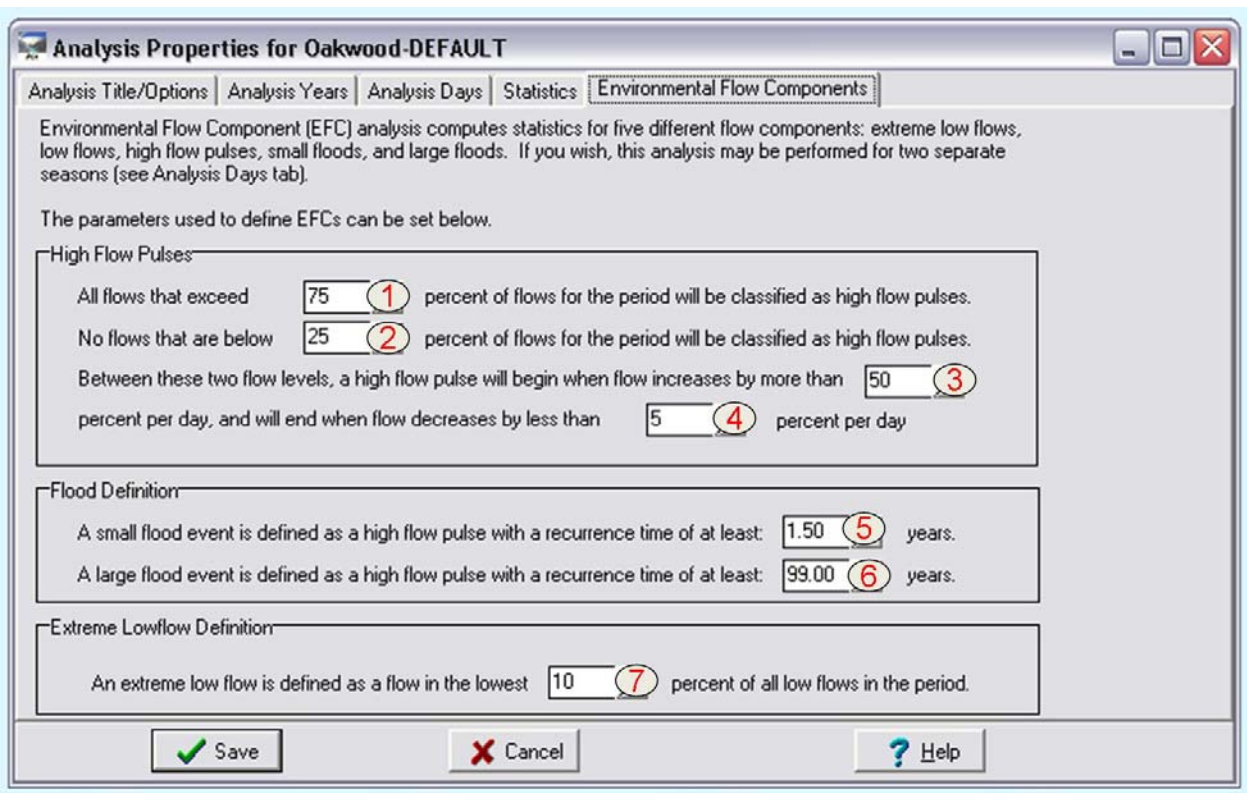


Figure 5.1: IHA dialogue box for analysis input with default parameters specified by the SAC.

[2] It is important to acknowledge that by TIFP definition, an environmental flow recommendation might have multiple levels of overbank events if there is a specific desirable ecologic function served.

The first step in assigning a type to each flow value is the categorization of a flow as *generally high-flow* or *generally low-flow*[3]. Although the concept is similar, the algorithms used to detect this are fundamentally different in IHA and MBFIT.

IHA uses two initial tests for high flow, checking on a given day: (1) is the flow greater than the 25th percentile of all flows (parameter 2 in Figure 5.1 above)? and (2) is the flow 50% greater than that of the previous day (parameter 3)? Following the initial test, a series of criteria are tested to differentiate ascending and descending limbs of high flow events. These additional checks compare the (percentile) rank of a flow on a given day to threshold values, and check the rise/fall rate between adjacent days against threshold values in order to isolate coherent flow events. IHA uses four parameters to ensure that all flows are divided into 2 populations: *generally high-flows* and *generally low-flows*. This categorization is significant because only flows classified as *generally* high are used for subsequent tests for high flow pulse versus overbank pulse, and only flows classified as *generally low* are considered for the baseflow versus subsistence flow categories.

Likewise, MBFIT uses multiple parameters to separate *baseflow-* from *pulseflow-dominated* days, including checking against user-defined thresholds analogous to parameters 1 and 2 in IHA. In addition, MBFIT conducts a more complex comparison. While IHA looks at a single neighboring day, MBFIT examines windows of days (window length = parameter "n" specified by user). Conceptually, this is intended to smooth erratic or noisy behavior caused by 1-day fluctuations in daily average flows. The algorithm is conceived around isolating each "turning point"— a local minimum based on the user-specified parameter "f", and a "Runoff Fraction" (parameter "RF" specified by the user). If a day is isolated as a turning point, adjacent days are classified as *baseflow-* or *pulseflow-dominated* by comparing their flow rates to the value: [flow on turning point day *x* Runoff Fraction]. After making this initial baseflow/pulseflow distinction, MBFIT then compares the daily flow value to flow magnitudes calculated from user-specified thresholds (parameters D-G) to classify a day as subsistence flow, baseflow, high flow pulse, or overbank flow ('small flood').

[3] These flows are often referenced as "Group 1" (subsistence and base flows) and "Group 2" (overbank and high flows).

MBFIT			
Code1			
	MBFI Parameters		
N	A	9	
f	B	0.9	
Runoff Fraction	C	0.2	
	Thresholds		
	Percentile	Magnitude	
high flow upper	D	0.75	8400
high flow lower	E	0.25	860
Code3	Thresholds		
	Percentile	Magnitude	
extreme low flow	F	0.1	236
small flood	G	1.5	21367
large flood	H	99.99	999999

Figure 5.2: MBFIT parameters as saved in the Evadale example file.

The final step implemented in MBFIT is to associate each day with an event (subsistence, baseflow, high flow pulse, overbank pulse) and to ensure that each day within each event has the same flow classification.

IHA or MBFIT are similar in that they initially isolate the two primary flow populations (1) *generally high-flow/pulse-flow dominated* days, and (2) *generally low-flow/baseflow-dominated* days. The days in the higher flow group are then separated into Overbank Flow Pulses or High Flow Pulses, respectively, based on whether the peak of an event has a recurrence of 1.5+ years (default value, parameter 5 in IHA/'G' in MBFIT) or less. Within the *generally low-flow/baseflow-dominated* days the lowest 10th percentile (default, parameter 7/'F') are categorized as subsistence flow. The upper 90 percent of *generally low-flow/baseflow-dominated* days are categorized as baseflow.

Conceptually, the MBFIT approach is appealing in that it situates flow on any given day within the context of neighboring days (using n-day windows, turning points, and Runoff Fractions), whereas IHA looks at relative rise/fall rates (% change in flow) from only one day prior and subsequent. In practice, however, the user is left to qualitative assessment of 'goodness of fit' for both tools, and it is possible that for some hydrograph types IHA might perform better. There is no theoretical basis offered for the selection of parameters, and default values are chosen somewhat arbitrarily from one of many possible values that lie within what can objectively be considered a reasonable range. (e.g. the subsistence flow threshold should obviously not be the median flow of the entire record)

Theoretically, there should be parameter trends which apply to hydrographs exhibiting certain patterns of behavior (e.g. characteristics such as generally rapid ascending limbs, which might

imply values for the rise threshold/RF; proclivity for prolonged baseflow to experience mild perturbations which do not perform the functions requisite for classification as high flow pulse, which might imply increase in low-flow threshold). In practice, each hydrograph is quite unique and requires attentive assessment by a skilled user.

Evaluation of 'goodness of fit'[4] is generally a subjective and time-consuming process, however tools for preliminary assessment are readily available: IHA can plot the hydrograph with flow components visible by color[5], and MBFIT can make a similar plot which also includes comparison of MBFIT results to IHA results. (The MBFIT spreadsheet makes a side-by-side calculation of a user-parameterized IHA run.) These built-in tools are helpful yet somewhat cumbersome because of the relative ease of setting up plots at a readable scale and making side-by-side comparisons. (Hence the plots such as Figures 9-16 in "the HEFR document" (SAC, 2009b) which are created in Excel rather than from direct IHA and MBFIT outputs.)

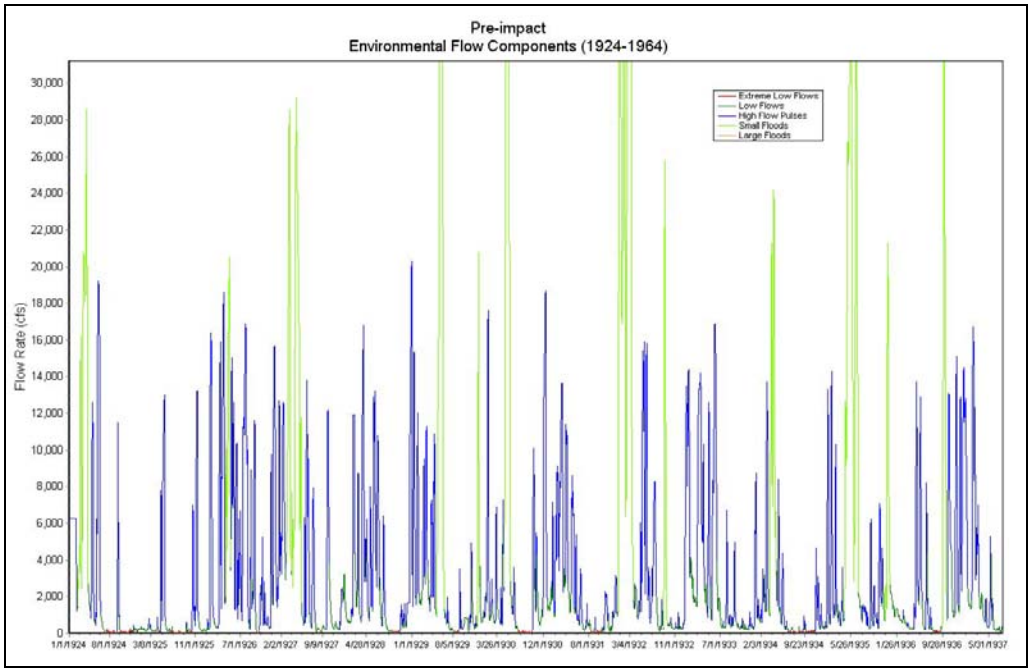


Figure 5.3: The Environmental Flow Components output plot from IHA is convenient for viewing the full record, but requires multiple toggles to view on an annual scale or side-by-side with results from a different run.

[4] Here the expression 'goodness of fit' is not meant to express the more rigorously-defined statistical sense of data-fitting which can be quantitatively expressed using a variety of methods, but rather the more informal, qualitative assessment by a user of the daily characterization of flow into one of the four flow categories.

[5] IHA is also known to have a glitch in that the color-coded hydrograph plots are off (shifted) by one day. (Source: written communication with Dan Opdyke, TPWD)

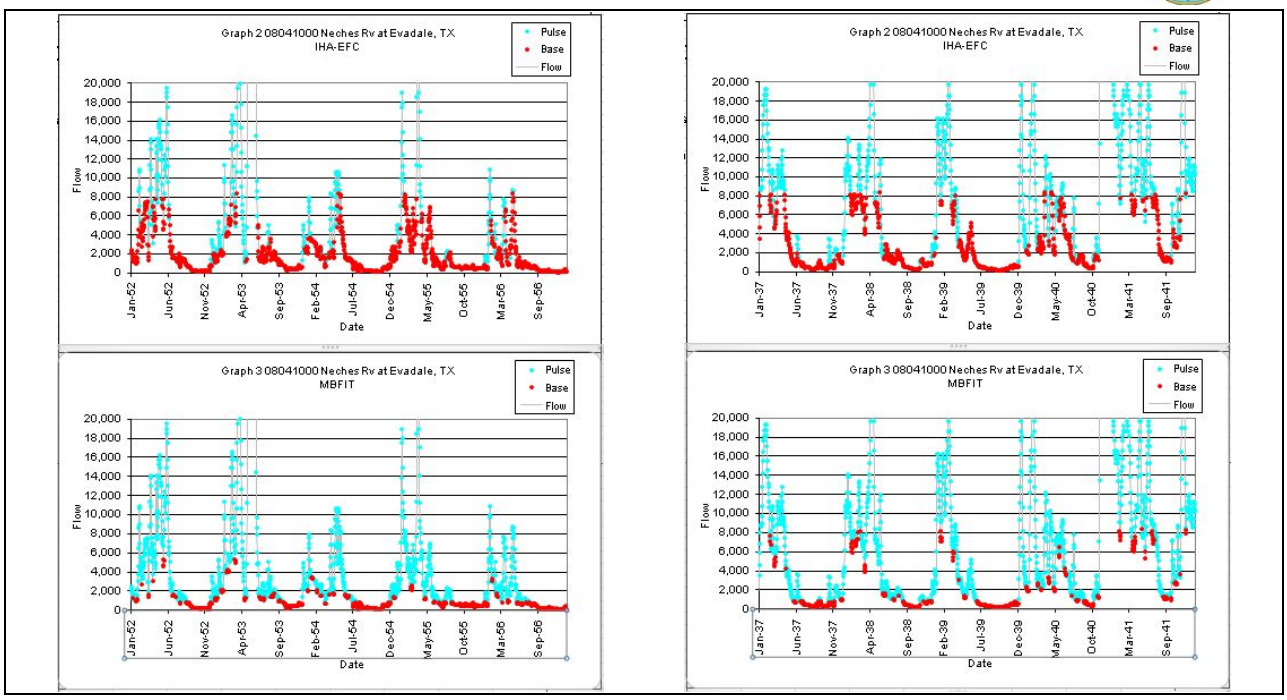


Figure 5.4: MBFIT displays side-by-side (actually above and below) comparisons of IHA and MBFIT results. A macro is run to generate plots which cycle through from start to end year, and the user can vary the timescale and length of time that each plot appears.

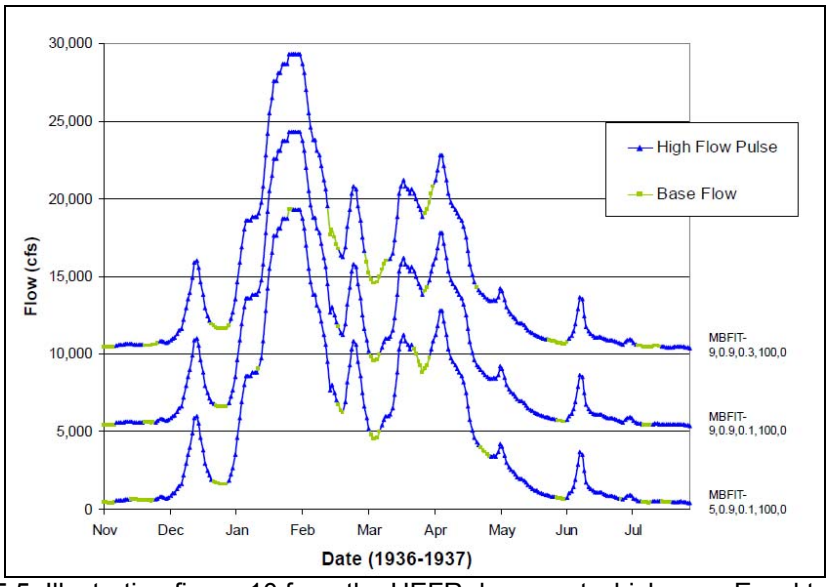


Figure 5.5: Illustration figure 10 from the HEFR document which uses Excel to display results so that the effect of parameters on flow classifications at tail of events and at minor perturbances in base flows.

Evaluation of results ultimately entails viewing enough of the hydrograph and flow categorization results to 'get a feel' for whether in total the relative number of days and corresponding rates of flow are characterized appropriately (i.e. within their functional group as defined by TIFP), and whether what appear to be distinct events are separated by a change in classification.

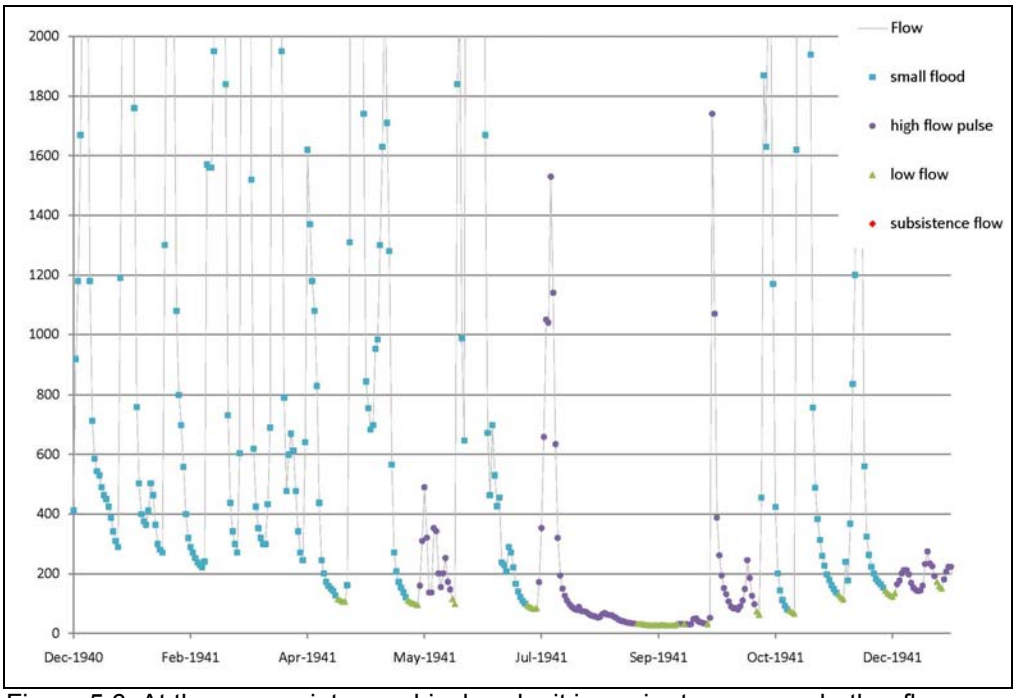


Figure 5.6: At the appropriate graphical scale, it is easier to assess whether flows are being adequately classified and the potential need to use the HEFR multipeaks multiplier. It may be more appropriate to not lump the volume and duration characteristics of the overbank flows ("small flood") of early 1941 into one single event.

If the former condition appears to be met, while the latter does not, it may be possible to use an adjustment in HEFR to properly account for separate events (the 'multi-peaks multiplier').

The flow separation analysis conducted using IHA or MBFIT provides the input (date, average daily flow rate, and flow component assignment—the "Environmental Flow Component") used by HEFR. The HEFR tool, an add-in module to Excel, is then used to conduct 'Episodic Event Analysis' (described in Section 5.3).

5.2 Flow Components

5.2.1 Overbank Flows

The definition of overbank flow provided in the Texas Instream Flow Program Technical Overview (TIFP, 2008) is:

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

Of the four flow components, the threshold for overbank flow may be perceived to have a more tangible physical reference point in that one can physically measure the geometry of a channel and interpret (perhaps supplemented by other surrogate measurements such as reference streams and gages) using well-established guidance. However, there are also well-established questions/doubts about the accuracy and precision of such techniques. The relative frequency of flows that equal or exceed the functional channel-forming discharge is dependent (to varying degrees of sensitivity) on disturbances in the channel and on the upstream watershed and hydrology. Data from sources such as USGS rating curves, the National Weather Service, and frequency relationships developed with tools such as PKFQ can provide somewhat objective quantitative input. The approximate value established by any reasonable means is a significant qualifier for evaluating parameters/goodness of fit in IHA and MBFIT.

While these metrics rely on assumptions about the correlation of current and historic overbank-type flows with current or historic channel morphology, there are widely-available data (NWS, USGS) that provide a useful starting point in the absence of detailed study especially in the context of work conducted under the SB2 mandate (77th Texas Legislature, 2001).

In computing overbank flow recurrence intervals, peak flows, and volumes using the Alternative, frequency-based method[6] in HEFR, the entire population of Overbank Flows and High Flow Pulses is utilized, essentially overriding the high flow pulse versus overbank flow classification assigned by either MBFIT or IHA. By using the entire population of flows classified as High Flow Pulses and Overbank Flows for the characterization of episodic events, the HEFR tool utilizes a larger set of observed data to develop correlations between storm magnitude, duration, and frequency[7].

5.2.2 High Flow Pulses

This component of flow is characterized physically by “short-duration, in-channel, high flow events following storm events” and functionally helps to “maintain important physical habitat and longitudinal connectivity along the river channel.” (TIFP, 2008) The maintenance of physical habitat includes water chemistry, nutrient delivery, and morphological processes. This component of flow is on one hand easy to identify on the hydrograph (you pretty much know it when you see it[8]), and on the other, because of the stochastic nature of runoff events, high flow is difficult to efficiently characterize in a manner adequate to ensure that all functions are achieved over time.

While the HEFR algorithms (Alternate, frequency-based method) use the entire population of high and overbank flow pulses, it seems that parameters used by the pre-processor to

[6] Throughout this document, the original, percentile-based method is used to refer to the percentile-based method which was used at the origin of HEFR. Subsequently the “Alternative Method” feature has been included, which is frequency-based. Thus, the reader should

[7] It is important to note that HERF uses Partial Duration Series to compute recurrence intervals, whereas flood frequency analysis typically uses Annual Maxima Series.

[8] It should be noted that while a hydrograph pulse may be readily observed, the functional categorization may rightly be affected by one’s perspective (e.g. hydrologist vs. ecologist)

distinguish HFPs from OBPs (upper threshold and recurrence interval) are not independent from affecting the overall distribution of flows assigned to each category—increasing the number of days assigned as overbank can affect the number of days assigned as baseflow. See Section 6 for additional information.

5.2.3 Baseflows

If baseflows are "the component of an instream flow regime that represents normal flow conditions (including variability) between precipitation events" (TIFP, 2008), the question of '*what is normal and how often do we expect it to occur?'* may demand some attention. It is important to distinguish that the goal is to identify flow which is functionally (per TIFP definition) acting as baseflow, rather than the conventional vernacular which defines baseflow as river flow sourced from groundwater (or any non-surface runoff).

For practical purposes in terms of flow separation, the classification of baseflow is significant in that (1) it is helpful to parameterize the pre-processor such that one or multiple baseflow days are inserted as separators between peaks of multi-pulse high flow events in order to facilitate the computation of representative volumes and durations in the post-processor (HEFR); and (2) the relative proportion of baseflow days to highflow days may provide some useful insight into the nature of the hydrologic regime at a gage or to the goodness of fit assessment of the pre-processor parameters.

The concept of baseflow is complicated by increases in return flow volume and flow rate. Return flows at all gages have tended increase consistently each year, and return flows exhibit no or very little seasonal variation. Furthermore, little is known about how to assess inter-annual variability (e.g. is there a 'wet year' baseflow which is functionally different than and 'average' year, and how can we assess thresholds within baseflows to provide meaningful values for wet/average/dry flows).

5.2.4 Subsistence Flows

Subsistence flows are defined in the Technical Overview of the TIFP as:

> The component of an instream flow regime that represents infrequent, naturally-occurring low flow events that occur for a seasonal period of time. They maintain water quality criteria and provide sufficient habitat to ensure organism populations capable of recolonizing the river system once normal, base flows return (TIFP, 2008).

In practice, subsistence flows are identified by both MBFIT and IHA via a user-defined threshold which effectively takes an ordered array of low flows and categorizes all days within the lowest percentile as 'subsistence flows'. The typical default threshold is 10th percentile, however some percentile of this is taken by HEFR for the flow matrix output (HEFR default = 0.5→5th percentile flow).

The functional interpretation for the TIFP in conjunction with the assertion of 'hydrology as the master variable' might imply that for every season (and all of the complex processes occurring which support every trophic level of the lotic system) there must be some value of minimum flow which occurred historically and which was needed to support a 'sound ecology'. That is, based on historical observation of flow in the spring season, the lowest of the low flows was an upper limit of what is needed in order for survival. A fundamental question might be: do we believe that there is some minimum (subsistence) flow which must occur during the spring in order to ensure that healthy repopulation of distressed reaches can occur? Based on what is commonly and intuitively known about reproduction and life cycles, could we possibly accept that a minimum threshold should not be assigned for every season?

Flows are assigned by MBFIT and IHA as subsistence flow based entirely upon rank within the *generally low-flow/base-flow dominated* category and seasonal evaluation and assignment occurs within HEFR. If no flow within a given seasonal period falls within the user-specified thresholds for subsistence flow, HEFR outputs a subsistence threshold of "N/A". This discussion is developed further under Section 6.2, "Seasonality".

5.3 Episodic Event Analysis

The Hydrology-Based Environmental Flow Regime (HEFR) methodology was developed to provide a tool for the rapid and reasonable development of environmental flow recommendations as mandated by SB3 (SAC, 2009b). Under the auspices of SB2, more rigorous work for the TIFP to study and develop suitable environmental flow thresholds is ongoing (TIFP, 2008). Therefore, the HEFR methodology must be understood and evaluated in the context of how/whether, as a relatively quick approximate method, the tool reasonably supports the development of flow recommendations which could be anticipated to 'support a sound ecology.'

HEFR is a key tool for interpreting the flow category assignments made by IHA/MBFIT because additional information is synthesized regarding the nature of historical events (peak flow, recurrence interval, volume, duration) and the seasonal variation among those events.

This discussion will focus on the alternative, frequency-based method of episodic event analysis developed more recently as an adaptation toward an increasingly useful tool which supports the development of environmental flows. Whereas the original, percentile-based method jumped straight from user-defined input to a resultant flow matrix, the Alternative, frequency-based method has an interim step which allows the user to view graphical and tabular relationships between flowrate, volume, and duration, and has additional functionality for investigation of seasonal relationships.

The HEFR algorithms are essentially comprised of those which process *generally high-flow/pulseflow-dominated* events, and those which process *generally low-flow/baseflow-dominated* events. Within HEFR, the high flow pulse (HFP) and overbank flow pulse (OBP)

assignments made by IHA/MBFIT are trivial, as the tool uses the entire 'large flow' population when analyzing flows in the HFP and OBP categories. The HEFR guidance document explains that the Alternative, frequency-based method uses a paradigm of recurrence intervals in contrast to the Original, percentile-based method which uses non-parametric statistics to qualify high flow pulses (SAC, 2009b).

Recurrence intervals are established using partial duration series (rather than annual maxima) computations. The Hazen plotting position equation presented by Claps and Laio [eq. 1] (Claps, 2003) is used to establish plotting positions and rank actual events (SAC, 2009b).

[Eq 1]

$$T_j = \frac{N}{\lambda\left(N + 0.5 - j\right)}$$

T_j = a return period
N = number of events
λ = average number of events per year
j = position of Tth term in a series [1, N]

After running the first step in HEFR, the user can view results (presented in the "Charts_Freq" tab) including a plot of observed peak flows versus frequency/recurrence interval based on ranking the entire HFP and OBP series (annual) or in part as observed by season.

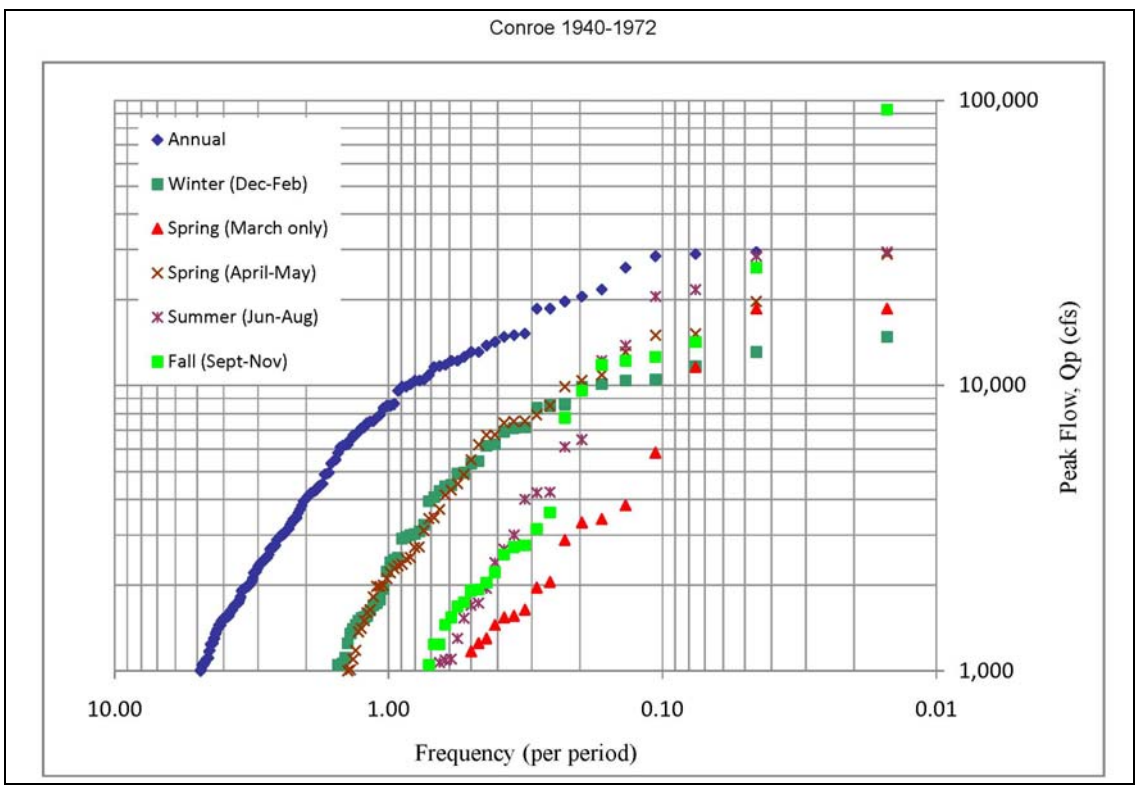


Figure 5.7: Example of peak flow versus frequency plot from "Charts_Freq" tab, including effect of varying seasonal selection from the default values.

The intent at this stage is for the user to examine (1) the relative frequency of flows in relation to magnitude of peak, and (2) the effect of the user's selection of seasonal periods.

While on one hand, plots which show two seasons that seem to significantly overlap might lead a user to conclude that the two overlapping seasons are not distinct; perhaps a more appropriate interpretation would be that the selection of seasonal periods (i.e. month or range of months) may not capture the true annual variability. For example, if the flow-frequency plot exhibits marked similarities between spring and fall, the user could change spring from [March-May] to [April-June]. The user should avail him/herself of this feature relative to their belief that there are fundamentally distinct ecological processes that occur throughout different seasons of the year, and that the hydrologic regime under which the trophic system evolved does or should exhibit unique behavior each season.

The Alternative, frequency-based method allows great flexibility for assignment of seasons, including assessing each month as its own season. Additional functionality could even be added which allows seasons to overlap so that within one run a user could see whether there is a significant difference between Spring = [March-May] and Spring = April-May].

The user is instructed to "combine their [sic] knowledge of the system and understanding of ecosystem roles of flows of different magnitudes and characteristics" in order to proceed with the second step of the HEFR run, which produces the output flow matrix table (SAC, 2009b). This is a key component around which the HEFR methodology was conceived—that the user has some level of "biological overlay" data which can inform their decisions and eventual recommendations. In practice, the actual availability of reliable information which can consistently be used in this way has to date proved dubious. Furthermore, if ongoing exploration for appropriate biological overlay data does not yield the input needed for this design of HEFR methodology, the question that must asked is whether flow recurrence intervals and magnitudes can possibly be selected which will result in the intended/desired consequence: 'a sound ecological environment.' This concept is here presented based on an understanding that these methodologies are all at once the product of collaborative and deliberative effort of numerous highly qualified scientists and stakeholders, and likewise that these processes are under ongoing development as the community increases its understanding of what is possible given all of the myriad constraints.

As the user selects possible recurrence intervals and peak flows, these parameters are entered into cells F62:K67 of the 'Charts_Freq" tab created in the first step of the HEFR run. Based on the cells populated and a user-input "significance level" (cell i54), a series of tabs are generated (by commanding "Continue HEFR"). By definition, the user should ensure that flows entered into the "Overbank Pulses" row exceed all of the high flow pulse values.

	B	C	D	E	F	G	H	I	J	K	L	M
40					Annual	By Season						
41			f	f	Qp(ann)	Qp1	Qp2	Qp3	Qp4	Qp5		
42			1 per 5 years	0.2	20500							
43			1 per 2 years	0.5	13100							
44			3 per 5 years	0.6	12200							
45			1 per year	1	8510							
46			2 per 3 years	1.5	6170							
47			2 per year	2	4070							
48			1 per 5 seasons	0.2		9570	2910	10100	6170	7920		
49			1 per 2 seasons	0.5		5450	1180	5830	1730	1930		
50			3 per 5 seasons	0.6		4490	647	4220	1100	1500		
51			1 per season	1		2290	206	2210	424	570		
52			2 per 3 seasons	1.5		1060	85	839	152	312		
53			2 per season	2		420	#N/A	343	91	147		
54	User Input Area			Please give significance level here:				68.3				
55				Please indicate how to choose regression method by placing X mark in corresponding cells.								
56					Volume	Duration						
57				LN/LN	X	X						
58				Quadratic								
59			Please define overbank flow and high flow tiers immediately down below, following the examples given.									
60			When ready, resume HEFR by clicking menu bar 'HEFR' and choose 'Continue HEFR'.									
61					Frequency	Winter	Spring	Spring	Summer	Fall		
62			Overbank Pulses		2 per 3 years	6170	6170	6170	6170	6170		
63				Tier1	1 per 2 seasons	5450	1180	5830	1730	1930		
64				Tier2	1 per season	2290	206	2210	424	570		
65			High Flow Pulses	Tier3	2 per season	420		343	91	147		
66				Tier4								
67				Tier5								
68				Examples	2 per 3 years	24800	24800	24800	24800			
69					5 per 5 years	21000	21000	21000	21000	To create a regression period of more than one season, enter identical values in adjacent seasons.		
70					10 per 5 seasons	12000	12000					
71					15 per 5 seasons	5000	5000					
72					5 per 5 seasons			3000	3000			

Figure 5.8: Step 2 input requirements are indicated by the blue cells, F62:K67 and i54. Cells F57:G58 allow the user to select whether results from the log-log or quadratic regressions are displayed in the output table.

The "significance level" may be adjusted by the user, and functions as a boundary width for the prediction interval developed as the log-log and quadratic regressions are computed for the observed data. The High Flow Pulse tiers are potentially analogous to the wet/average/dry characterization employed by the Original, percentile-based method in that the selected frequencies/flows become those whose characteristic volumes and durations are presented as output in the "FlwMtxMnthUS" and "FlwMtxSssnUS" tabs.

Because the algorithms of HEFR use familiar statistical concepts, the actual meanings of which are relevant to ascertaining whether resultant flow recommendations are likely to support a sound ecological environment, they are presented in this discussion. Furthermore, the BBEST subcommittee has expressed an interest to better understand the meaning of all aspects of the flow separation and episodic event analysis process. In order to create a coherent process which can then be deployed by users in the Trinity/San Jacinto and other basins of Texas, it seems necessary to understand the function, assumptions, accuracy, and limitations of the process and computational algorithms. It is as simple as acknowledging what we are deliberately choosing to neglect, the rationale for the decision, and the consequences/implications for the resultant product.

Conceptually in the HEFR methodology, the user examines the flow-frequency plot to correlate desired ecological flow rates and frequencies with events observed in the historical record on an annual and seasonal basis (Figure 5.7). Presumably desirable ecological flows should correlate well with actual prior events, in that if a flow has ecologic benefit then it should have occurred (such that the ecology has been served by it). HEFR regresses the data using log-log and quadratic fitting, and develops prediction intervals (not equivalent to confidence intervals) based on the user-input "significance level." A prediction interval is distinct from a confidence interval: the more familiar concept of confidence interval tells us that, for example, there is a 68% chance that the average value of all future events will fall within the confidence bounds. Prediction intervals are by definition much wider than confidence intervals and tell us that, for example, based on all observed events there is a 68% chance that the next observed event will fall within the prediction bounds. The default significance value of 68.3 corresponds to the percentage of data that falls within +/- one standard deviation from the mean for normally distributed data.

The user can view plots of regression curves in the 'Tier/Period' tabs generated when the user commands "Continue HEFR". The R-squared and Standard Error of Estimate values do not plot on the graphs, but can be found in columns "EI" and "ER" on each tab containing four regression plots (i.e. T1P1, T1P2, etc). These 'goodness of fit' parameters indicate how well the plotted lines and prediction intervals include the observed data, which implies that a future observation (having the volume and duration presented in the output table) has a 68% chance of occurring.

The user will notice on the flow-volume and flow-duration plots that observed data is clustered in one region and is increasingly scattered as flow increases. This is inherent in the nature of recorded flow data—the highest magnitude events (outlying events) are observed/occur less often. Because the prediction lines are designed to fit around ALL of the observed HFP and OBP data, the range of values for volume and duration for any given discharge is relatively wide. Consequently for flows on the low end (and often also on the high end), the prediction range is within the negative region when using a quadratic regression form. Because it is physically not possible for volume or duration to be negative, the value output to the flow matrix is substituted with "N/A". Alternately, the user may select to display log-log results in the table simply to force a non-negative (non-"N/A") output. The user will observe that while by selecting the log-log regression, one is able to avoid a negative ("N/A") volume or duration result; however, as the peak flow increases, the range of possible volumes and durations increases dramatically.

The HEFR guidance documentation suggests that users should "carefully consider the…fit of the regression (particularly in the vicinity of desired Q_p values)". For example if biological overlay data suggest that a spring peak flow of 5,000 cfs should occur twice per season (perhaps input as tier 1 in the "Charts_Freq" tab), assuming the default season for spring, the user should examine the Q-V and Q-D plots for the appropriate tier and period tab (e.g. T1P2). The examination would include viewing the observed data in the 5,000 cfs range to see how well it fits within the prediction lines. The HEFR guidance further suggests that this evaluation might lead to an iterative process and multiple HEFR runs. Since the program uses the same

regressions when using the same input file, there are four options for how the user can produce different results within HEFR: (1) adjust the seasonal assignment, (2) use/adjust the high flow pulse multipeaks multiplier, and/or (3) use/adjust the overbank flows multipeaks multiplier. The adjustment of the significance parameter might be considered to be a fourth option.

The HEFR manual contains guidance and cautions, highlights that there is “a potential need to evaluate the data using other means that better characterize the relationships,” and suggests potential alternate computational processes such as piecewise regression that might be developed to improve results.

The HEFR methodology was designed to enable users to target key peak flows at specific recurrence intervals and through analysis of observed events, associate an appropriate volume and duration for future events. The method relies on biological overlay data to produce appropriate output, and because the output produced relies upon a single regression fit to an entire widely-varying data set it is difficult for the user to assess whether the resultant flow volumes and duration are reasonable; if not, why not and how to appropriately adjust; and ultimately whether their implementation would support a sound ecological environment. The user can run multiple scenarios for any gage or flow record, and compare many different sets of plots and flow matrices, but it having multiple sets of results may not empower the user to make any scientifically based assertion about relative merit of one result over another.

In the interim, users may also find it helpful to run HEFR using the Original, percentile-based method to view non-parametric results. While there is little guidance on how to determine whether the 75th percentile peak flow and/or volume and/or duration might be better than the 85th percentile volume, the output may be used to quickly provide a feeling for the magnitude of a given percentile storm.

6. Detailed Studies

6.1 Pre-Impact Analyses

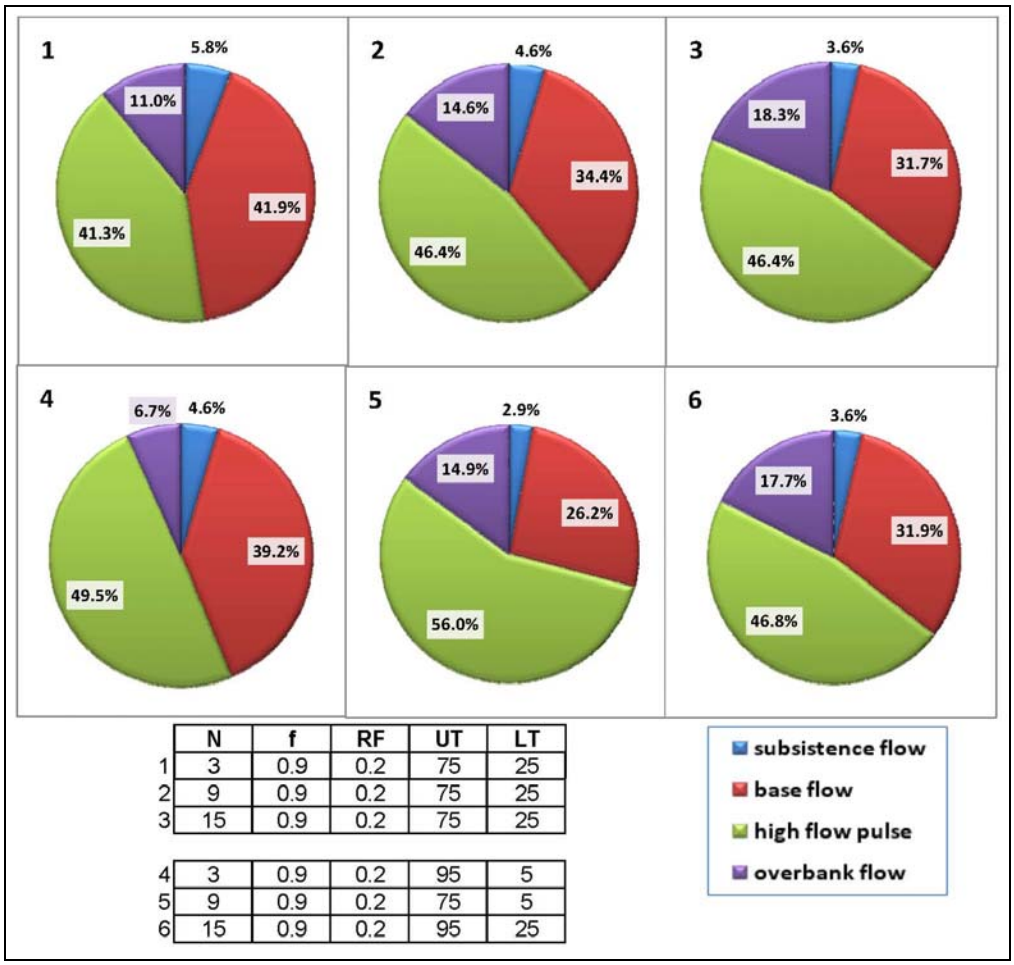
A relatively detailed process was employed in the separation of flows at Conroe and Oakwood, in order to investigate:

- The effect of systematic parameter adjustment on flow separation results;
- How 'goodness of fit' can be evaluated, ideally by quantitative means;
- The extent to which parameterization can be generalized, both into patterns of a hydrograph which point toward adjustment of a specific parameter, and in applicability of the parameterization of one gage to different record periods at the same gage or to other gages within the basin;
- Quantitative metrics and evaluation tools that might facilitate efficiency within the flow separation task;
- The extent to which correlations between flow separation results affect results of the episodic event analysis; and,
- The components of a step-wise pathway for flow separation within the context of the ongoing work of SB3: numerous gages in several different/unique basins need to be consistently and efficiently studied by multiple individuals and entities. (See section 7.)

There are many facets revealed in such an investigation and, due to time and resource constraints, the ability to conduct the adequate testing and assessment required to fully synthesize conclusions was limited. The best hope is that ideas, hypotheses, and recommendations for future study can be adequately documented so that others may discuss and wisely select items for further pursuit.

6.1.1 West Fork of San Jacinto near Conroe

The MBFIT pre-processor was used to separate flows for the pre-impact gage record at Conroe. The default parameters were run in conjunction with parameters systematically adjusted to isolate the effects of each modification.



	N	f	RF	UT	LT
1	3	0.9	0.2	75	25
2	9	0.9	0.2	75	25
3	15	0.9	0.2	75	25
4	3	0.9	0.2	95	5
5	9	0.9	0.2	75	5
6	15	0.9	0.2	95	25

Figure 6.1: A series of parameter adjustments was evaluated to demonstrate the effect on results. MBFIT runs 1-3 (Conroe pre-impact) use the same parameters while varying the length of the N-day window, while from top-to-bottom (i.e. run 1 and 4, run 2 & 5, run 3 & 6) the "N", "f", and "RF" are consistent while Upper and Lower Thresholds are modified.

The pie charts shown in Figure 6.1 facilitate relatively expedient observations of many different relationships. For example, with the exception of the HFP count for N=9 and N=15, changing the N-day window (runs 1-3) affects each flow category: the number of subsistence flow days decreases dramatically (if there were 100 subsistence flow days in run 1, there are only 63 days in run 3—a 38% decrease). The overall number of overbank + high flow pulse days also increases significantly with change in N. For this gage record, lowering the Lower Threshold does (as may be intuitive) increase the number of HFP days in run 5 as compared to run 3, while results are not so sensitive to the increase of the Upper Threshold (runs 3 vs. 6). Widening the interval between Upper and Lower Thresholds (run 1 vs. run 4) has the effect of increasing the number of HFPs and decreasing the number in all other categories. Conclusions about the effect of parameters drawn from this particular case study cannot be generalized with confidence due to the limited number of tests and ultimately because of the very different behavior of the hydrograph at different locations and in response to unique types of hydrologic alterations.

Summary tables may also prove useful, especially when quantitative effects on flow rates within categories within a run are of interest.

Table 6.1: Summary of flow results for parameterization test runs. Numerical flow results may be useful in calibrating the pre-processor, for example by evaluating the 75th percentile baseflow versus 25th percentile high flow pulse in conjunction with impressions from the plotted hydrograph (e.g. see run 3-5).

MBFIT Parameter Test Runs - Conroe 1940-72

	N	f	RF	UT	LT
1	3	0.9	0.2	75	25
2	9	0.9	0.2	75	25
3	15	0.9	0.2	75	25
4	3	0.9	0.2	95	5
5	9	0.9	0.2	75	5
6	15	0.9	0.2	95	25

		COUNT	PROPORTION	MIN	25TH %	MEDIAN	75TH %	MAX	PROPORTION
1	subsistence flow	702	5.8%	0	8.8	9.3	10	11	47.7%
	base flow	5048	41.9%	12	23	29	57	213	
	high flow pulse	4976	41.3%	27	84	134	364	5510	52.3%
	overbank flow	1328	11.0%	28	438	806	2902.5	92900	
2	subsistence flow	554	4.6%	0	8.4	9	9.7	10	39.0%
	base flow	4151	34.4%	11	20	24	45	213	
	high flow pulse	5591	46.4%	27	70	109	295	5510	61.0%
	overbank flow	1758	14.6%	27	255	451	1920	92900	
3	subsistence flow	434	3.6%	0	8.2	8.5	9.2	9.7	35.3%
	base flow	3819	31.7%	9.8	18	22	35	213	
	high flow pulse	5593	46.4%	27	65	99	260	5510	64.7%
	overbank flow	2208	18.3%	27	200	342	1500	92900	
4	subsistence flow	554	4.6%	0	8.4	9	9.7	10	43.8%
	base flow	4725	39.2%	11	26	36	73	1890	
	high flow pulse	5968	49.5%	11	67	114	368	5510	56.2%
	overbank flow	807	6.7%	16	585.2	1420	4525	92900	
5	subsistence flow	353	2.9%	0	7.9	8.4	8.8	9.3	29.1%
	base flow	3159	26.2%	9.4	22	29	55	213	
	high flow pulse	6746	56.0%	11	49	80	223	5510	70.9%
	overbank flow	1796	14.9%	16	245	438	1850	92900	
6	subsistence flow	434	3.6%	0	8.2	8.5	9.2	9.7	35.5%
	base flow	3848	31.9%	9.8	18	22	36	342	
	high flow pulse	5644	46.8%	27	66	100	272.25	5510	64.5%
	overbank flow	2128	17.7%	27	191.45	339	1500	92900	

Qualitative evaluation by the user (described further below) is in every case required for the assessment of what threshold achieves the desired outcome. This requires that the user has both an understanding of both the functional role of each flow category AND how these data are aggregated and analyzed in HEFR.

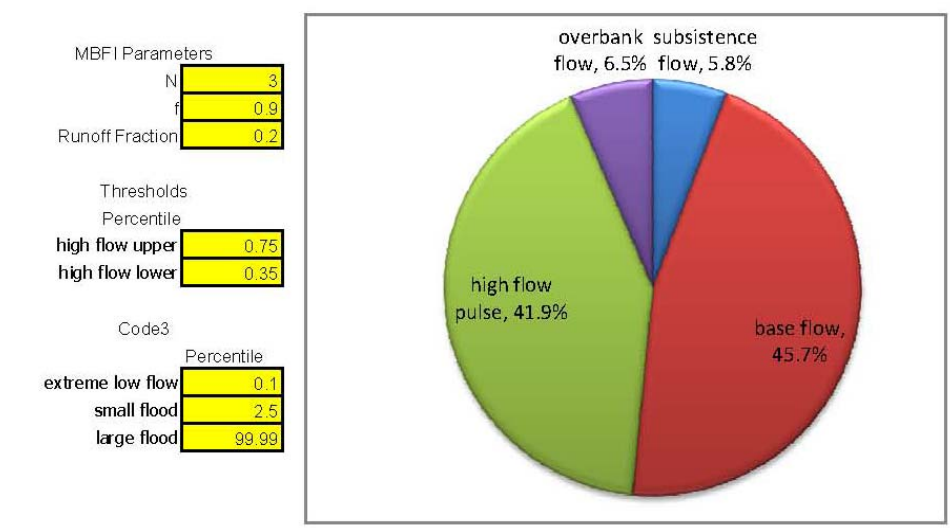
One very relevant conclusion that can be drawn from this set of 6 runs is that changing N, f, UT, or LT affects the allocation of flows to each category such that results of episodic event analysis are also affected. That is, the sum of days and thus the population classified as *generally high flow/pulse-dominated* (high flow population$_1$ = HFP_1 + OBP_1) is different, the change does not occur exclusively within the 2 subpopulations (i.e. $HFP_1 + OBP_1 \neq HFP_2 + OBP_2$).This is significant because the function of HEFR is to characterize episodes of events, and if the

generally high flow population changes, the results of event volume and duration will also be affected.

In conjunction with the overview assessment demonstrated with pie charts (with which the user can ask such questions as “do I believe that this relative distribution of baseflow days could be realistic?), the user can benefit from detailed examination of graphical results, including a plot of the full record and shorter (easier-to-read) time increments.

It also seems that after some experience with many different gages, a user will develop a feel for how to select parameters based on the shape of the observed hydrograph. For example, if a hydrograph tends to be very peak-y, contain multiple sequential peaks, or seems to exhibit a pattern of large storms that tend to have a HFP→OBP→HFP rhythms (perhaps also implied by the contributing basin/tributary relationships and characteristics), a user might intuitively adjust some parameter(s) if they desire certainty that these pulses will be characterized as separate events in HEFR.

The calibrated parameters for the Conroe pre-impact period, from 1940-1972 are shown within Figure 6.2. The final parameters were selected by comparing a series of results from 22 MBFIT runs. The process included compiling summary statistics (as shown in Table 6.1) and plotting the full hydrograph as shown in Figures 6.3 and 6.4 for 10 select runs.



	COUNT	PROPORTION	MIN	25TH %	MEDIAN	75TH %	MAX	PROPORTION
subsistence flow	702	5.8%	0	8.8	9.3	10	11	51.6%
base flow	5514	45.7%	12	24	30	54.75	213	
high flow pulse	5056	41.9%	38	109	185	532.5	9900	48.4%
overbank flow	782	6.5%	39	425	820.5	3257.5	92900	

Figure 6.2: Parameters for Calibrated MBFIT run (Conroe, pre-impact).

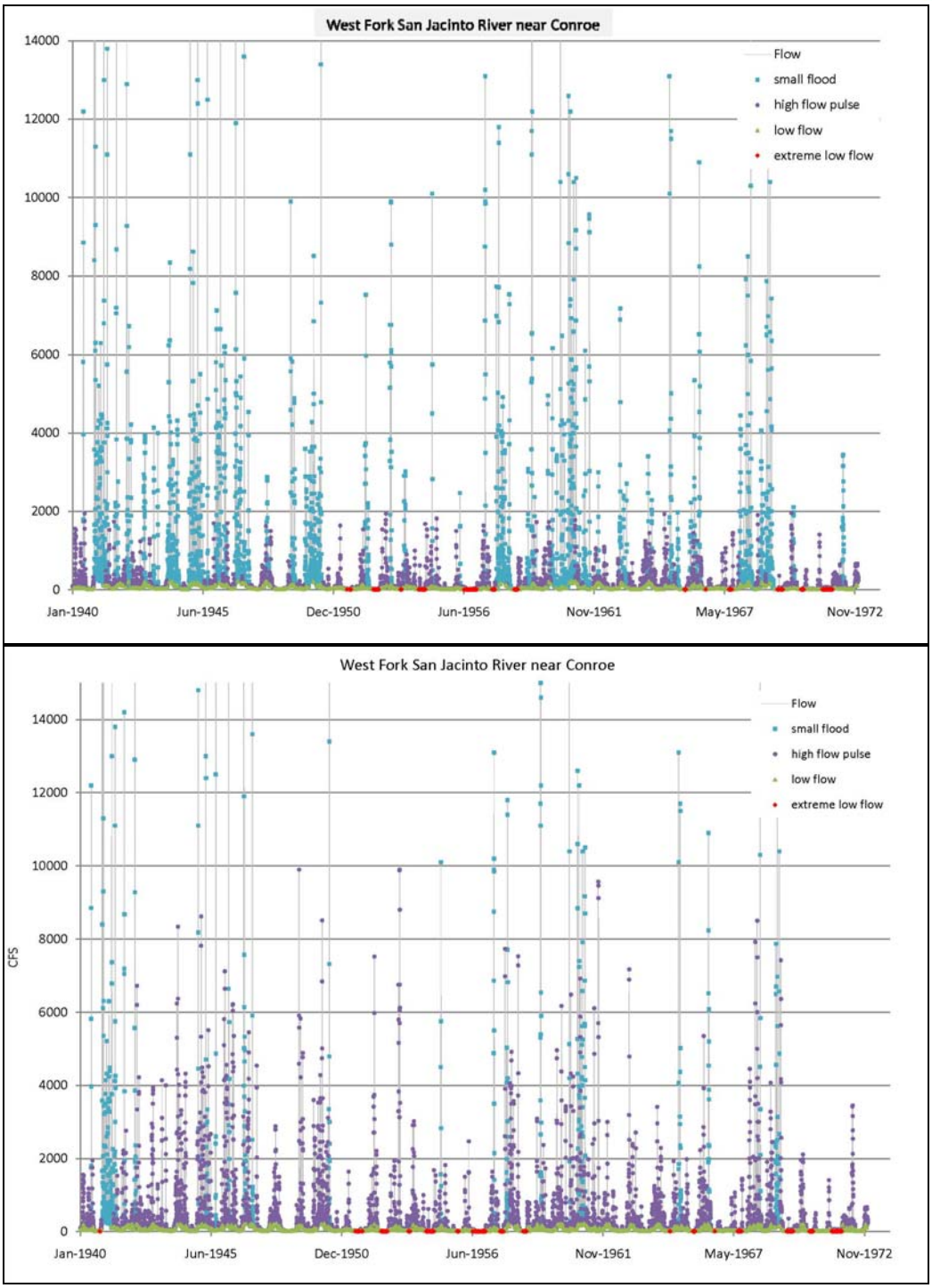


Figure 6.3: Results of the full hydrograph with flow categories displayed are helpful to view in conjunction with the corresponding pie chart so that the user can correlate the parameterization with the relative distribution in each flow category and the shape of the hydrograph. Easily visible at this scale is the approximate flow threshold for overbank events. In the hydrograph above, we see that high flow pulses seem to generally peak below 2,000 cfs, whereas the 1.5-2 year flow at Conroe was determined to be on the order of 6,100-9,600 cfs. The plot of full-record results is also helpful for examining the frequency and distribution of subsistence ('extreme low') flows. The upper plot uses the default MBFIT parameters with N=3; the lower plot correspond with the final parameters for Conroe 1940-1972 (see Figure 6.2).

The user can view the full-record plot in conjunction with pie charts to determine how to modify parameters to move toward a preliminary fit. More detailed plots (smaller time scale) are more suited to final parameterization of the flow separation model due to resolution.

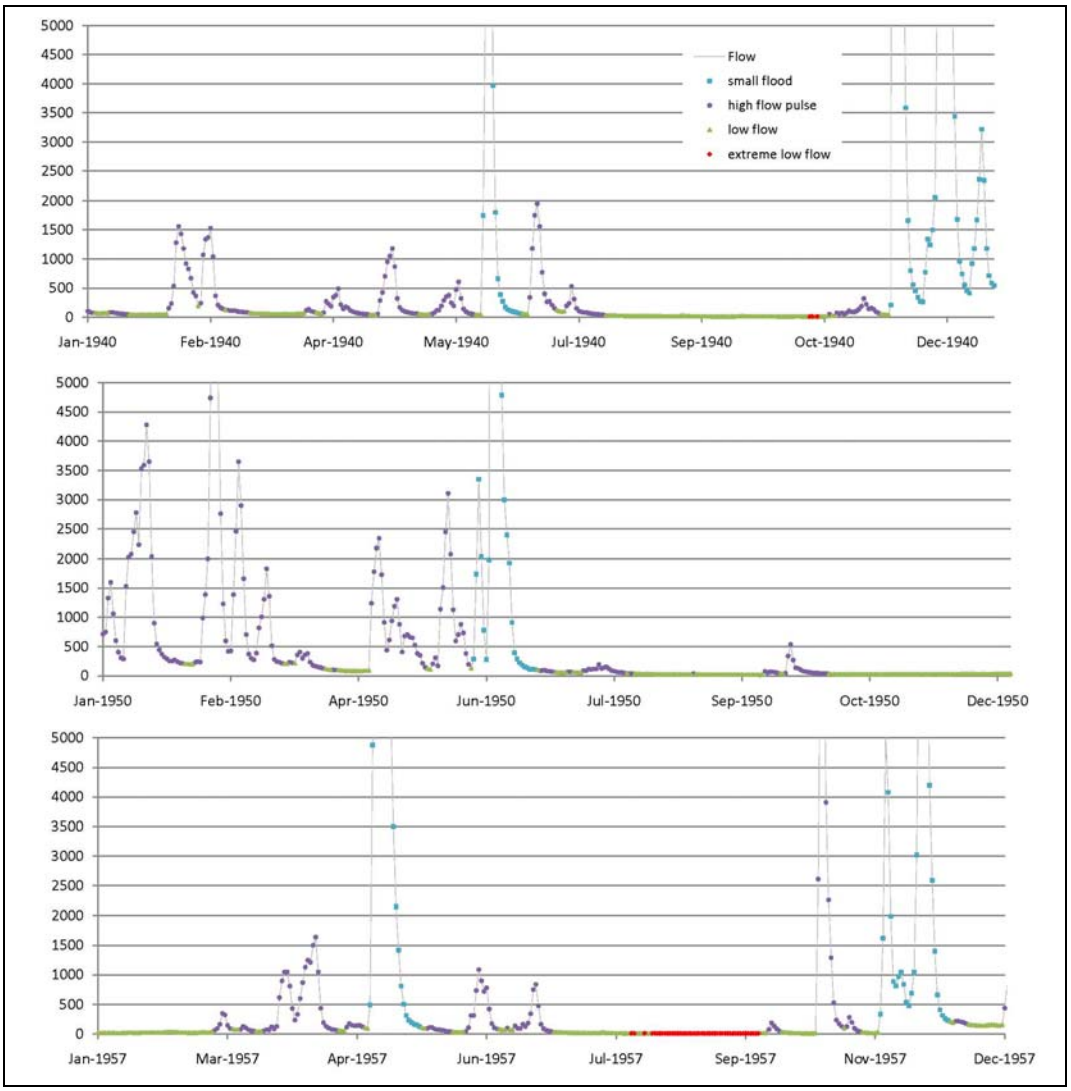


Figure 6.4: Goodness of fit is more easily evaluated at a smaller time scale. One can observe that while there is room for improvement, in general, flows are appropriately classified according to their functional category.

The extent to which the Conroe calibration experience can be used as an analogue for other gages remains inconclusive. Ultimately, because only a very limited number of runs could be pursued, there is insufficient information to support any conclusion about whether the patterns exhibited by the Conroe pre-impact parameter modifications can be appropriately applied even to other periods of the Conroe record, not to mention any other gages. However, automated tools could be developed which would (1) allow future users to more quickly conduct pre-processor parameterization, and (2) allow future detailed study to determine the extent to which generalizations can be made so that both future users and future evaluators of model results

can begin with *a posteriori* expectations. No current conditions or full record runs of Conroe were conducted.

The HEFR model was run using the Alternative, frequency-based method default setting. As discussed in Section 5.3, it is intended that the user have specific knowledge of key peak flow rates (and seasonal relationships) to select the parameters which generate the output flow matrix. “Calibration” of parameters in HEFR includes assignment of seasons (discussed in Section 6.2), option to use the multi-peaks multiplier for high- and overbank-flows, selection of the percentile value of subsistence flows which will be output for each month/season, option to include a 7Q2 or other subsistence flow threshold which becomes the lowest possible flow value in the flow matrix displayed regardless of lower results which may be computed in HEFR.

Based on the investigation of HEFR as explained in Section 5.3 and because no biological overlay data was available, no calibration was attempted, and none of the output provided in this report should be interpreted as useful flow recommendations. As noted in Section 5, there is significant uncertainty in the regression analyses conducted by HEFR, which make it extremely difficult to use the tool as currently programmed to actually formulate defensible recommendations. To some extent this can easily be remedied through improved regression analyses which would allow more rational correlation with observed data and well-known physical constraints. It is very important that users understand the algorithms employed by HEFR in order appropriately interpret output, especially the range and uncertainty of estimates.

6.1.2 Trinity River near Oakwood

The process for separating flows at Oakwood was similar to that conducted for Conroe, and details are not repeated in this section in the interest of discussing new information, including the use of HEFR.

The Oakwood pre-impact record was parameterized initially using IHA. When a suitable parameter set was found, an attempt was made to apply a parameter set which was similar to an MBFIT run of the same flow record.

Resultant allocations of flows to each category was nevertheless, markedly different[9], as show in Figure 6.7.

[9] It is important to distinguish that in this context, “markedly different” refers to the 5.8% difference in the number of days classified as high flow versus low flow. The Oakwood record has a total of 15018 days, so the population of high flows which will be considered in HEFR’s episodic event characterization would be different by 871 days (2.4 years).

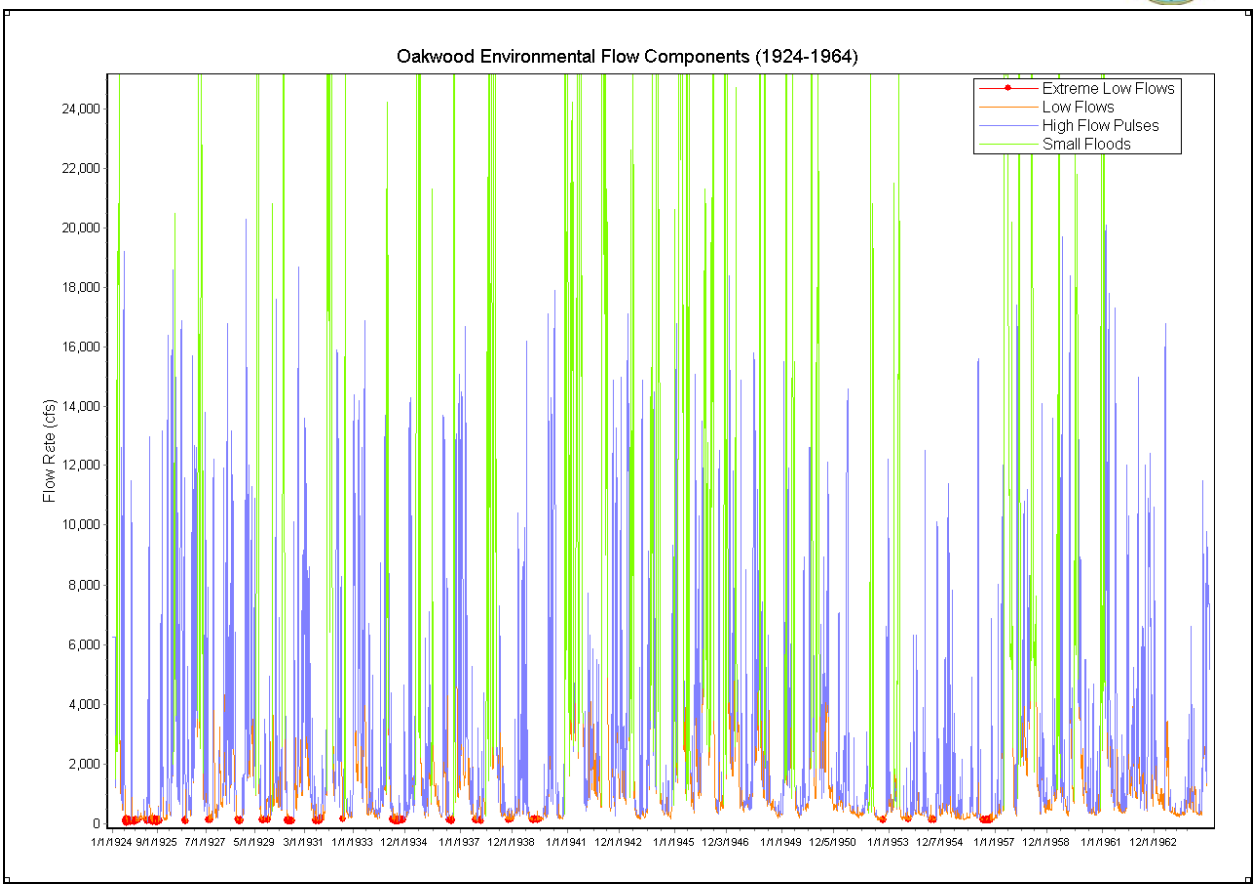


Figure 6.5: EFC plot for parameterized IHA run of Oakwood, pre-impact.

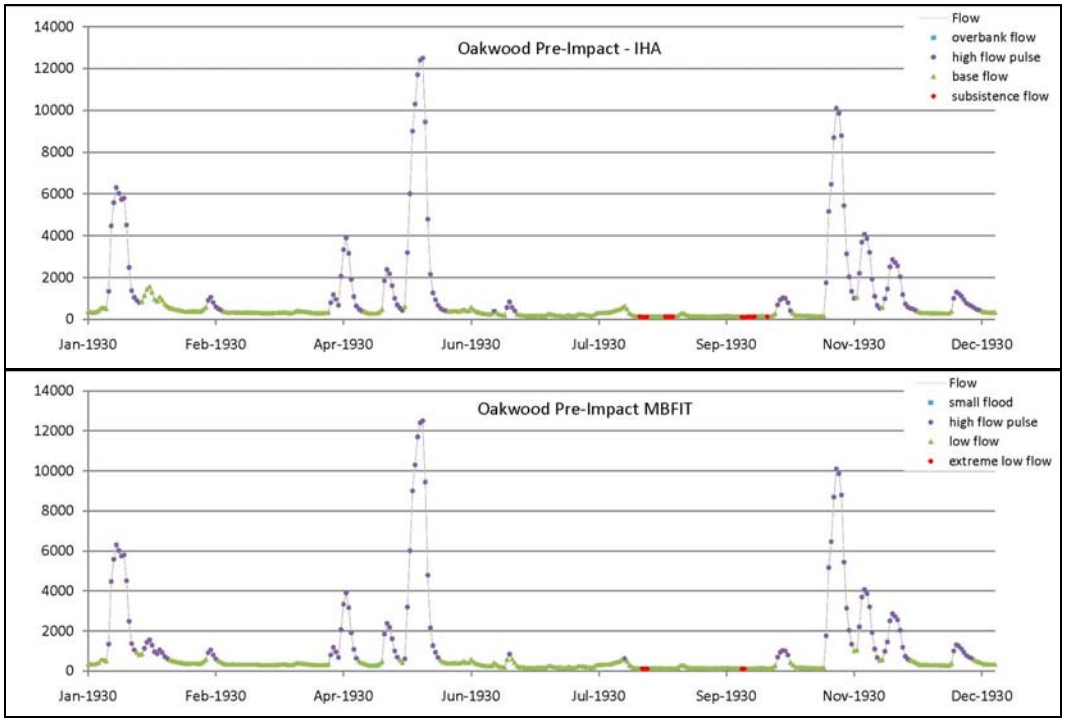


Figure 6.6: Comparison of results for 1930 from parameterized IHA (above), and MBFIT (below).

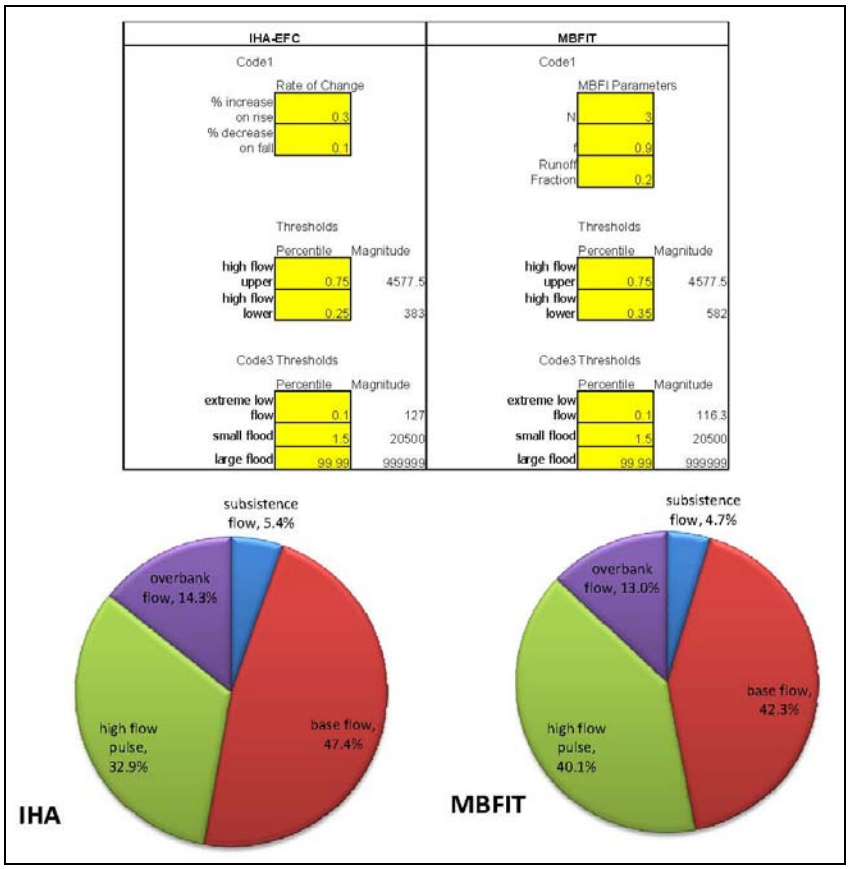


Figure 6.7: IHA and MBFIT parameters developed for Oakwood, pre-impact, and resultant pie charts showing relative distribution of daily flow values to each category.

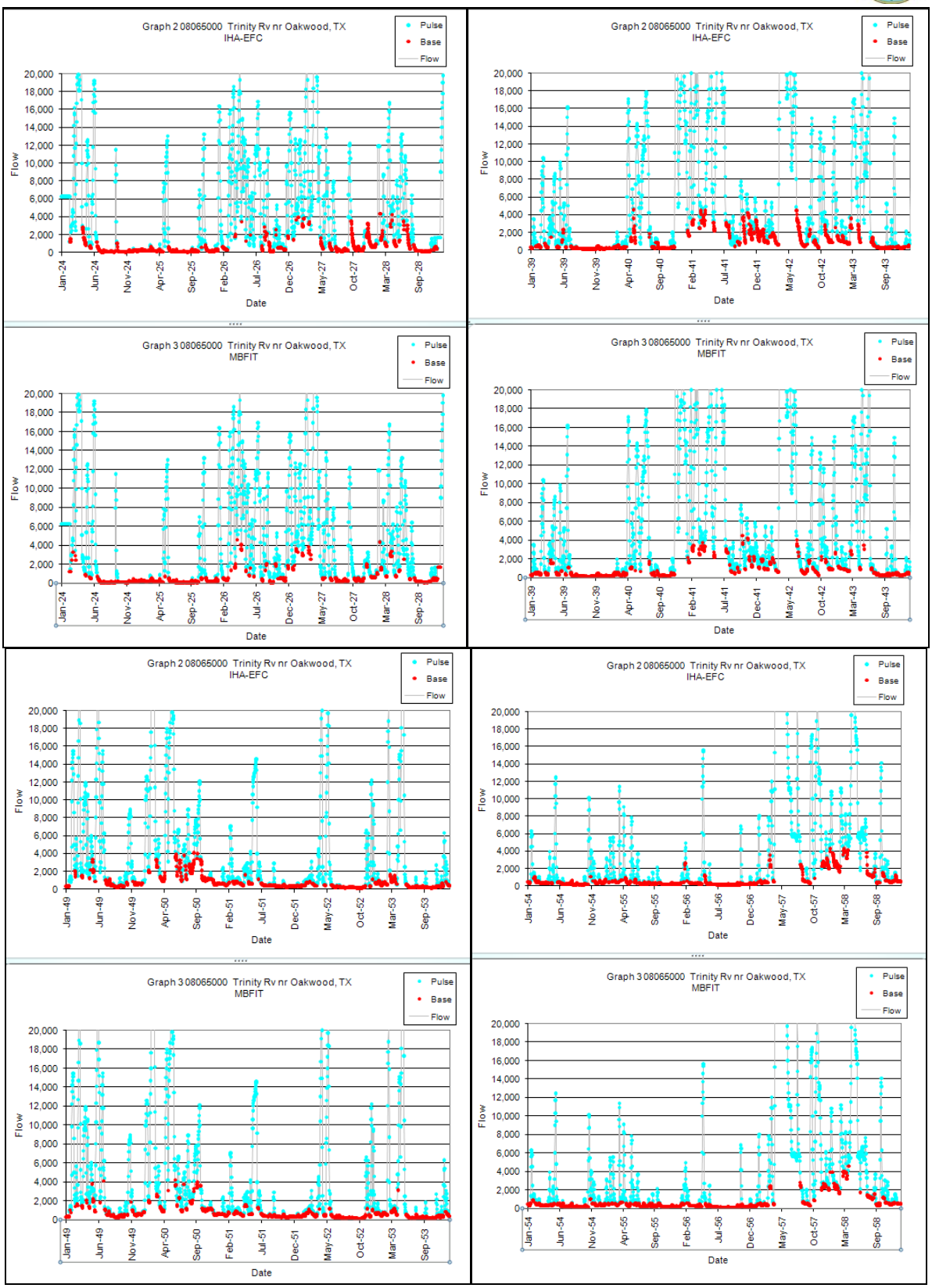


Figure 6.8: MBFIT (+IHA) comparison plots for parameterized Oakwood, pre-impact.

Overbank Flows	Return Period (R) : 1.5 (years)		Duration (D) : 33 (days)	
	Volume (V) : 1048979 (ac-ft)		Peak Flow (Q) : 29200 (cfs)	
High Flow Pulses	F: 1	F: 1	F: 2	F: 1
	D: 13	D: 15	D: 11	D: 12
	Q: 10300	Q: 10300	Q: 5320	Q: 5313
	V: 170242	V: 164351	V: 58765	V: 54068
	F: 2	F: 2	F: 2	F: 3
	D: 8	D: 9	D: 6	D: 7
	Q: 3860	Q: 5350	Q: 2000	Q: 2170
	V: 42322	V: 63880	V: 15747	V: 20361
	F: 4	F: 3	F: 3	F: 4
	D: 5	D: 5	D: 4	D: 5
	Q: 1320	Q: 2480	Q: 956	Q: 952
	V: 12120	V: 17614	V: 6443	V: 7340
Base Flows (cfs)	1355	1770	816	585
	599	914	418	340
	319	473	246	224
Subsistence Flows (cfs)	112	92	86	96

Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Winter			Spring			Summer			Fall		

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D* = Duration (days)
	Q = Peak Flows (cfs)
	V* = Volume (ac-ft)

* This characteristic not included in HFP frequency

Overbank Flows	Return Period (R) : 1.4 (years)		Duration (D) : 27 (days)	
	Volume (V) : 885065 (ac-ft)		Peak Flow (Q) : 28700 (cfs)	
High Flow Pulses	F: 2	F: 2	F: 2	F: 2
	D: 12	D: 13	D: 10	D: 11
	Q: 6535	Q: 8620	Q: 4283	Q: 4800
	V: 81739	V: 114874	V: 44658	V: 53088
	F: 3	F: 3	F: 3	F: 3
	D: 7	D: 8	D: 6	D: 6
	Q: 2835	Q: 3720	Q: 1935	Q: 2000
	V: 25469	V: 37060	V: 17203	V: 18621
	F: 4	F: 5	F: 5	F: 4
	D: 4	D: 4	D: 3	D: 4
	Q: 1248	Q: 1665	Q: 839	Q: 947
	V: 7780	V: 12850	V: 5602	V: 6156
Base Flows (cfs)	1000	1535	542	473
	481	686	368	316
	305	368	218	202
Subsistence Flows (cfs)	105	92	80	86

Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Winter			Spring			Summer			Fall		

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D* = Duration (days)
	Q = Peak Flows (cfs)
	V* = Volume (ac-ft)

* This characteristic not included in HFP frequency

Figure 6.9: Comparison of Oakwood pre-impact HEFR results for IHA-generated input (above) and MBFIT-generated input (below). The flow matrix output using the Original, percentile-based method shows results developed from non-parametric statistics rather than recurrence interval-based computations. In general, one can observe differences, but the exact reasons and relative 'goodness' of one result over another remain elusive.

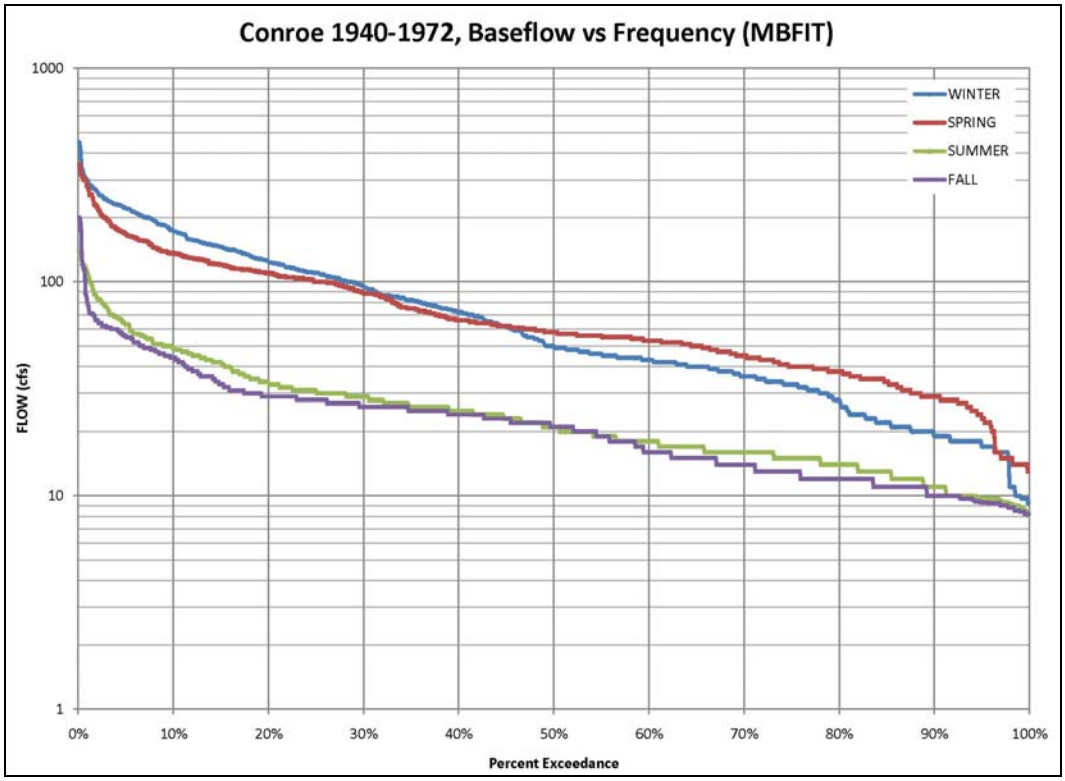
6.2 Low Flows and Seasonality

Baseflow and subsistence flow are the two components of low or "baseflow-dominated" flow. Each daily flow value is classified by the pre-processor, and for low flows, this assignment is not changed by HEFR operations.

A significant challenge for the user is the logical evaluation of thresholds which are used to determine the output for "wet, average, dry" conditions. The default parameters are 75th, 50th, and 25th percentile flow, respectively. Several ideas are presented for how this question might be explored, however it seems that no conclusive, physically-based rational can be interpreted, or further exploration would be needed in order to do so.

Perhaps the center of mass or moment of inertia statistics[10] could provide insight, however this would require assumption of a distribution for the data. There may be validity in use of parametric statistics, since a sufficient number of observations/realizations should exhibit characteristics of the normal distribution.

Various figures are displayed below with descriptions of how they might provide perspective about baseflow or seasonality.



[10] The applicability of the Central Limit Theorem has not been investigated, which might permit use of the normal distribution and mean, standard deviation, coefficient of variation, etc. (i.e. the '1st, 2nd, and 3rd moments').

Figure 6.10: The flow-duration curve shows some tail behavior on the high end of flows, which is caused to an unknown extent by one-day duration baseflows that are sometimes used in flow classification to distinguish multiple peaks for high flow events. These 'high outliers' could easily be filtered out with an algorithm to seek isolated single-day baseflows, or baseflows above a given threshold.

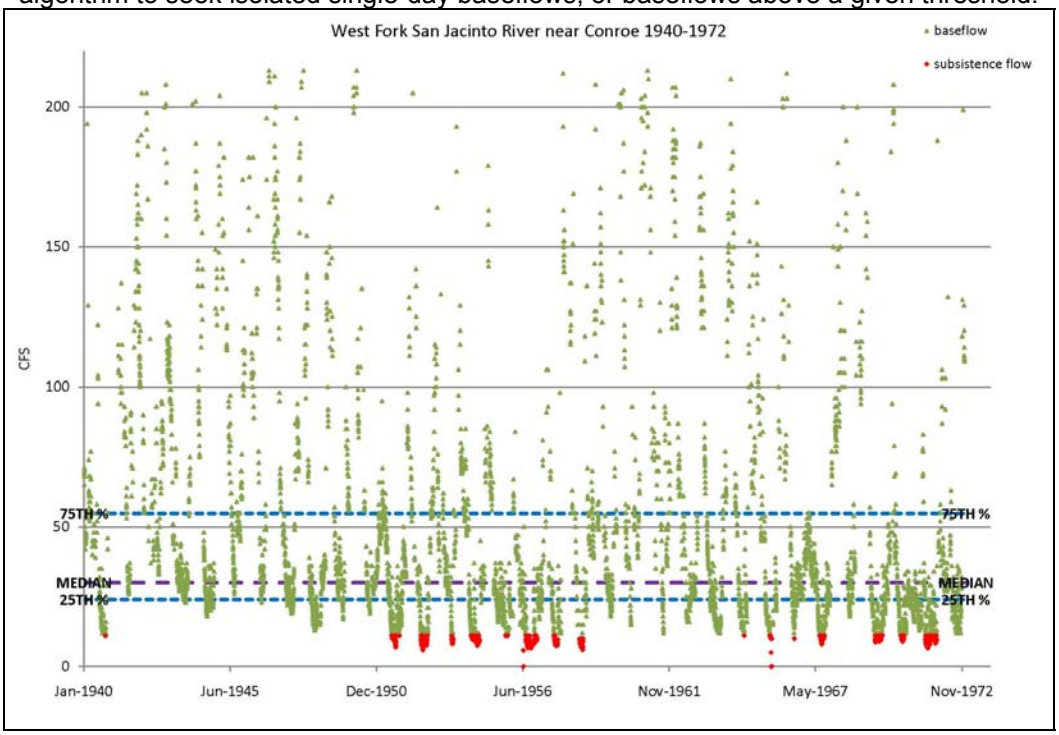


Figure 6.11: The hydrograph with only low flow points plotted is interesting, but does not yield conclusive results. There are various statistical tests which could be applied to determine whether these data are normally distributed. The standard moments might then provide useful insight (e.g. standard deviation, coefficient of variation, etc.)

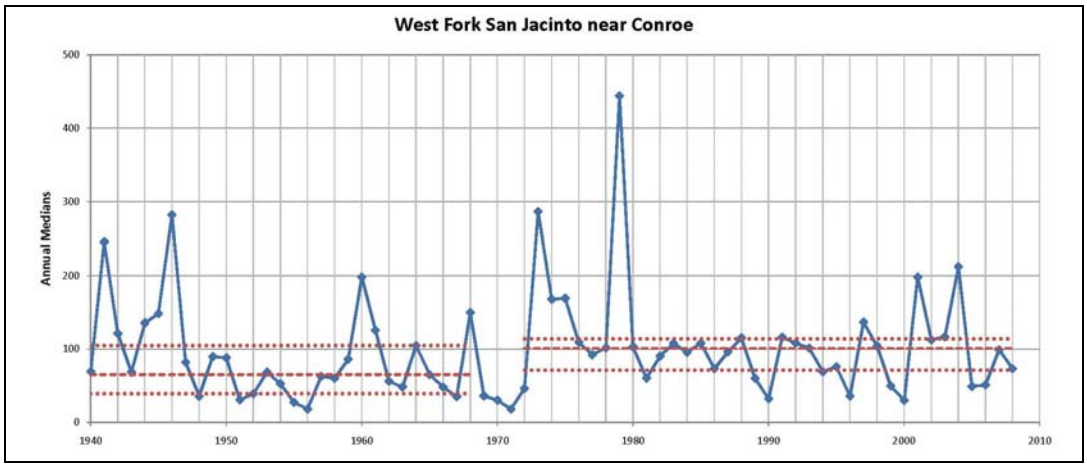


Figure 6.12: Another test for baseflow thresholds, seasonality, or inter-annual patterns might involve classifying entire years as wet, average, or dry based upon the median or some other characteristic. This is aligned with our intuitive sense of relative wetness, dryness, and average conditions—that some years are particularly wet or dry (however this is not necessarily the intended meaning within the TIFP). The red dotted lines represent the 75th, 50th, and 25th percentile of the data for pre-impact and current conditions. The number of events above, below, or within an assigned window may correspond to cyclic behavior, or could be compared with behavior at other gages in the basin.

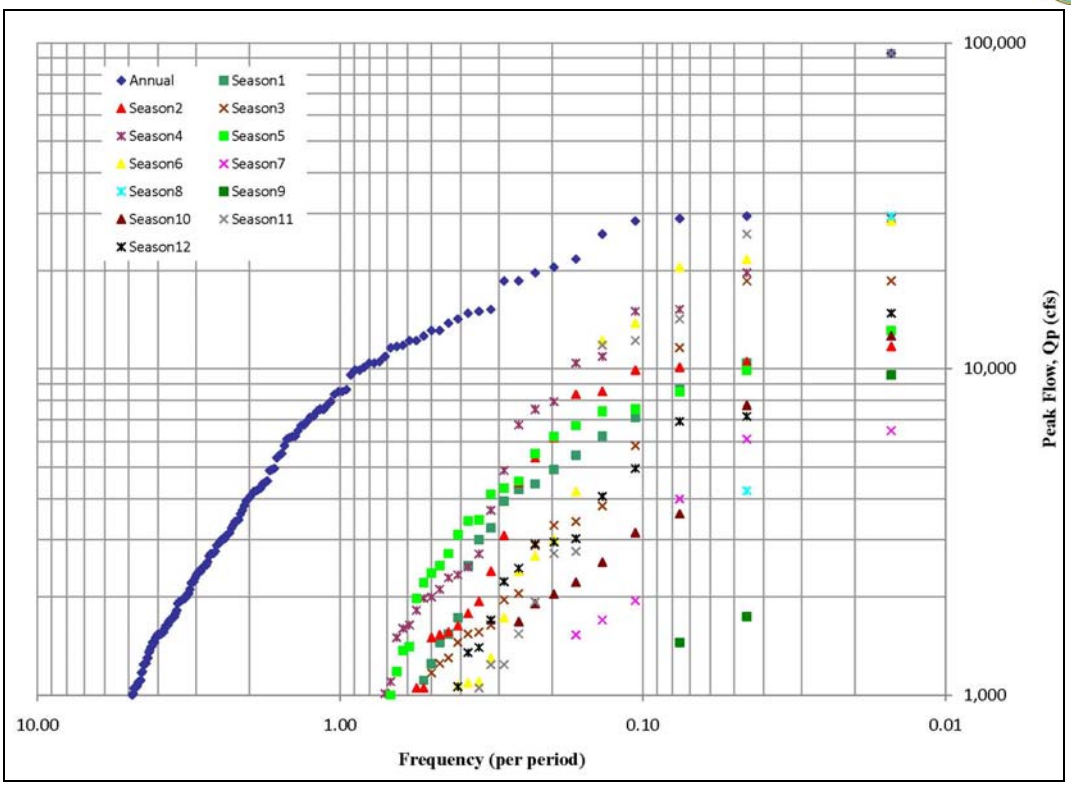


Figure 6.13: HEFR Alternative, frequency-based method run for Conroe, pre-impact, with 12 monthly seasons. The relative frequency of events per month may be insightful in making seasonal assignments/correlations. For example it appears that there were only 3 observed high flow events in Season {month} 9, September, and 2 in August.

The assignment of subsistence flows is made in both MBFIT and IHA by applying a user-input threshold (default = 10th percentile) to the entire record. HEFR then outputs the seasonal or monthly flow rate based on a user-input threshold (default = 50th percentile) for all flows classified as subsistence.

Consequently, there are often records which produce flow matrix output indicating that there is no subsistence threshold for a given month or season. This indicates that when using the full record, the lowest (effectively) 5th percentile flow does not ever occur in a specific month(s).

To some extent this seems counter-intuitive. If the ecosystem evolved under conditions that included flows consistently above the lowest 10th percentile, then perhaps the lowest flows within each month should be the more appropriate record used to assign subsistence flows.

A test was run, whereby the lowest 3rd percentile of each month was reclassified as subsistence flow, and the median (default) value taken from the revised “daily_efcs” file.

Overbank Flows	Return Period (R) : 2.4 (years)		Duration (D) : 24 (days)	
	Volume (V) : 134131 (ac-ft)		Peak Flow (Q) : 14000 (cfs)	
High Flow Pulses	F: 2	F: 2	F: 2	F: 2
	D: 14	D: 14	D: 11	D: 10
	Q: 1438	Q: 1500	Q: 266	Q: 509
	V: 14529	V: 12824	V: 2820	V: 4211
	F: 3	F: 4	F: 3	F: 3
	D: 8	D: 8	D: 5	D: 6
	Q: 329	Q: 284	Q: 89	Q: 143
	V: 2655	V: 2652	V: 691	V: 1135
	F: 5	F: 5	F: 4	F: 5
	D: 4	D: 4	D: 2	D: 2
	Q: 103	Q: 98	Q: 49	Q: 64
	V: 763	V: 562	V: 186	V: 269
Base Flows (cfs)	104	104	32	31
	50	60	24	24
	33	40	17	16
Subsistence Flows (cfs)	10	N/A	10	10
	Dec, Jan, Feb (Winter)	Mar, Apr, May (Spring)	Jun, Jul, Aug (Summer)	Sep, Oct, Nov (Fall)

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D* = Duration (days)
	Q = Peak Flows (cfs)
	V* = Volume (ac-ft)

* This characteristic not included in HFP frequency calculations

Overbank Flows	Return Period (R) : 2.4 (years)		Duration (D) : 24 (days)	
	Volume (V) : 134131 (ac-ft)		Peak Flow (Q) : 14000 (cfs)	
High Flow Pulses	F: 2	F: 2	F: 2	F: 2
	D: 14	D: 14	D: 11	D: 10
	Q: 1438	Q: 1500	Q: 266	Q: 509
	V: 14529	V: 12824	V: 2820	V: 4211
	F: 3	F: 4	F: 3	F: 3
	D: 8	D: 8	D: 5	D: 6
	Q: 329	Q: 284	Q: 89	Q: 143
	V: 2655	V: 2652	V: 691	V: 1135
	F: 5	F: 5	F: 4	F: 5
	D: 4	D: 4	D: 2	D: 2
	Q: 103	Q: 98	Q: 49	Q: 64
	V: 763	V: 562	V: 186	V: 269
Base Flows (cfs)	110	110	32	31
	55	66	25	24
	36	47	18	16
Subsistence Flows (cfs)	18	22	10	10
	Dec, Jan, Feb (Winter)	Mar, Apr, May (Spring)	Jun, Jul, Aug (Summer)	Sep, Oct, Nov (Fall)

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D* = Duration (days)
	Q = Peak Flows (cfs)
	V* = Volume (ac-ft)

* This characteristic not included in HFP frequency calculations

Figure 6.14: Above are the HEFR original, percentile-based method results for Conroe, pre-impact, using the default subsistence methodology. Below are subsistence flow results when the HEFR input file is adjusted such that the lowest 3% of flows for all e.g. January flows are assigned as subsistence flows, and HEFR takes the median value for output.

Overbank Flows	Return Period (R) : 1.5 (years)		Duration (D) : 33 (days)	
	Volume (V) : 1048979 (ac-ft)		Peak Flow (Q) : 29200 (cfs)	
High Flow Pulses	F: 1	F: 1	F: 2	F: 1
	D: 13	D: 15	D: 11	D: 12
	Q: 10300	Q: 10300	Q: 5320	Q: 5313
	V: 170242	V: 164351	V: 58765	V: 54068
	F: 2	F: 2	F: 2	F: 3
	D: 8	D: 9	D: 6	D: 7
	Q: 3860	Q: 5350	Q: 2000	Q: 2170
	V: 42322	V: 63880	V: 15747	V: 20361
	F: 4	F: 3	F: 3	F: 4
	D: 5	D: 5	D: 4	D: 5
	Q: 1320	Q: 2480	Q: 956	Q: 952
	V: 12120	V: 17614	V: 6443	V: 7340
Base Flows (cfs)	1355	1770	816	585
	599	914	418	340
	319	473	246	224
Subsistence Flows (cfs)	112	92	86	96

Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Winter			Spring			Summer			Fall		

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D* = Duration (days)
	Q = Peak Flows (cfs)
	V* = Volume (ac-ft)

* This characteristic not included in HFP frequency

Overbank Flows	Return Period (R) : 1.5 (years)		Duration (D) : 33 (days)	
	Volume (V) : 1048979 (ac-ft)		Peak Flow (Q) : 29200 (cfs)	
High Flow Pulses	F: 1	F: 1	F: 2	F: 1
	D: 13	D: 15	D: 11	D: 12
	Q: 10300	Q: 10300	Q: 5320	Q: 5313
	V: 170242	V: 164351	V: 58765	V: 54068
	F: 2	F: 2	F: 2	F: 3
	D: 8	D: 9	D: 6	D: 7
	Q: 3860	Q: 5350	Q: 2000	Q: 2170
	V: 42322	V: 63880	V: 15747	V: 20361
	F: 4	F: 3	F: 3	F: 4
	D: 5	D: 5	D: 4	D: 5
	Q: 1320	Q: 2480	Q: 956	Q: 952
	V: 12120	V: 17614	V: 6443	V: 7340
Base Flows (cfs)	1420	1850	816	585
	640	1000	423	340
	340	574	252	224
Subsistence Flows (cfs)	157	220	92	96

Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Winter			Spring			Summer			Fall		

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D* = Duration (days)
	Q = Peak Flows (cfs)
	V* = Volume (ac-ft)

* This characteristic not included in HFP frequency

Figure 6.15: Similar to Figure 6.14 above, the Oakwood flow separation assignments were adjusted to ensure that subsistence flows were assigned to each month. The subsistence flows shown in the flow matrix below are the 1.5th percentile values for each month. Note also that the baseflow values are affected by the reassignment of subsistence flows. This is true in the Alternative, frequency-based method as well.

7. The Pathway Forward

The process of developing instream flow recommendations includes:

- the study and selection of flow gage locations;
- assimilation of biological overlay data and synthesis into selection of targets (species, flows, etc.) for incorporation into the hydrologic analysis;
- understanding of implementation and water resource management strategies; and,
- involvement of stakeholders to ensure that socio-economic-ecologic objectives are prioritized (Poff et al, 2009).

These elements are beyond the scope of this project, and the discussion which follows is limited to a process for taking a study of previously-selected gages though to flow recommendations.

While timelines mandated in SB3 are extremely aggressive, the importance of developing a rational and defensible procedure for hydrologic analysis at *this time*, before an abundance of other work is prosecuted, cannot be overstated. Because of the severe time limitations, it should be apparent to all that simplifying assumptions must be made, approximate methods will be employed, and uncertainty will be higher than that of better-resourced (time, budget) deployment. It may be of benefit to all participants to have the opportunity to more specifically understand what assumptions and approximations were made, why, and what the implications might be, so that all can be engaged in a discussion of acceptable risk, consequences, and implications. The level of effort employed in analysis should always be proportional to the level of risk which is acceptable (and which is inherent in the uncertainty of simplifying assumptions). Open discussion of the realities and imperfections can help create alignment toward a common goal because all reasonable people understand this truth—our ability to fully comprehend and act will always be imperfect.

The scope of work for this project was perhaps too broad for the resources allocated (time, budget); nevertheless the clarification of scope priorities and resultant focus on where we go from here should prove extremely useful. While there were some fundamental questions that could not be answered, such as whether MBFIT or IHA will be used as the pre-processor, there is value in identifying key questions and suggesting how they might be resolved.

A pathway for engaging the hydrologic analysis is discussed in four parts:

A. Pre-processing of available data to support parameterization of flow separation and episodic event analysis.
B. The evaluation and parameterization of each gage record in the flow separation process.
C. The evaluation and parameterization of each gage record in HEFR.
D. Application and incorporation of biological overlay data.

The information in this section is synthesized from experience with procedures described in previous sections, and is intended to present key synopses rather than reiterate each step in detail. Discussion of uncertainties, limitations, and possibilities are included within the discussion below, and it is intended that the ideas presented may stimulate productive conversation within the Expert Science Team so that hopefully the few ideas which may have merit in the context of overall BBEST objectives and constraints, can be pursued.

A. Pre-Processing of Available Data to Support Parameterization

Gage/Site Selection – Site selection within a basin should consider gages with similar lengths of record to facilitate comparisons between sites and reduce statistical variation caused by droughts and wet periods.

Determination of Pre-Impact and Current Condition Record Periods – A number of methods can be utilized to identify the pre-impact and current conditions. These can include:

- Checking of return flows compared to the 7-day annual low flows to identify minimally impacted periods and to avoid periods where return flows change rapidly
- Comparing the annual naturalized flows to gage flows to verify approximate pre-impact conditions
- Using PeakFQ by splitting the peak flow record in half and comparing the early and later periods for significant change, considering potential changes in urbanization or other land use change
- Performing basinwide rainfall analyses to identify wet and dry periods in order to check selected period for applicability, without the variability of impoundments, return flows and urbanization that could have impacted the gage record.
- Utilizing IHA statistics and plots for the two period analysis in order to:
    - Identify if the pre-impact and current condition records are different
    - Select periods with relatively consistent periods throughout

  Some of the key analyses from IHA are plots of 7-day low flow, High Flow Pulse peak, 30-day maximum, the monthly comparison of periods along with the statistics table. Examples of the High Flow Pulse plots for Oakwood and Conroe are shown in Figures 7.1 and 7.2.

Return Flow and 7-Day Low Flows – Return flows and 7-day annual low flow from gage records can be utilized to further consider the non-stationary nature of the return flows in the historical record. Sufficient return flow and gage information is available to identify the timing and general magnitude in the change in low flows. This information can be used to select data sets that are representative of consistent return flows, and evaluate results from HEFR and other programs.

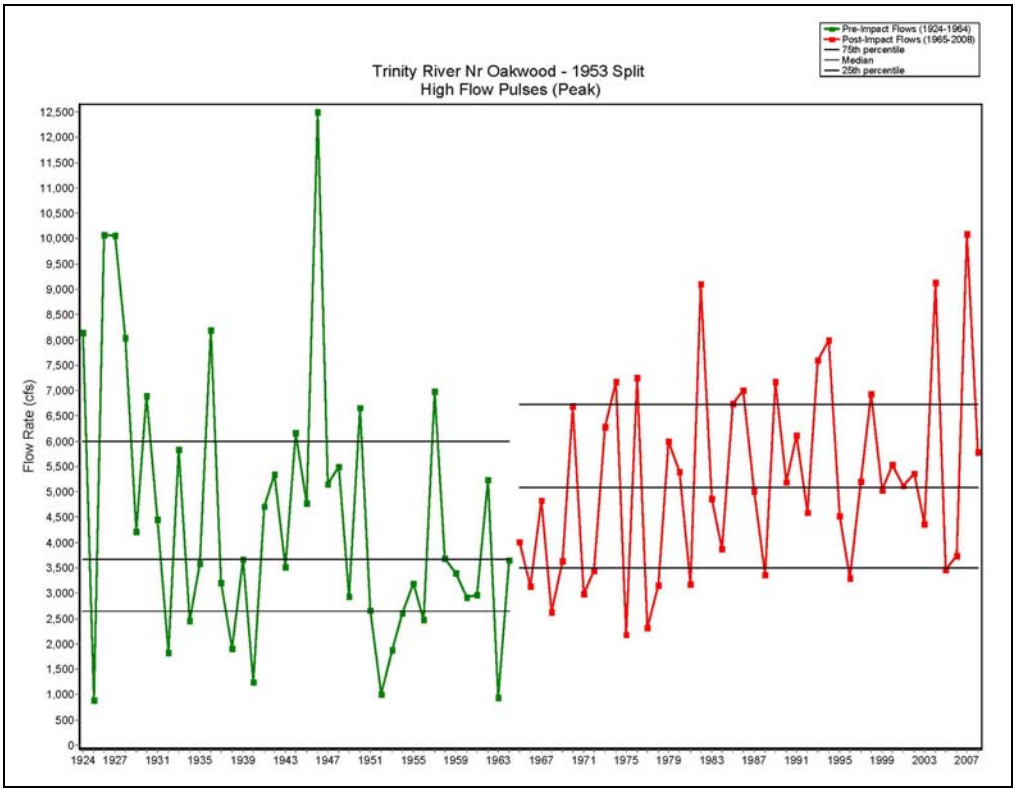


Figure 7.1: Oakwood flow alteration plot from IHA.

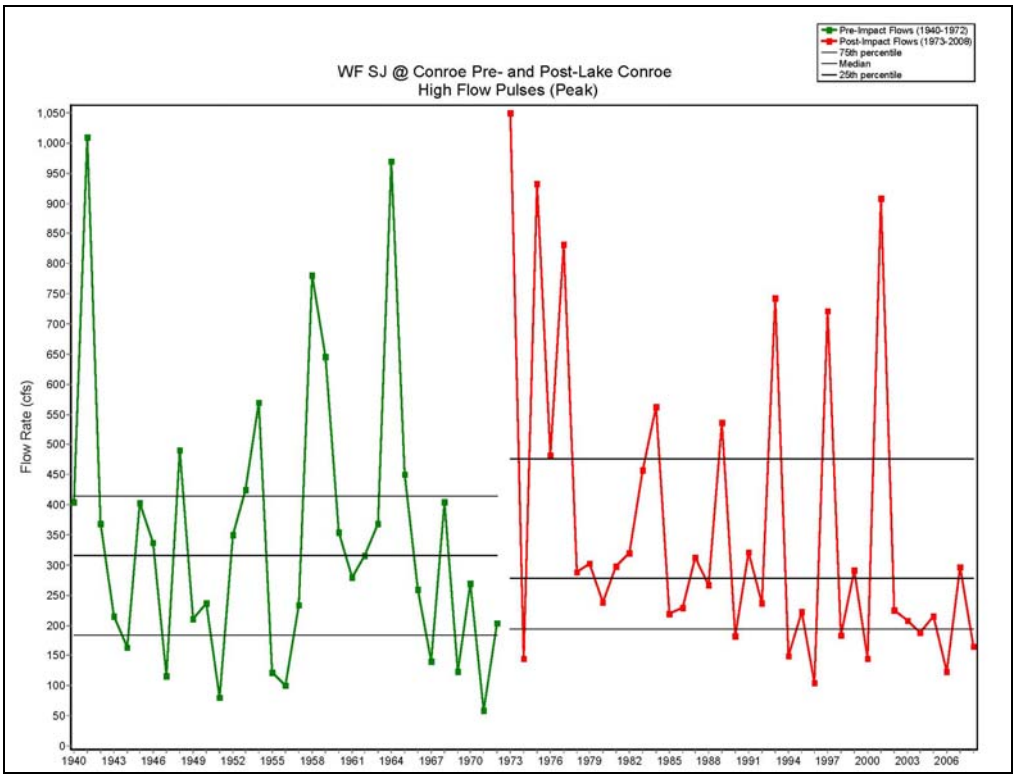


Figure 7.2: Conroe flow alteration plot from IHA.

Peak Flows – Peak flow analysis appears to be one way to identify impacts from urbanization, and also for nearby reservoir impacts. These results can also be used as a general check on the selection of small flow values, although different data sets and statistical analyses limit potential for a direct input.

Overbank Flows – As described in section 4.5, some additional information can be developed from NWS flood warning information and the USGS rating curves. This information, in combination with the peak flow statistics, can be used to refine estimates of overbank flow related to small floods. Due to the complexity of flood warnings and the uncertainty of bank full occurrence based on the rating curve, some additional refinement may be needed, such as topographic review of the floodplain and/or modeling of the 1.5-year or 2-year flows with available floodplain models.

B. Flow Separation

Based on evaluation of MBFIT and IHA, the following points are offered:

1. *Appropriate categorization of flows is predicated on user understanding of the algorithms employed both in the pre-processor and post-processor in conjunction with the functional classifications utilized by the Texas Instream Flow Program. Summary documentation highlighting the key information may be useful if this work is to be conducted by multiple parties.* (On one hand it is extremely beneficial to increase the knowledge pool with fresh minds and on the other it may be exceedingly resource-intensive to constantly employ new users because these methodologies do not lie within the rubric we know as the *standard* of practice, but rather forge the limits of the state of knowledge.)

2. *There are tools useful to determination of 'goodness of fit' when tuning the parameters of flow separation algorithms which are readily available. These could be codified within a procedure with information about their use.* A summary of possible assessment tools are is provided below.

Tool	Assessment Function
IHA EFC plot (IHA; Fig 5.3, 6.5)	"High level" look at flow separation results, including apparent threshold for overbank flow, maximum values for baseflow and whether highflow pulses are separated, relative position (on timeline) and frequency of subsistence flows.
IHA vs MBFIT plots (MBFIT; Fig 5.4, Fig 6.8)	"High level" comparison of relative distribution of generally high-flow/pulseflow-dominated vs. generally low-flow/baseflow-dominated days.
IHA 90-day maximum/minimum flows	Examination of relative wetness/dryness which

	may facilitate selection of percentile thresholds.

3. *Develop supplementary tools to make qualitative user evaluation more efficient, in order to allow users to establish increasingly appropriate parameters*. The fundamental question of whether IHA or MBFIT should more appropriately be used for separating flows into functional categories is difficult to answer because of the qualitative nature of the assessment and because of the process of evaluating many sets of results is extremely cumbersome and time-consuming. To some degree this is easily remedied through the development of automated tools which can rapidly generate summaries of key results and graphical output whose scale is tailored to the component being assessed.

Tool	Assessment Function
Excel spreadsheet which allows user to document multiple model runs with corresponding parameters and provides helpful summary information (e.g. counts, stats, pie charts).	Rapid iteration and ability to correlate effects of parameter modification.
Excel spreadsheet which allows user to graphically compare multiple hydrographs with flows color-coded by category.	Rapid iteration and ability to correlate effects of parameter modification.
Excel spreadsheet which allows user to graphically evaluate goodness of fit by smaller time increment, such as annum.	Fine-tuning assessment of 'goodness of fit' for final model parameterization.

4. *Conduct a study focused on determining whether IHA or MBFIT should be used as the exclusive pre-processor, or whether there are cases when one program performs significantly better than the other.* It is more efficient to have one study make such determination, using an appropriate distribution of gages, than to rely on users to evaluate this question on a case by case basis. Piecemeal evaluation does not provide consistency and expends copious resources for results of indeterminate caliber.

C. <u>Episodic Event Analysis</u>

Based on investigation of HEFR, the following steps and suggestions are proposed:

1. *Consider whether all important variables affecting the soundness of the ecological environment are incorporated in current methodology, and if not, state explicitly why this is deemed appropriate and how it affects uncertainty in the recommendations.* The rate of change of flow, for example, is often cited as a key variable of hydrology. The current

HEFR output includes the volume and duration that correspond to a user-selected peak flow. Just as characteristic volumes and durations are computed on an episodic basis, the rise and fall rates characteristic at a gage location might also be presented.

2. *Increase the user-friendliness of HEFR by ensuring that plots which the user is intended to evaluate provide key information and are presented at a helpful scale. There are additional plots that may be meaningful in evaluating the nature of the hydrograph on an aggregated or episodic basis, and which could be added to the computations/information synthesized by HEFR.* For example, if evaluation of regression plots is a key step in making a flow recommendation, they should be appropriately sized and provide key summary information (such as error, number of observations, etc.) Other plots that would be helpful in evaluating results of episodic analysis should also be automated, especially if this process is to be repeated hundreds of times (perhaps even for a single basin, such as the Trinity/San Jacinto with 13 gages x 3 record periods each = 39 runs if 0 iterations). It is also very difficult to assess the effect and reasonableness of the multi-peaks multiplier, or to determine how this parameter should be set/fit to data.

3. *Consider whether the biological overlay data requisite for employing the extant HEFR methodology will in fact be available within the needed timeframe*.
    a) *If so, there are refinements of functionality which would be helpful for episodic event analysis and computation/evaluation of seasonality. The quality and uncertainty of the available biological overlay data should be assessed so that additional helpful analysis tools can be incorporated into HEFR.* For example, if literature points toward the suggestion that a certain species requires some depth of flow during a given season, HEFR (or some other tool) could be adapted to make an approximation of the corresponding flow rate (with an associated uncertainty)
    b) *If not, an alternate methodology should be developed.* For example, when hydrologic information cannot be calibrated to biologic overlay data, the study focus could revert focus to characterizing the nature of the hydrograph using hypotheses (Poff et al, 2009). As in all circumstances, appropriate characterization of uncertainty is a key element.

4. *Key variables of interest with respect to biology could potentially be evaluated within HEFR so that flow recommendations could be further based upon observed historical events*. For example, as currently conceived, biological input would include flow rate and season. However this starting information could be further evaluated in HEFR *vis a vis* an exploration of how often and when this peak flow occurred. Likewise, if all that is known is that seasonal highflows trigger spawning of a key species, HEFR could be designed to output information on the nature of flows within that seasonal window. Basically the question is rephrased “provide information on how often, how much, or how long high flow pulses characteristically happen in spring” And the response (output) could be “there are typically 6 high flow pulses each spring, the total median volume of

spring high pulse flow is X, in spring the median high flow pulse duration is X days" This is similar to what HEFR already does, but rather than beginning with a recurrence interval and associated flow, the user could query based on a season and the entire subpopulation within it or present recommendations in another form (rather than 'once every 2 seasons the flow should be like this', return '75% of all spring seasons observed experience 6 or more high flow pulse events'.)

5. *It may be useful to update tools for evaluating seasonality, especially in order to facilitate determination of appropriate seasonal selection.* The current feature allows users to customize the allocation of seasons, up to 12 seasons of one month each. Given the lifespans of species which support the success of juvenile long-lived species, it may actually be appropriate to consideration seasonality on a monthly time scale during portions of the year. As an analysis tool, HEFR could be modified to allow selection of seasonal periods which overlap (e.g. 'spring 1' = [Mar-May], 'spring 2' = [April-May]), so that the user can more easily evaluate whether a given month or period is truly distinct.

6. *While the Alternative, frequency-based method represents significant improvement in analytical process relative to the Original, percentile-based method, based on the design intention (recurrence intervals versus non-parametric characterization), there is significant room for improvement of the regression analysis used to characterize high flow events*. The current methodology uses observed events in conjunction with either a single log-log or quadratic fitting equation applied to the entire high flow population. Because high magnitude events occur less frequently, a better fit could be achieved using, for example, piecewise regression. Furthermore, a suite of tests could be applied so that the user could quantitatively understand the goodness of fit in a meaningful way (such as those tests exemplified in Claps and Laio, 2003) rather than 'eyeballing'. Tests could include statistical relevance of sample size, bias, etc.

   While the R-squared and Standard Error of Estimate results are available for each fit, these descriptors to not provide a meaningful characterization if the user is powerless to improve the results and/or has little guidance on how to further refine a flow recommendation.

   The user is also asked to determine the significance interval, and it would be helpful to provide additional (computed) information so the user could evaluate the implications of their selection (and thus be equipped to make wise selections). For example, would there be a reason to select a 50% significance level? If it is desirable to narrow the (often wide) range of volume or duration in the flow matrix, a user could conceivably seek a significance interval from a range width and be provided the resultant increase in error.

7. *The functionality of subsistence calculations could be improved so that a real value for subsistence flow is returned for each month/season.* HEFR may currently return a value of "N/A" for subsistence flow (or baseflow), if no observations of such flow occurred within a given month or season. Furthermore, the recommended subsistence value may

be based upon a single observation. If, as discussed in Section 5.2.4, that a value of "N/A" defies intuitive knowledge, this computation could be improved by reassigning the subsistence flow classification based on a threshold percentile on a monthly or seasonal, rather than an annual basis. See Section 6.2 for further discussion.

Improving subsistence calculations (can be done exclusively in post-processing or pre-post-processing

8. *More tools could be provided for evaluating baseflow and the appropriate selection of threshold parameters*. It has been suggested that flow-duration curves plotted on a seasonal basis, or [baseflow] vs. [day observed] plotted on a seasonal or annual basis, may provide insight into the selection of threshold values. If such graphical displays seem useful, consideration should be given to automating their creation within HEFR. A determination should first be made (i.e. conduct study) about whether there is a meaningful, physically-based rational for expecting to observe correlations between, for example, flow exceedance and flow rate (i.e. a flow-duration curve). See Section 6.2 for additional discussion.

D. <u>Biological Overlay</u>

While biological overlay data which could be incorporated into model parameterization was not provided for use in this project, the methodology as it has been designed relies upon the application of key knowledge. Based upon the understanding gleaned from the literature combined with investigation of the hydrologic tools to be employed, the following thoughts are offered:

1. *Tables 4-7 from "The Essential Steps for Biological Overlays in Developing Senate Bill 3 Instream Flow Recommendations" (SAC, 2009c) provide the theory for how to step through incorporation of biologic information with hydrologic. The process outlined seems appropriate and useful if (1) the information is actually available, (2) if evaluation tools can be developed to supplement or refine existing tools so that users could actually answer the questions being posed, and (3) any evaluation tools needed to execute this process are reasonable and efficient for the user.* For example, Table 5 ("Biologic Input for the IHA Hydrographic Characterization") notes that while high flow pulse rise and fall rates should ensure that organisms are not washed downstream, they should perhaps be rapid enough to potentially serve as spawning cues. The thresholds of IHA and MBFIT do not actually operate in this manner. Rather, their operation (colloquially) is to say, 'the rise must be at least this rapid to trigger a high flow pulse categorization'. It seems that a separate tool may be needed in order to assure appropriate rates of rise?

2. *Because the methodology developed for HEFR relies heavily on the availability of specific types of biologic overlay data, it should be determined (as soon as possible) what information will realistically be available so that the hydrologic analysis process can*

be tailored to accommodate this reality. As studies (SB2) are completed they can be incorporated into the hydrology process and/or hydrologic analysis tools can be adapted.

3. *Studies are needed in order to assess whether and how pre-impact, current conditions, or the full record should be used as the basis for hydrologic analysis and flow recommendations, based on significant species and the conditions that they are adapted to* (Poff et al, 2009).

It may be helpful to separate a few components of this work into more tractable (albeit incredibly complex) questions such as:

- How will these flow recommendations be implemented? (This may affect what information is needed and focus study and development of tools.)

- What are the characteristics of the pre-impact hydrograph, which is presumed to support a 'sound ecological environment'?

- How will we know when we have achieved success?

In summary, the pathway forward should include specific detail studies and improvements in functionality that can enable users to rationally and defensibly develop recommendations for flows that are sufficiently characterized and can be expected to support a sound ecological environment, within some quantifiable or explicit bounds of uncertainty. The Expert Science Team should carefully consider the possibilities and limitations of specific detail study in relation to (1) the need for information in order to keep moving forward, (2) the anticipated conclusiveness or ability to find resolution to the question being investigated.

8. HEFR Flow Matrices

As a product of this study, preliminary flow matrices were developed for all 13 gages for pre-impact, current conditions, and the full record. These flows should absolutely not be taken as recommendations, as the focus of this study was on conceptually and contextually understanding the pre- and post-processing algorithms employed by MBFIT, IHA, and HEFR. The necessary model parameterization was not completed for each gage, and no biological overlay information was applied in the production of these flow values.

A study of possible pre-processor parameters was conducted for the Oakwood and Conroe gages; however this work was inadequate to support even a preliminary recommendation because:

1. The time available for executing this project was too limited to allow for the necessary evaluation of goodness of fit for the hydrographic flow separation for Conroe and Oakwood. No evaluation of flow separation results was made for any other gages, and likewise no gage-specific parameterization was conducted.

2. Flow recurrence intervals in the episodic event analysis were not determined using any input from biological overlay, a requisite step for appropriate selection which then allows for regression results to be evaluated for goodness of fit. In the absence of specific biological, geomorphological, or other guidance, recurrence intervals were selected to provide a range of frequencies and magnitudes. Identical frequencies were used for each flow matrix presented.

3. The evaluation of seasonal behavior was limited at best, and was not conducted for each gage for pre-impact, current conditions, or full record.

4. No evaluation of current conditions was pursued—the extent of this study was limited to pre-impact conditions for the Oakwood and Conroe.

5. A key hydrologic variable, rate of change of flow, was not considered in this study outside of thresholds used in flow separation and consequently no guidance/recommendations are provided. It is believed that this is an essential component of flow that supports a sound ecological environment.

6. The default methodology for subsistence flow was utilized, which may contradict intuitive knowledge that (1) there could be a flow which is so low in any given month that organisms would not be able to recover, and (2) the historical pre-impact hydrograph should necessarily contain information about these minima. See Section 6.2 and Figures 6.14-15.

7. Based on available information and methodology, there is an inability to adequately establish suitable thresholds or to ascertain whether a baseflow is wet, dry, or average.

Only the Conroe and Oakwood flow separation parameters were refined, and even for these two gages, the episodic event selection and computation was not adequately evaluated due to lack of time and information which could possibly lead to a rational, defensible conclusion for pre-impact flows. Furthermore it is unknown whether pre-impact, current, or full record results would provide the most suitable recommendation and this question should be explored in general and on a case-by-case basis.

9. Summary and Conclusions

The Basin and Bay Expert Science Team has ambitious goals and is working under an aggressive timeline. The intent of this project was to contribute to that work by examining the pre- and post-processing tools used/developed for studies being conducted under Senate Bill 3, using 13 gages within the Trinity/San Jacinto Basin. The pre-impact period and current conditions were separated from the full record using available information such as Water Availability Modeling studies and features available in the Indicators of Hydrologic Alterations (IHA) software, and the impact and non-stationary nature of return flows was explored. There are several useful quantitative methods for establishing appropriate pre-impact and current conditions periods of record.

The IHA and MBFIT flow-separation software was examined using two gages: the Trinity at Oakwood and the West Fork of San Jacinto near Conroe. The pre-impact record was separated through a model parameterization process, and the results were input to HEFR for episodic event analysis. Significant consideration was given to the questions of how goodness of fit can be evaluated and whether one pre-processor could be conclusively considered to have overarching merit. The algorithms of IHA, MBFIT, and HEFR were assessed and explanations of their routines provided.

Ultimately, due to limited project resources, no conclusive statements about can be offered about whether IHA over MBFIT will perform better for any given hydrograph. However this study provided valuable opportunity for proliferation of ideas on how process and programmatic challenges can be addressed to promote the success of the entire effort being prosecuted by the Expert Science Team, and explanations which highlight the operations and algorithms employed by each software tool, along with limitations and suggestions for improvement. Furthermore, results that are provided may enable the reader to synthesize hypotheses or conclusions which can be tested.

Specific suggestions have been offered which should provide useful and tractable decision points and enable forward movement on the hydrologic analysis and development of flow recommendations. These can be found in Section 7, “The Pathway Forward.”

As a byproduct of this work, a series of HEFR output was developed (flow matrices). These outputs should absolutely not be construed as flow recommendations! Please refer to Section 8 for further detail.

While the challenges of developing environmental flow recommendations that can support a ‘sound ecological environment’ are many, the Scientific Advisory Committee and Expert Science Teams have demonstrated enormous dedication to the task. This project supports that trajectory by providing explanation and assessment of modeling tools in the context of SB 3 goals and an evaluation of how well-suited the tools and processes being employed seem to be for accomplishing their intended function.

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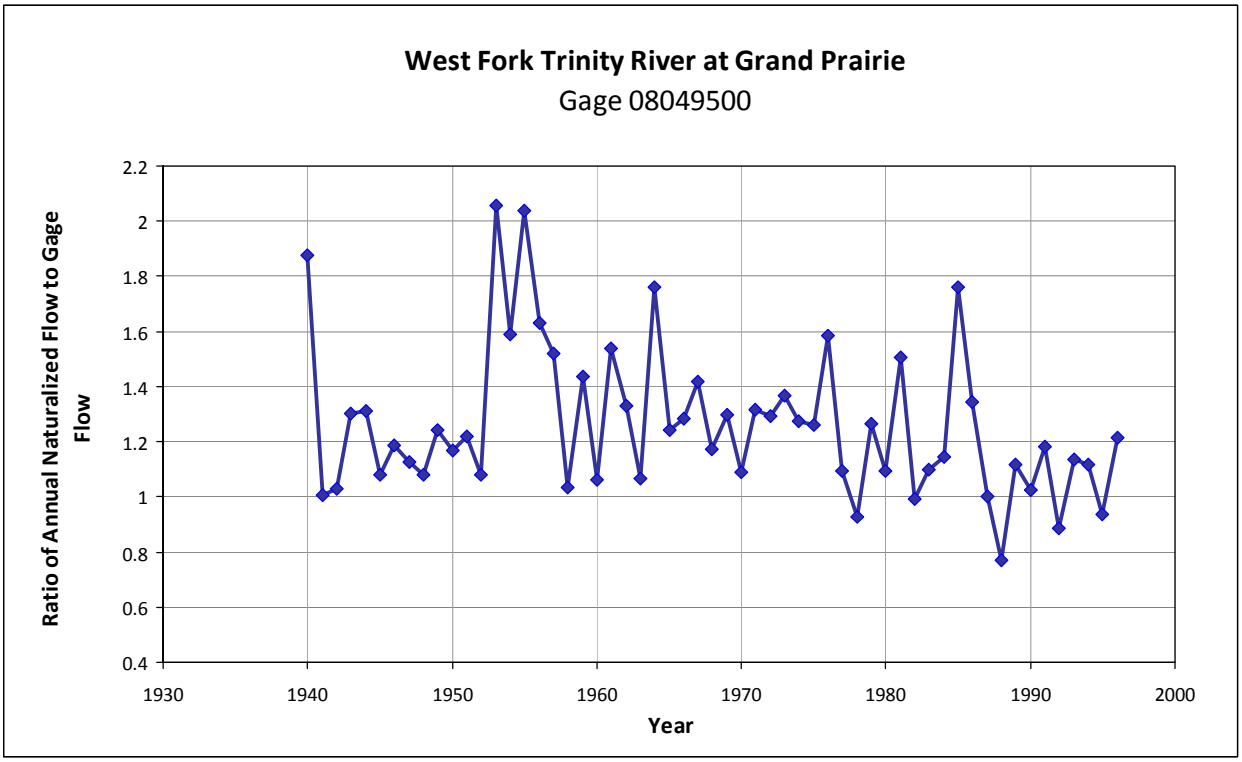
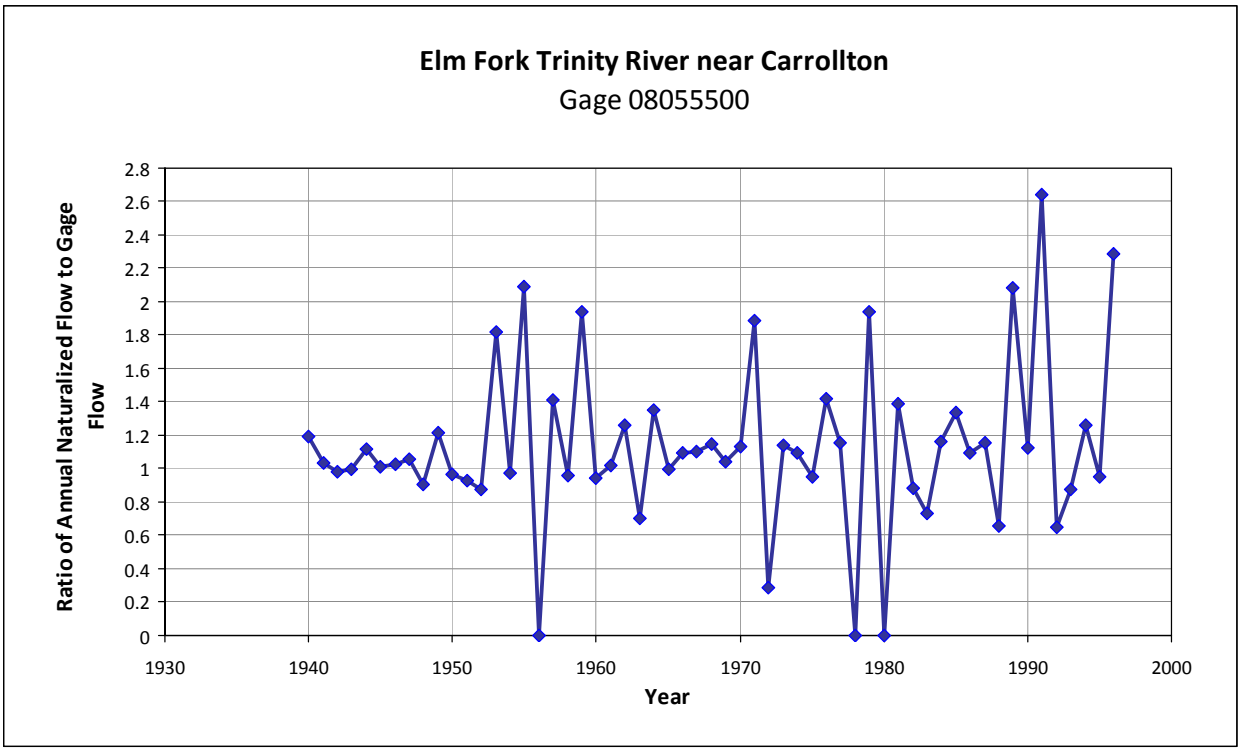
APPENDIX A – NATURALIZED FLOW COMPARISON CHARTS

A.1	TRINITY	A-1
A.2	SAN JACINTO	A-5

APPENDIX A: NATURALIZED FLOW CHARTS





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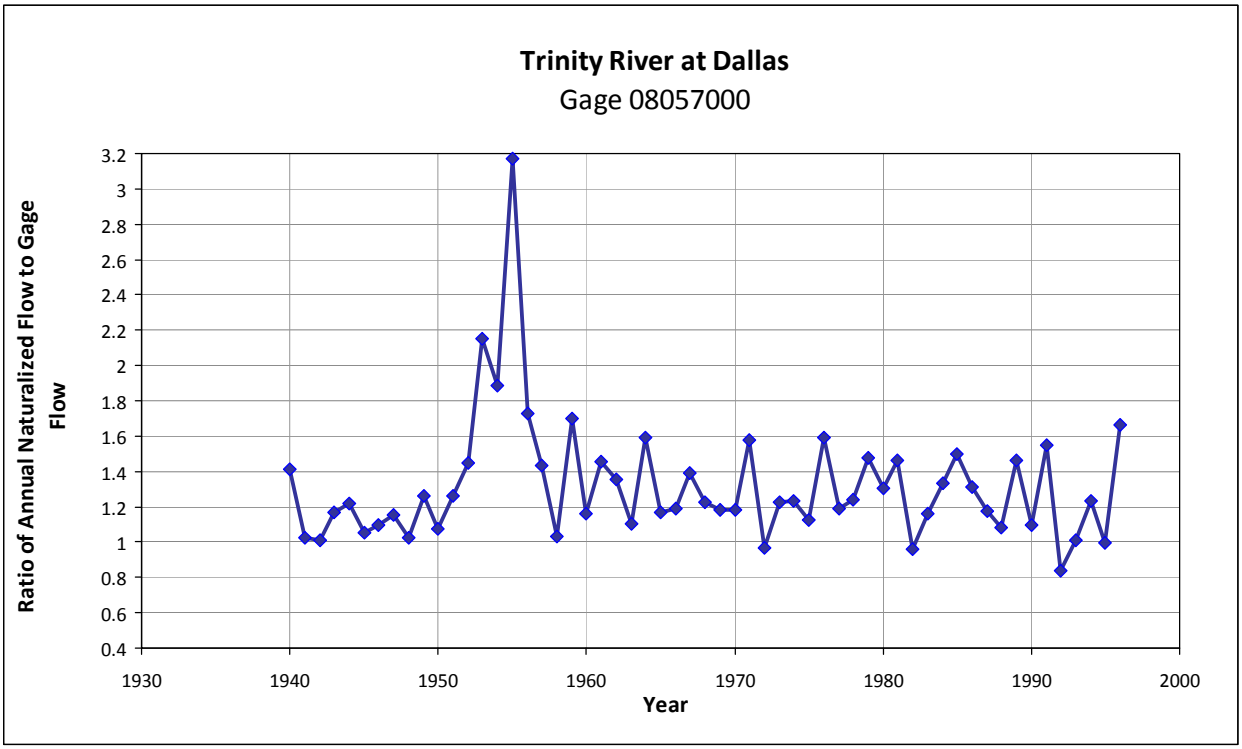

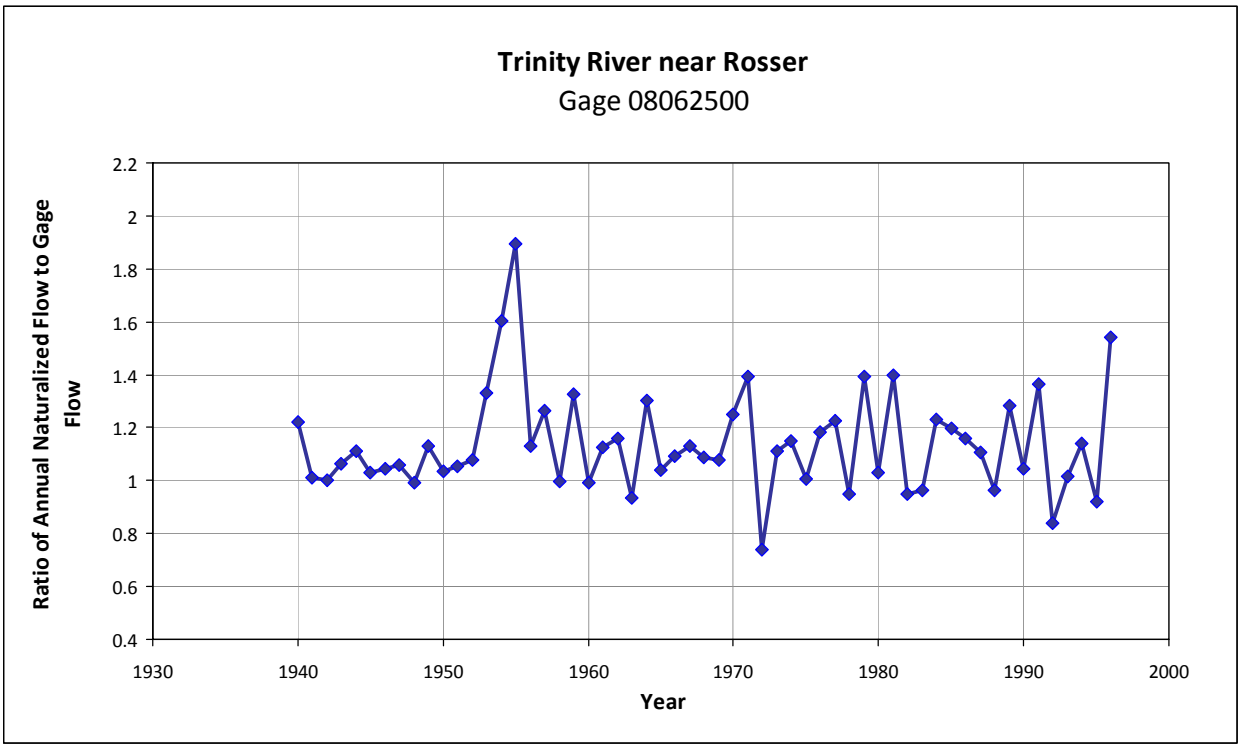

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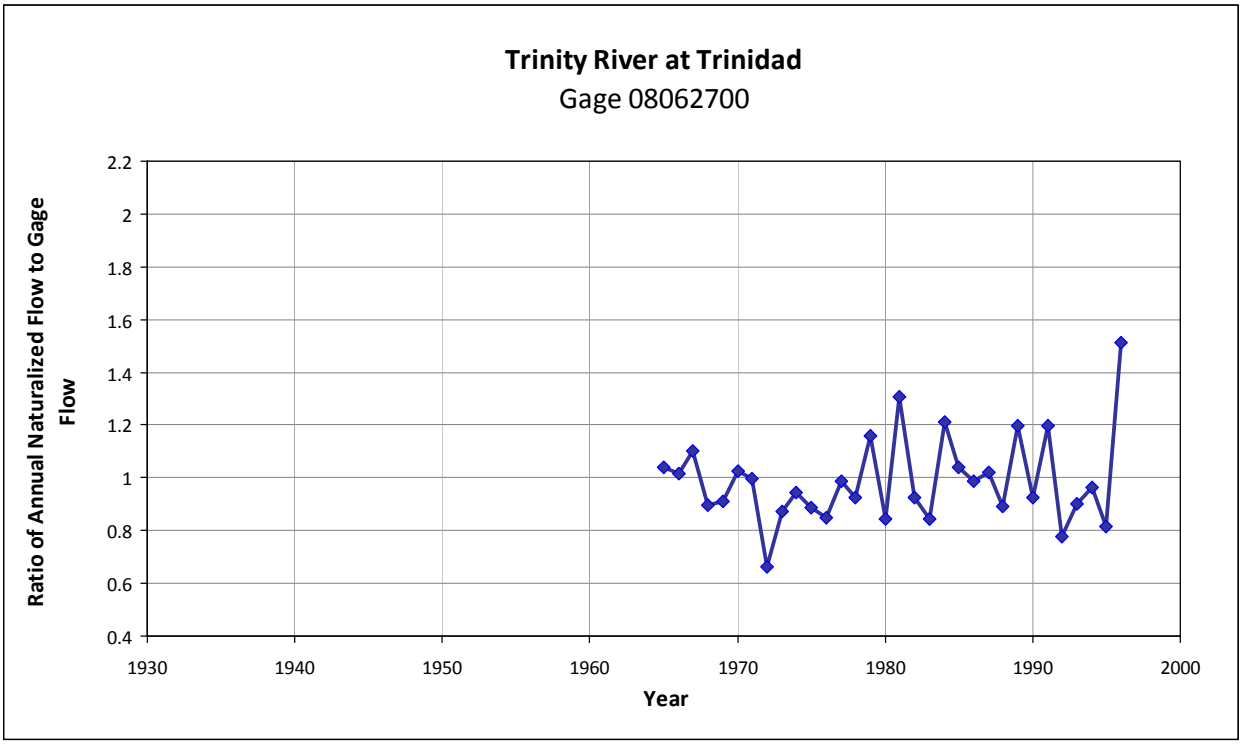

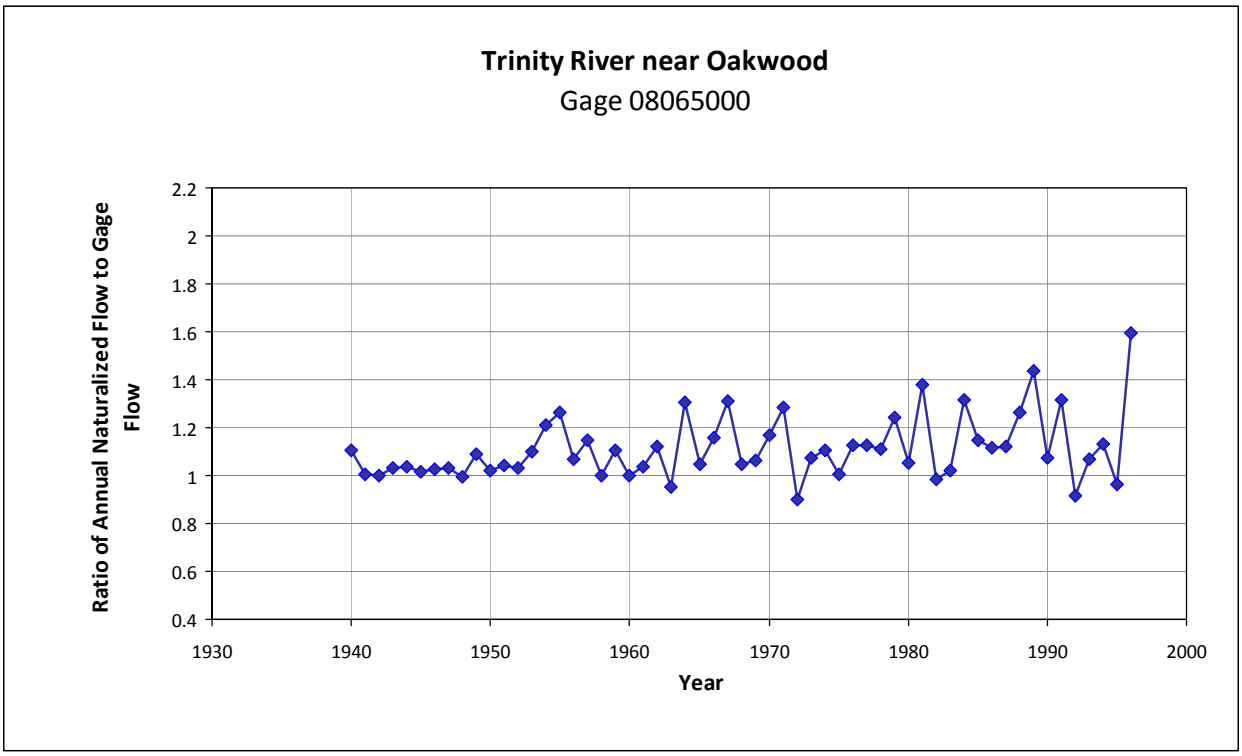

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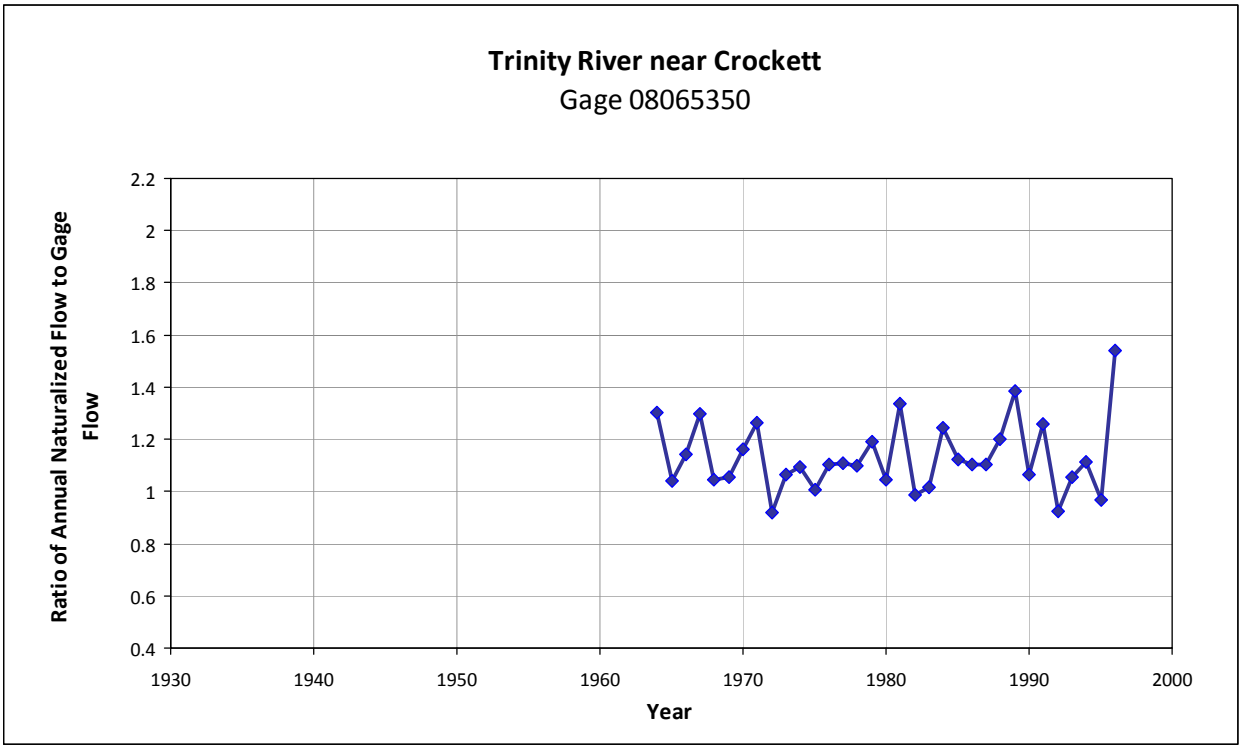

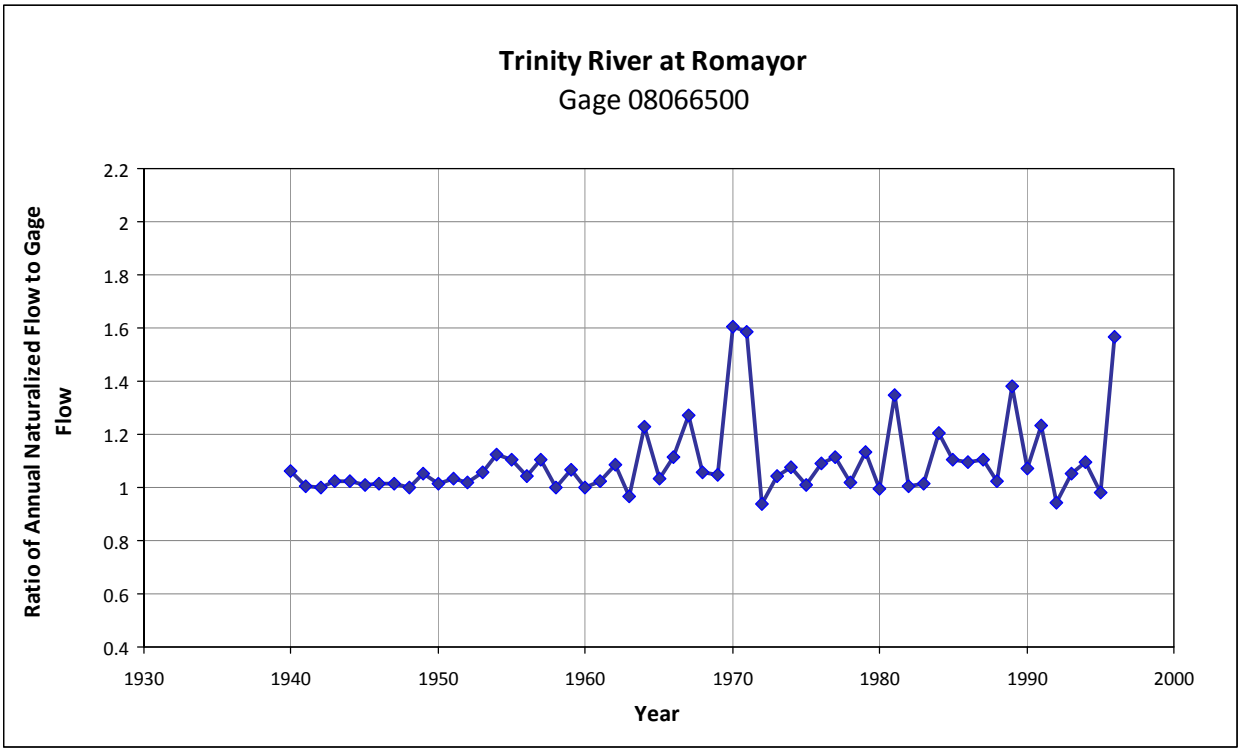

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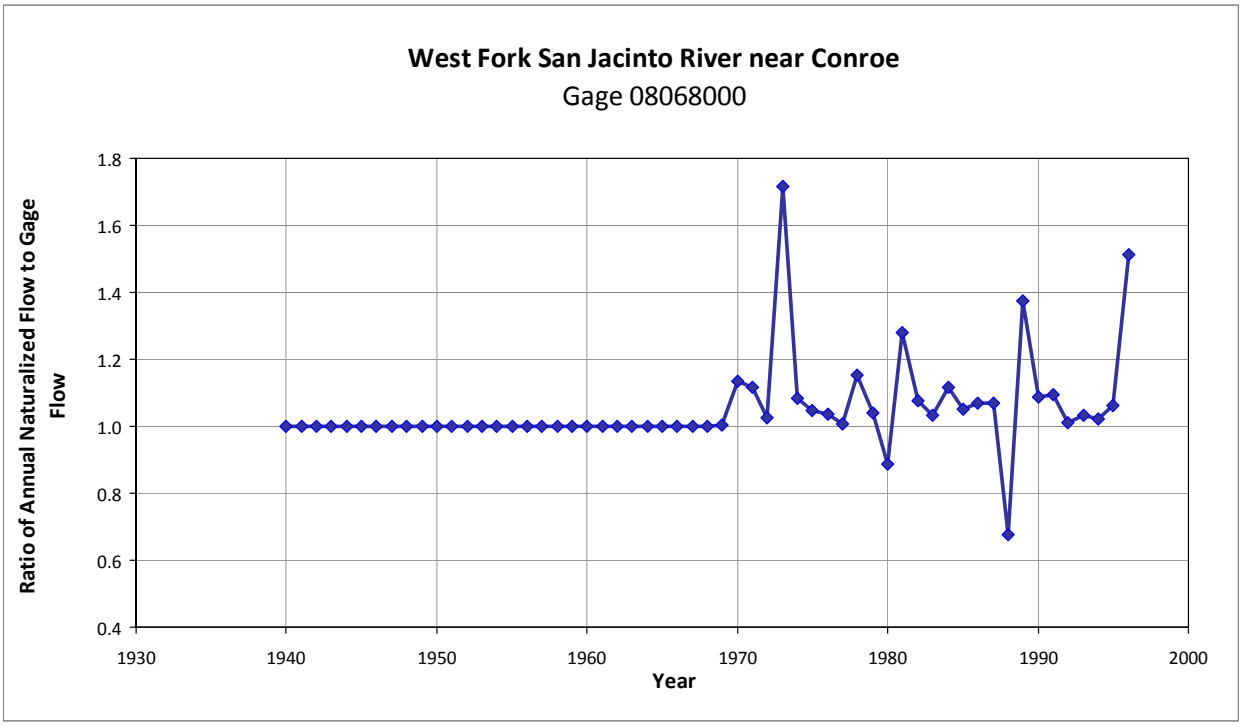

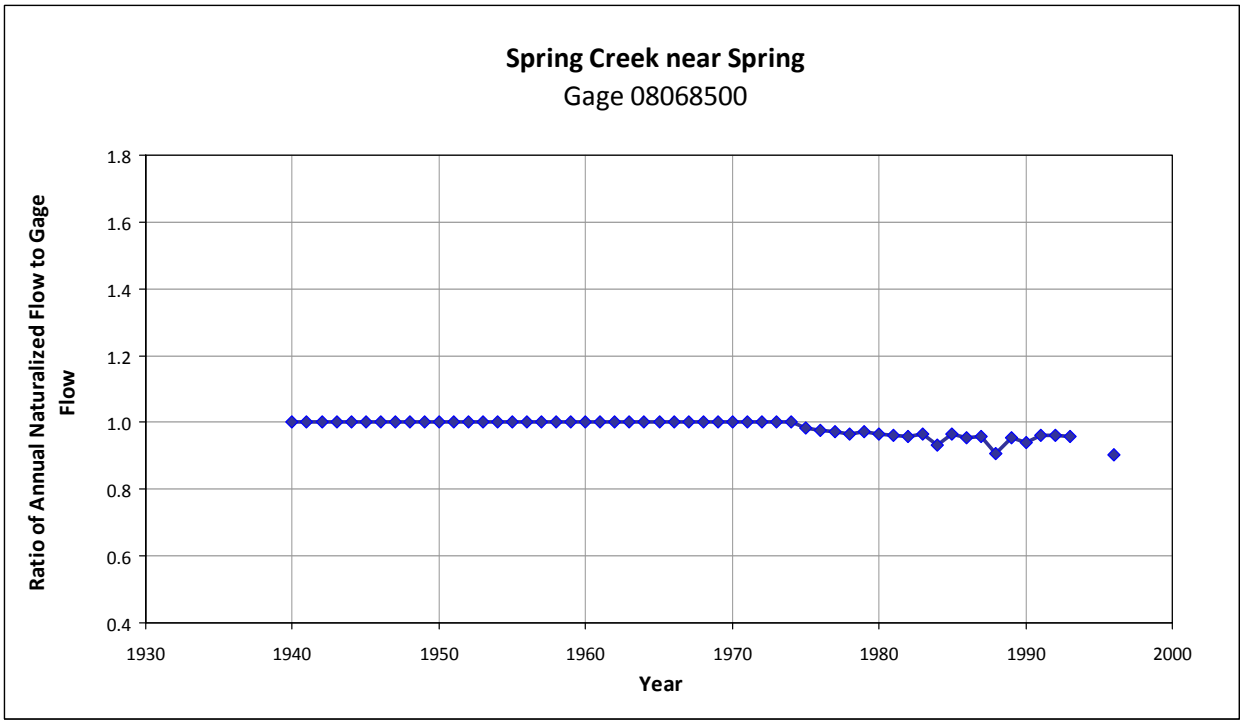

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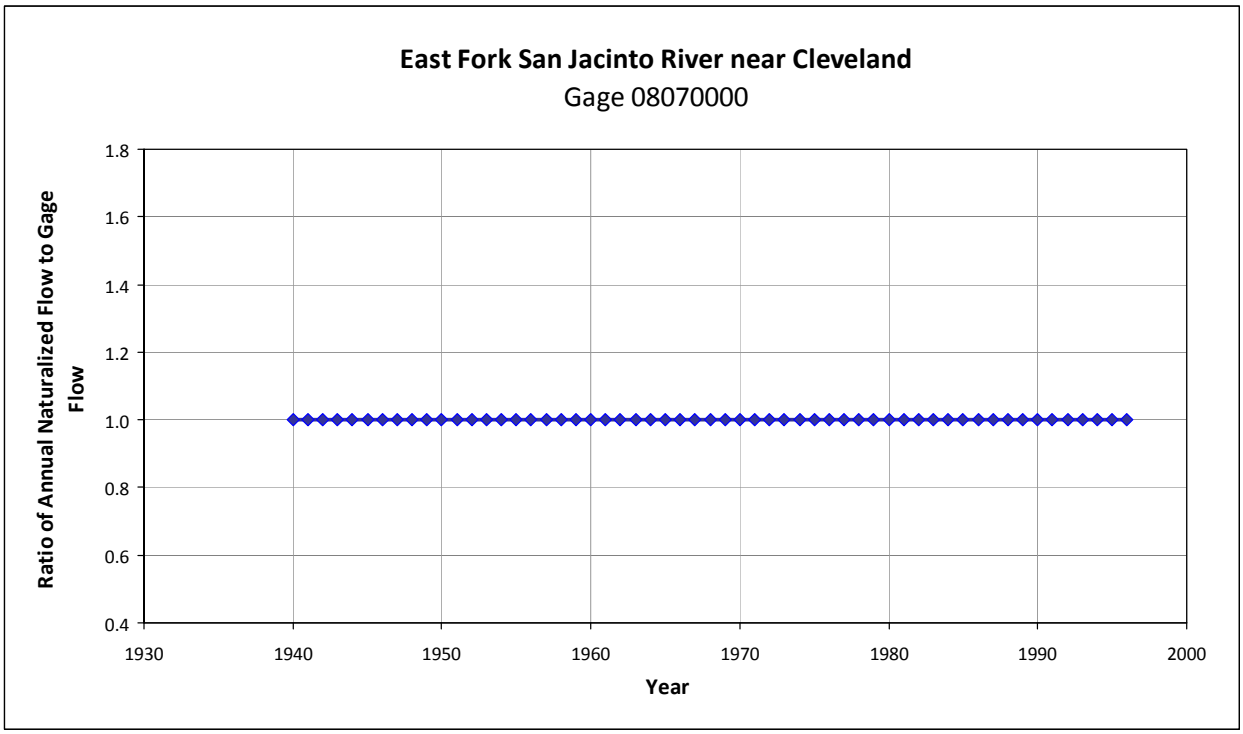

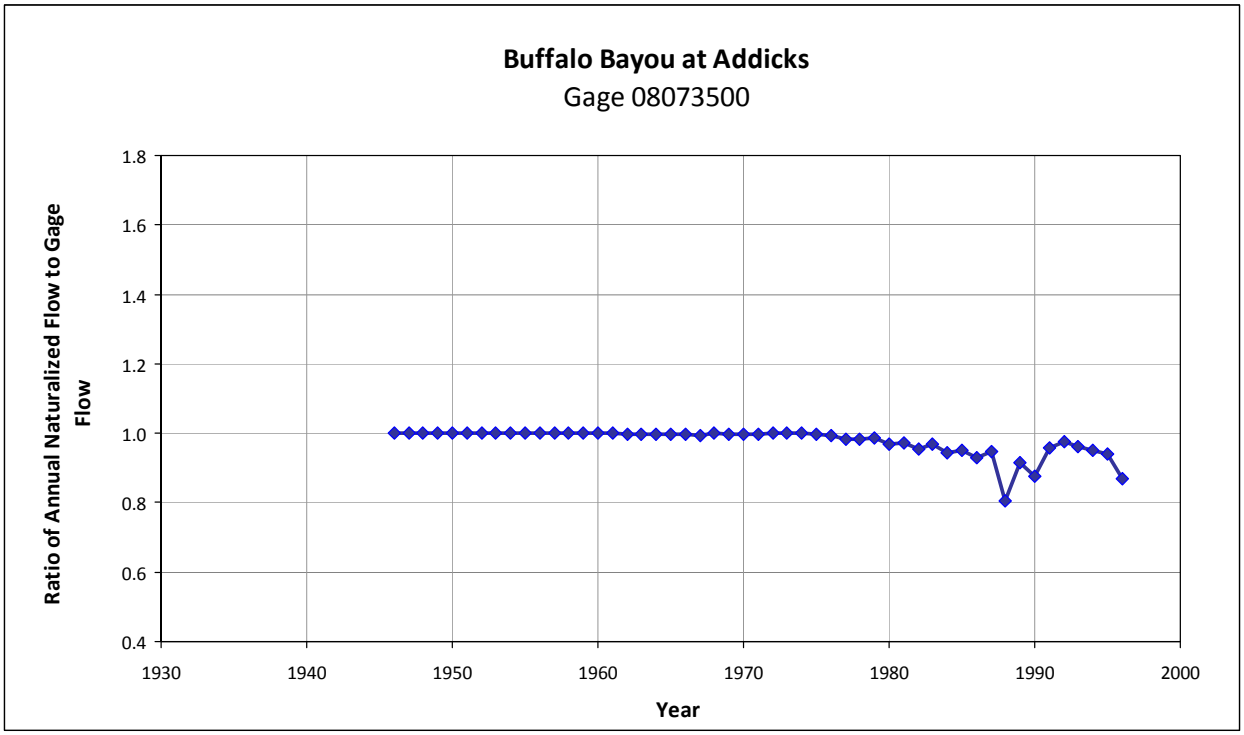

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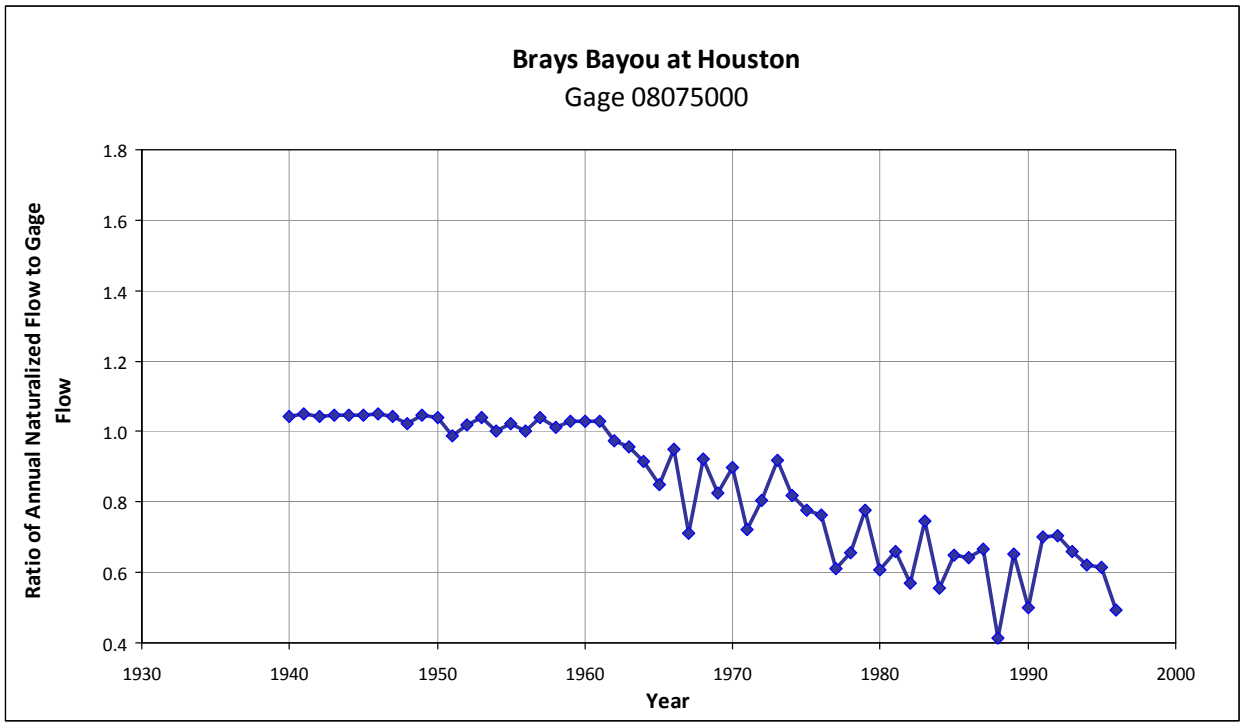
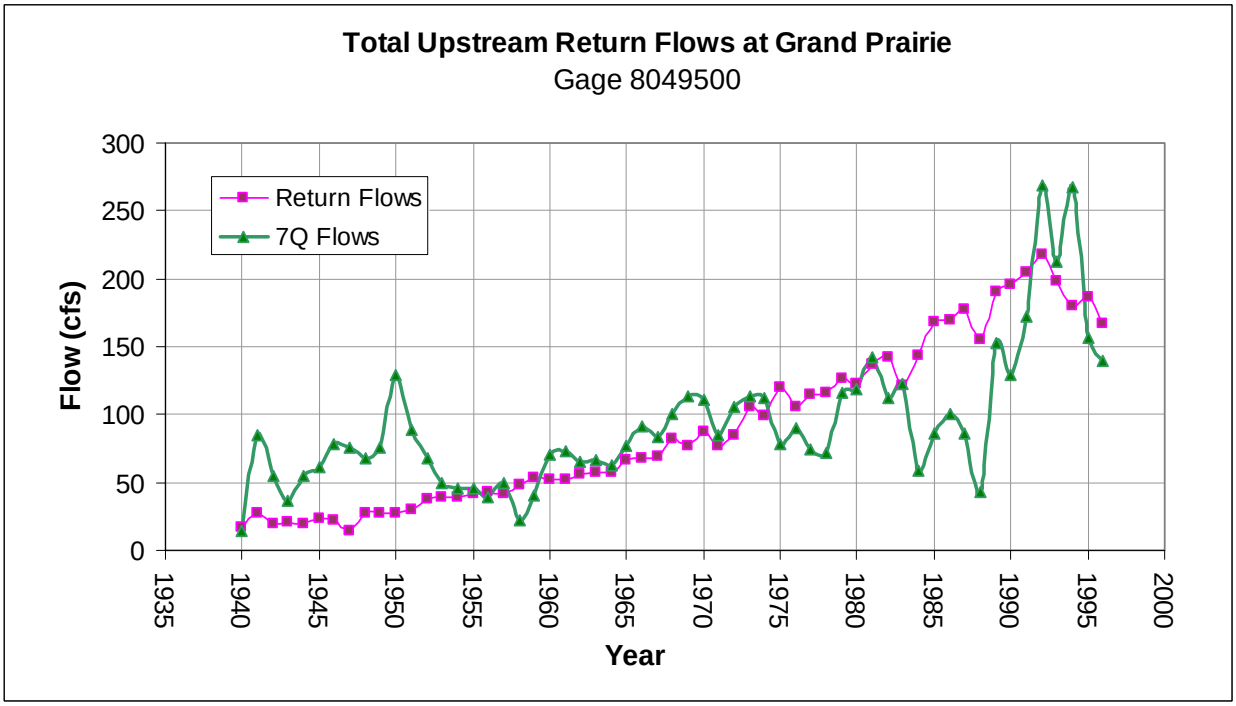
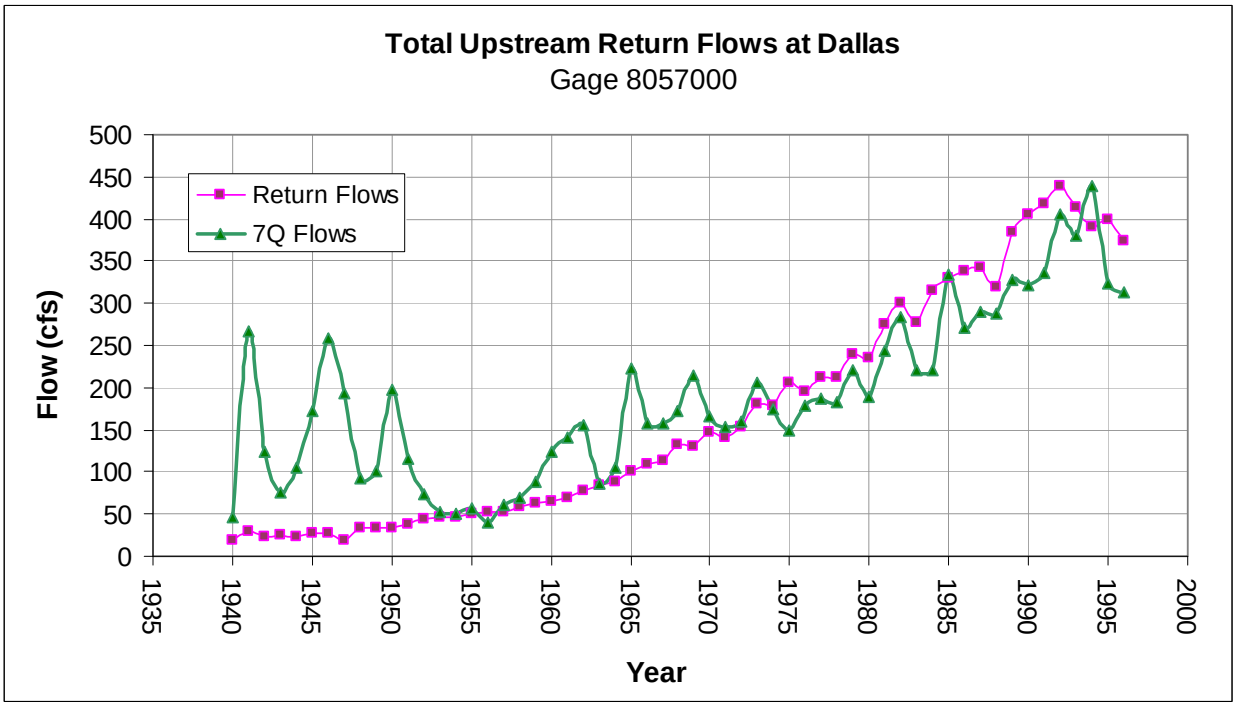


APPENDIX B – RETURN FLOW AND ANNUAL 7-DAY LOW FLOW COMPARISONS

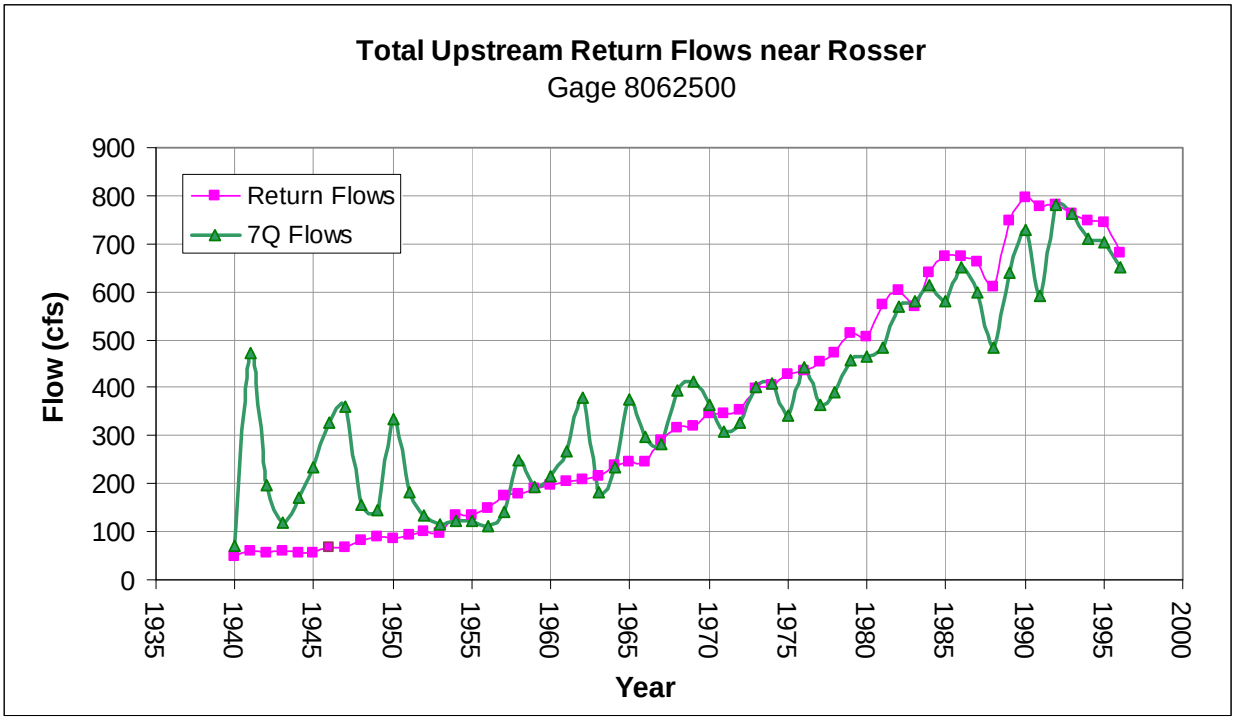
B.1	TRINITY	B-1
B.2	SAN JACINTO	B-5

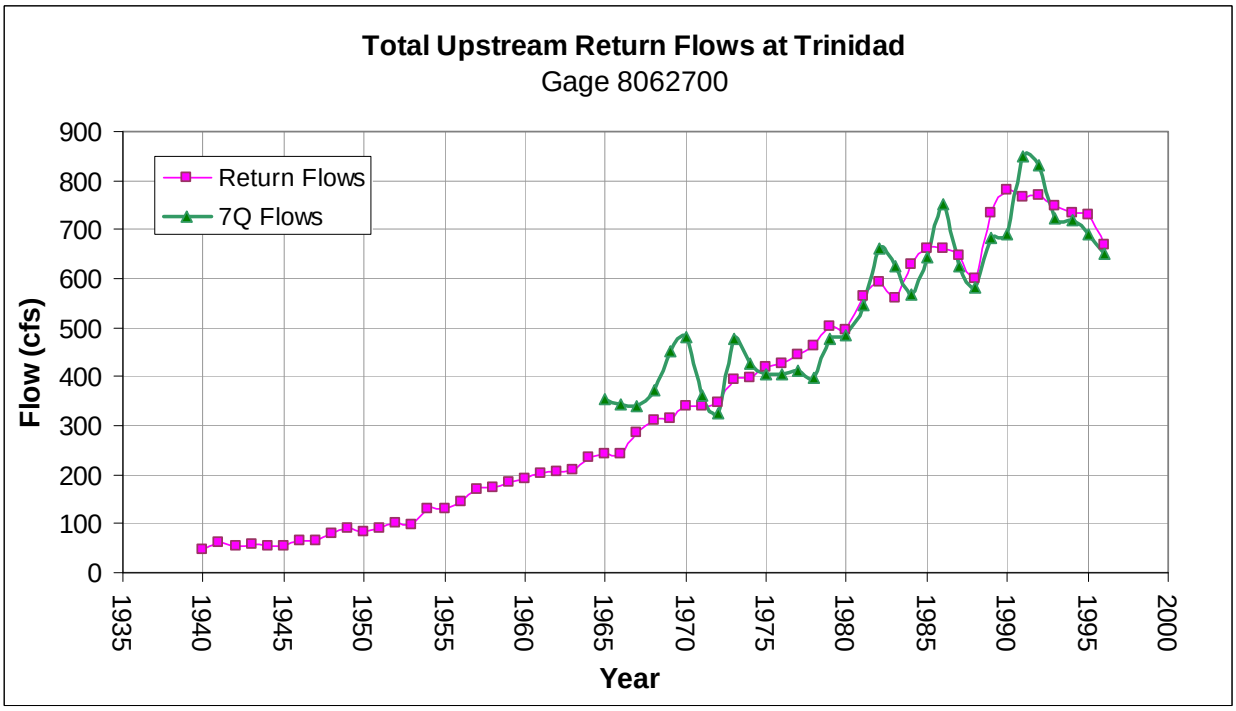
APPENDIX B: RETURN FLOW AND ANNUAL 7-DAY LOW FLOW COMPARISONS



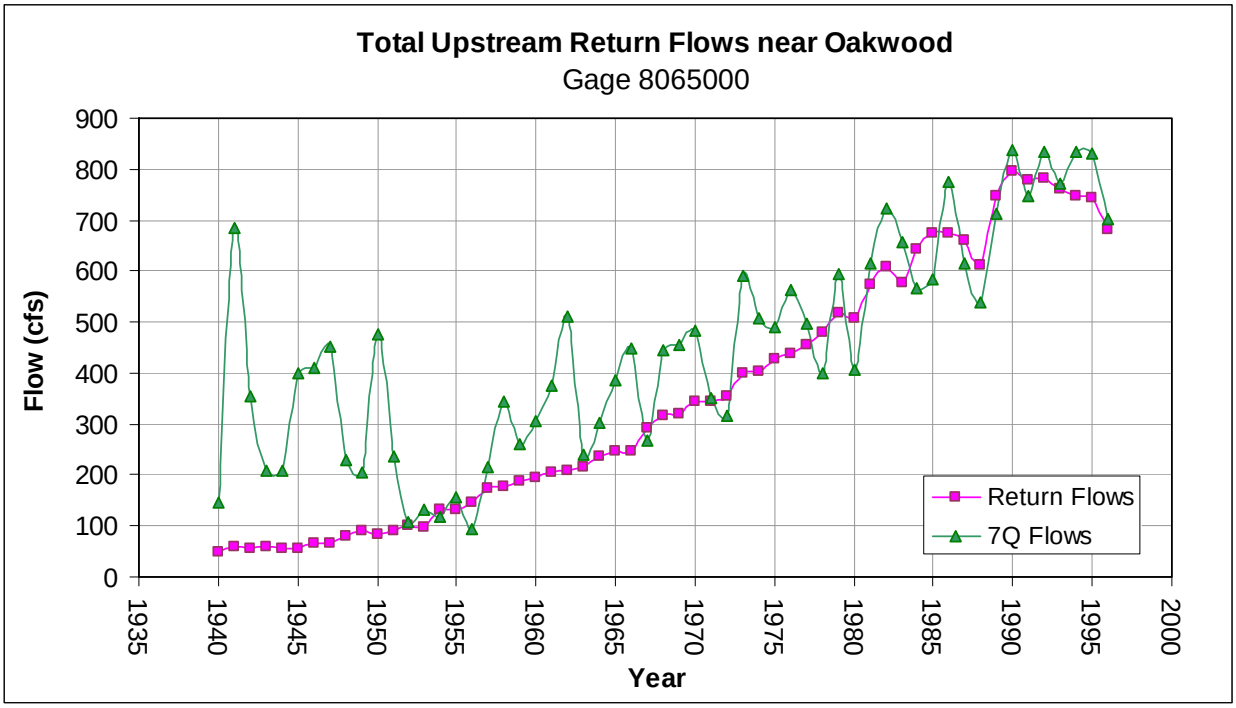


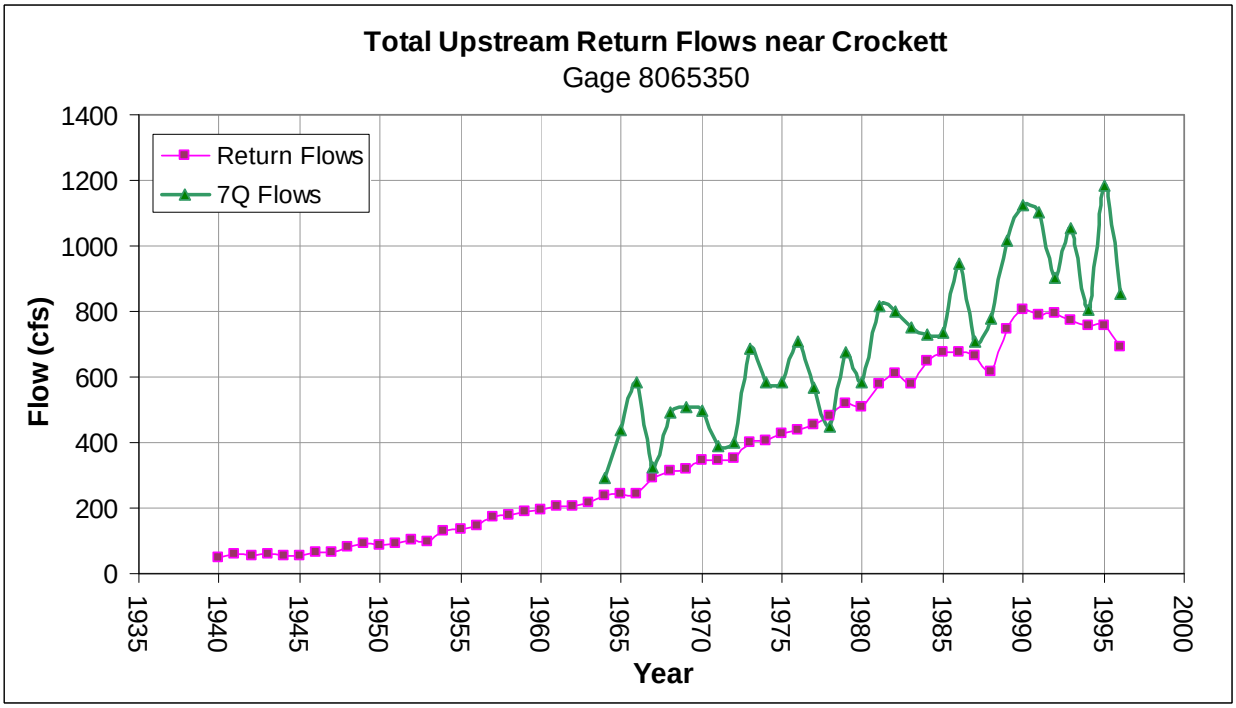
APPENDIX B: RETURN FLOW AND ANNUAL 7-DAY LOW FLOW COMPARISONS



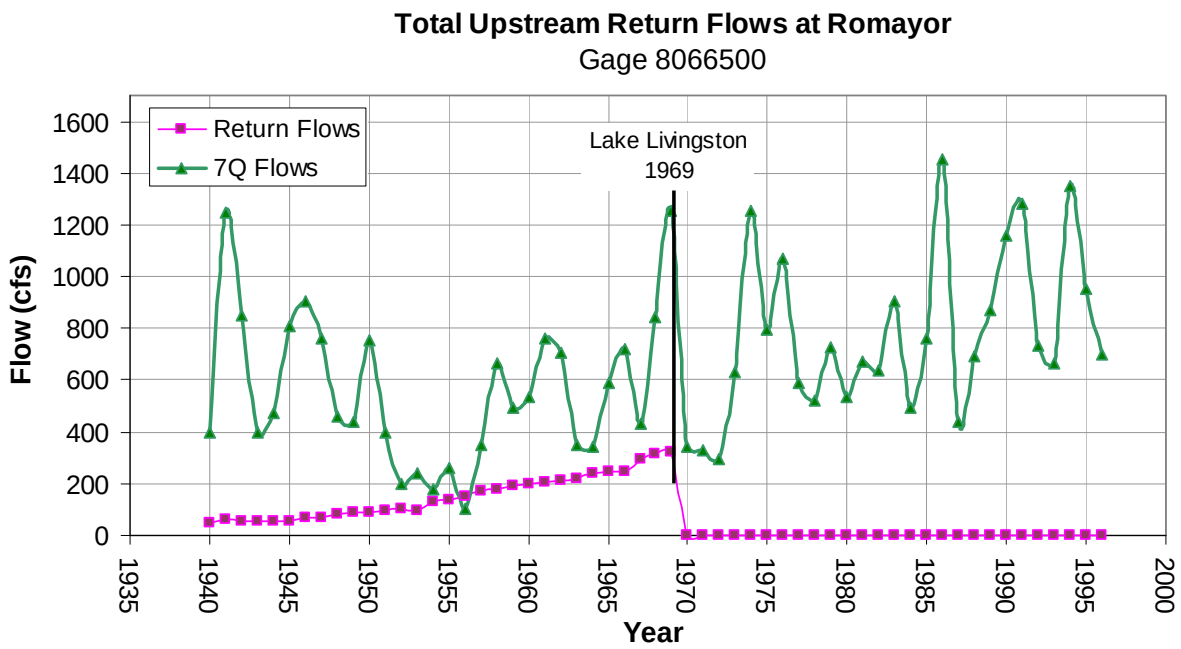


APPENDIX B: RETURN FLOW AND ANNUAL 7-DAY LOW FLOW COMPARISONS



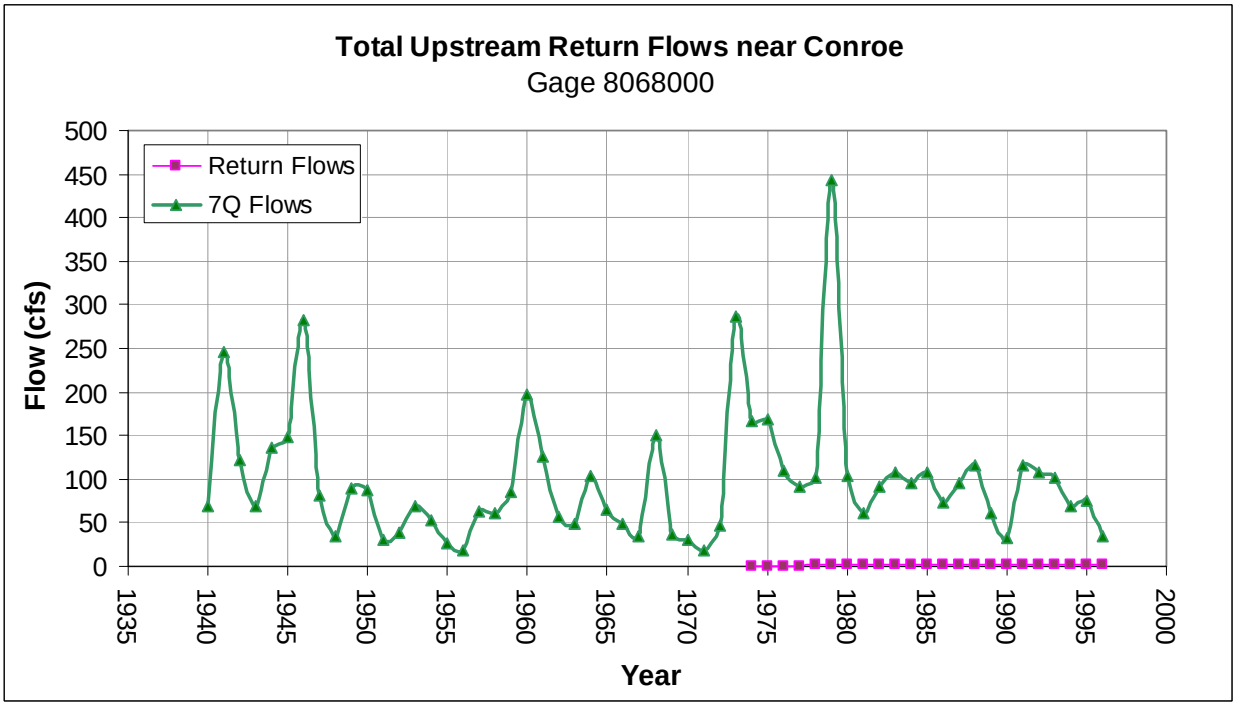


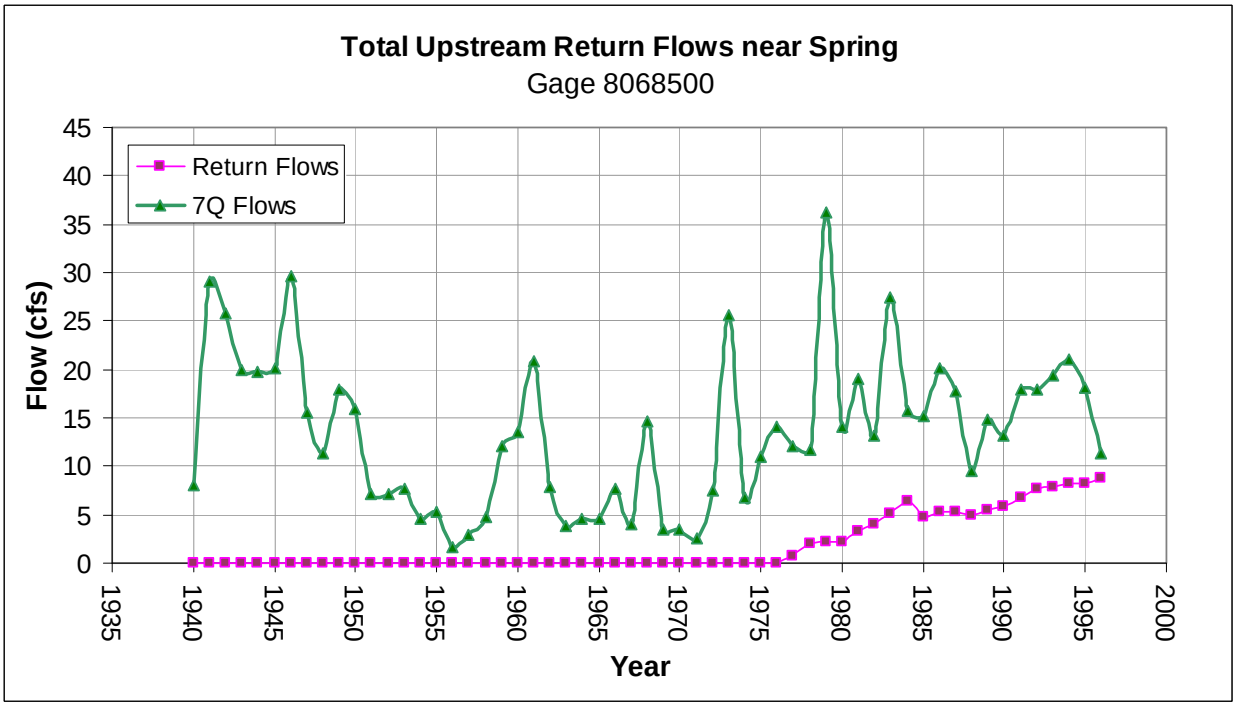
APPENDIX B: RETURN FLOW AND ANNUAL 7-DAY LOW FLOW COMPARISONS



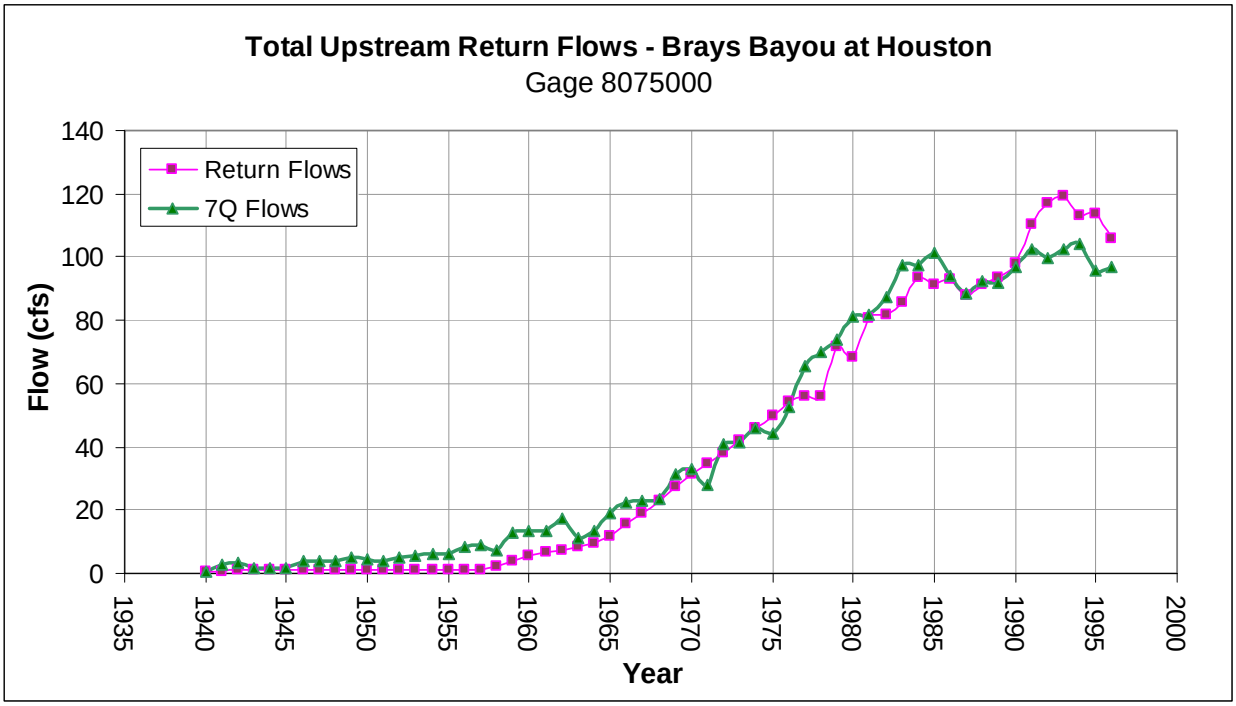
Note: Return flow volumes were calculated including 1969 impoundment of Lake Livingston.

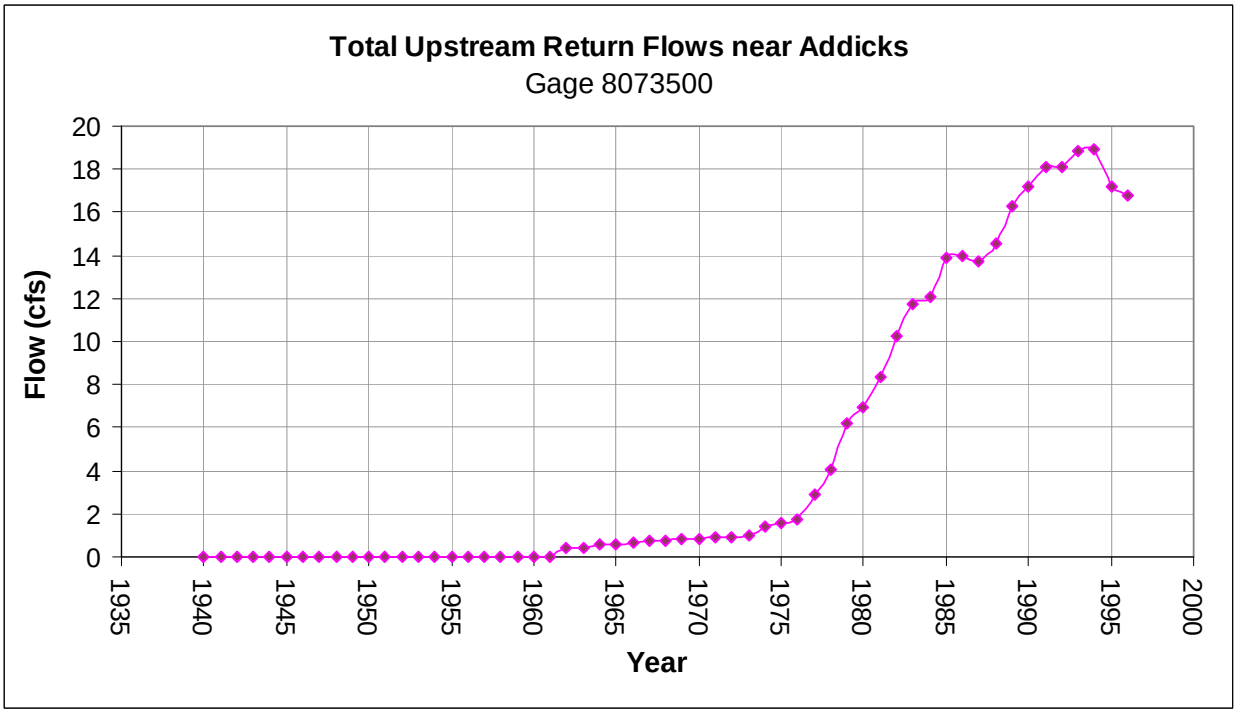
APPENDIX B: RETURN FLOW AND ANNUAL 7-DAY LOW FLOW COMPARISONS





APPENDIX B: RETURN FLOW AND ANNUAL 7-DAY LOW FLOW COMPARISONS





APPENDIX C – PEAKFQ COMPLETE RESULTS

C.1	FULL RECORD RESULTS	C-1
C.2	PRE-IMPACT RESULTS	C-2
C.3	CURRENT RESULTS	C-3

APPENDIX C: PEAKFQ COMPLETE RESULTS

Additional analysis of each gage provided in the .prt files in the working directory.

Full Record

STA ID	STA Name	P1.25	P1.5	P2	P2.33	P5	P10
8049500	W Fk Trinity Rv at Grand Prairie, TX	5,090	6,770	9,210	10,500	17,300	24,500
8055500	Elm Fk Trinity Rv nr Carrollton, TX	3,740	5,540	8,410	10,000	19,200	29,700
8057000	Trinity Rv at Dallas, TX	10,900	15,000	21,000	24,300	41,300	59,200
8062500	Trinity Rv nr Rosser, TX	14,500	19,400	26,400	29,900	47,500	64,200
8062700	Trinity Rv at Trinidad, TX	18,400	24,600	32,600	36,500	53,500	67,300
8065000	Trinity Rv nr Oakwood, TX	18,800	25,500	34,800	39,500	62,500	83,800
8065350	Trinity Rv nr Crockett, TX	20,200	26,300	34,300	38,100	55,600	70,400
8066500	Trinity Rv at Romayor, TX	26,600	34,000	43,400	47,800	67,500	83,500
8068000	W Fk San Jacinto Rv nr Conroe, TX	4,280	6,360	9,650	11,500	21,900	33,600
8068500	Spring Ck nr Spring, TX	2,480	3,950	6,270	7,530	14,300	21,200
8070000	E Fk San Jacinto Rv nr Cleveland, TX	2,150	3,410	5,500	6,710	14,000	22,800
8073700	Buffalo Bayou at Piney Point, TX	2,410	2,880	3,450	3,710	4,810	5,650
8075000	Brays Bayou at Houston, TX	4,370	6,530	9,640	11,200	18,800	25,500

		P25	P50	P100	P200	P500	# Years
8049500	W Fk Trinity Rv at Grand Prairie, TX	36,000	46,400	58,600	72,900	95,500	83
8055500	Elm Fk Trinity Rv nr Carrollton, TX	47,600	64,800	85,500	110,000	151,000	85
8057000	Trinity Rv at Dallas, TX	87,000	112,000	141,000	173,000	224,000	105
8062500	Trinity Rv nr Rosser, TX	88,000	108,000	129,000	152,000	185,000	70
8062700	Trinity Rv at Trinidad, TX	84,100	96,000	107,000	118,000	132,000	44
8065000	Trinity Rv nr Oakwood, TX	114,000	138,000	163,000	189,000	227,000	85
8065350	Trinity Rv nr Crockett, TX	89,400	104,000	118,000	132,000	151,000	45
8066500	Trinity Rv at Romayor, TX	103,000	118,000	132,000	146,000	164,000	84
8068000	W Fk San Jacinto Rv nr Conroe, TX	53,200	71,700	93,900	120,000	162,000	69
8068500	Spring Ck nr Spring, TX	31,300	39,700	48,700	58,200	71,400	69
8070000	E Fk San Jacinto Rv nr Cleveland, TX	38,300	53,500	72,200	95,000	132,000	69
8073700	Buffalo Bayou at Piney Point, TX	6,660	7,370	8,050	8,700	9,540	38
8075000	Brays Bayou at Houston, TX	34,100	40,400	46,500	52,500	60,100	72

APPENDIX C: PEAKFQ COMPLETE RESULTS

Additional analysis of each gage provided in the .prt files in the working directory.

Pre-Impact

STA ID	STA Name	P1.25	P1.5	P2	P2.33	P5	P10
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8055500	Elm Fk Trinity Rv nr Carrollton, TX	9,130	12,700	18,200	21,100	37,500	55,700
8057000	Trinity Rv at Dallas, TX	11,100	15,800	22,800	26,700	47,800	71,000
8062500	Trinity Rv nr Rosser, TX	18,200	24,900	34,400	39,300	63,600	87,000
8062700	Trinity Rv at Trinidad, TX	-	-	-	-	-	-
8065000	Trinity Rv nr Oakwood, TX	17,900	24,400	33,900	38,900	64,300	89,700
8065350	Trinity Rv nr Crockett, TX	-	-	-	-	-	-
8066500	Trinity Rv at Romayor, TX	23,700	30,100	38,400	42,400	60,400	75,600
8068000	W Fk San Jacinto Rv nr Conroe, TX	3,990	6,130	9,560	11,500	22,400	34,500
8068500	Spring Ck nr Spring, TX	2,480	3,950	6,270	7,530	14,300	21,200
8070000	E Fk San Jacinto Rv nr Cleveland, TX	2,150	3,410	5,500	6,710	14,000	22,800
8073700	Buffalo Bayou at Piney Point, TX	1,630	1,990	2,420	2,620	3,450	4,070
8075000	Brays Bayou at Houston, TX	2,020	2,780	3,800	4,300	6,630	8,630

		P25	P50	P100	P200	P500	# Years
8049500	W Fk Trinity Rv at Grand Prairie, TX	31,300	39,800	49,500	60,500	77,400	31
8055500	Elm Fk Trinity Rv nr Carrollton, TX	85,900	114,000	148,000	189,000	255,000	29
8057000	Trinity Rv at Dallas, TX	109,000	144,000	185,000	234,000	312,000	50
8062500	Trinity Rv nr Rosser, TX	121,000	149,000	179,000	212,000	259,000	14
8062700	Trinity Rv at Trinidad, TX	-	-	-	-	-	-
8065000	Trinity Rv nr Oakwood, TX	128,000	161,000	197,000	238,000	299,000	41
8065350	Trinity Rv nr Crockett, TX	-	-	-	-	-	-
8066500	Trinity Rv at Romayor, TX	95,300	110,000	125,000	140,000	160,000	44
8068000	W Fk San Jacinto Rv nr Conroe, TX	54,500	72,900	94,500	119,000	158,000	33
8068500	Spring Ck nr Spring, TX	31,300	39,700	48,700	58,200	71,400	69
8070000	E Fk San Jacinto Rv nr Cleveland, TX	38,300	53,500	72,200	95,000	132,000	69
8073700	Buffalo Bayou at Piney Point, TX	4,810	5,320	5,790	6,250	6,810	12
8075000	Brays Bayou at Houston, TX	11,200	13,100	15,000	16,800	19,200	24

APPENDIX C: PEAKFQ COMPLETE RESULTS

Additional analysis of each gage provided in the .prt files in the working directory.

Current

STA ID	STA Name	P1.25	P1.5	P2	P2.33	P5	P10
8049500	W Fk Trinity Rv at Grand Prairie, TX	8,330	10,700	14,100	15,900	25,100	34,600
8055500	Elm Fk Trinity Rv nr Carrollton, TX	4,680	5,610	6,840	7,450	10,400	13,000
8057000	Trinity Rv at Dallas, TX	17,600	21,900	27,600	30,400	43,300	54,700
8062500	Trinity Rv nr Rosser, TX	23,800	28,800	35,400	38,700	54,600	69,400
8062700	Trinity Rv at Trinidad, TX	25,800	31,000	37,500	40,700	54,800	66,900
8065000	Trinity Rv nr Oakwood, TX	26,700	34,000	43,500	48,100	69,300	87,500
8065350	Trinity Rv nr Crockett, TX	26,400	32,900	41,300	45,400	64,400	81,100
8066500	Trinity Rv at Romayor, TX	35,600	45,800	58,400	64,300	89,200	108,000
8068000	W Fk San Jacinto Rv nr Conroe, TX	4,440	6,460	9,620	11,400	21,400	32,700
8068500	Spring Ck nr Spring, TX	-	-	-	-	-	-
8070000	E Fk San Jacinto Rv nr Cleveland, TX	-	-	-	-	-	-
8073700	Buffalo Bayou at Piney Point, TX	3,060	3,570	4,160	4,420	5,480	6,250
8075000	Brays Bayou at Houston, TX	12,200	14,600	17,300	18,500	23,600	27,400

		P25	P50	P100	P200	P500	# Years
8049500	W Fk Trinity Rv at Grand Prairie, TX	49,600	63,100	78,800	97,200	126,000	20
8055500	Elm Fk Trinity Rv nr Carrollton, TX	16,800	20,000	23,400	27,200	32,700	20
8057000	Trinity Rv at Dallas, TX	70,000	82,100	94,700	108,000	126,000	20
8062500	Trinity Rv nr Rosser, TX	90,700	108,000	128,000	149,000	181,000	20
8062700	Trinity Rv at Trinidad, TX	82,800	95,100	108,000	121,000	139,000	20
8065000	Trinity Rv nr Oakwood, TX	111,000	130,000	149,000	168,000	194,000	20
8065350	Trinity Rv nr Crockett, TX	104,000	122,000	140,000	160,000	187,000	20
8066500	Trinity Rv at Romayor, TX	131,000	146,000	160,000	173,000	189,000	20
8068000	W Fk San Jacinto Rv nr Conroe, TX	51,900	70,300	92,500	119,000	163,000	35
8068500	Spring Ck nr Spring, TX	-	-	-	-	-	-
8070000	E Fk San Jacinto Rv nr Cleveland, TX	-	-	-	-	-	-
8073700	Buffalo Bayou at Piney Point, TX	7,130	7,730	8,280	8,800	9,440	21
8075000	Brays Bayou at Houston, TX	31,800	34,800	37,600	40,200	43,500	25

APPENDIX D – OVERBANK FLOW

D.1 USGS RATING CUVRES D-1

D.2 SUMMARY OF NATIONAL WEATHER SERVICE INFORMATION D-2

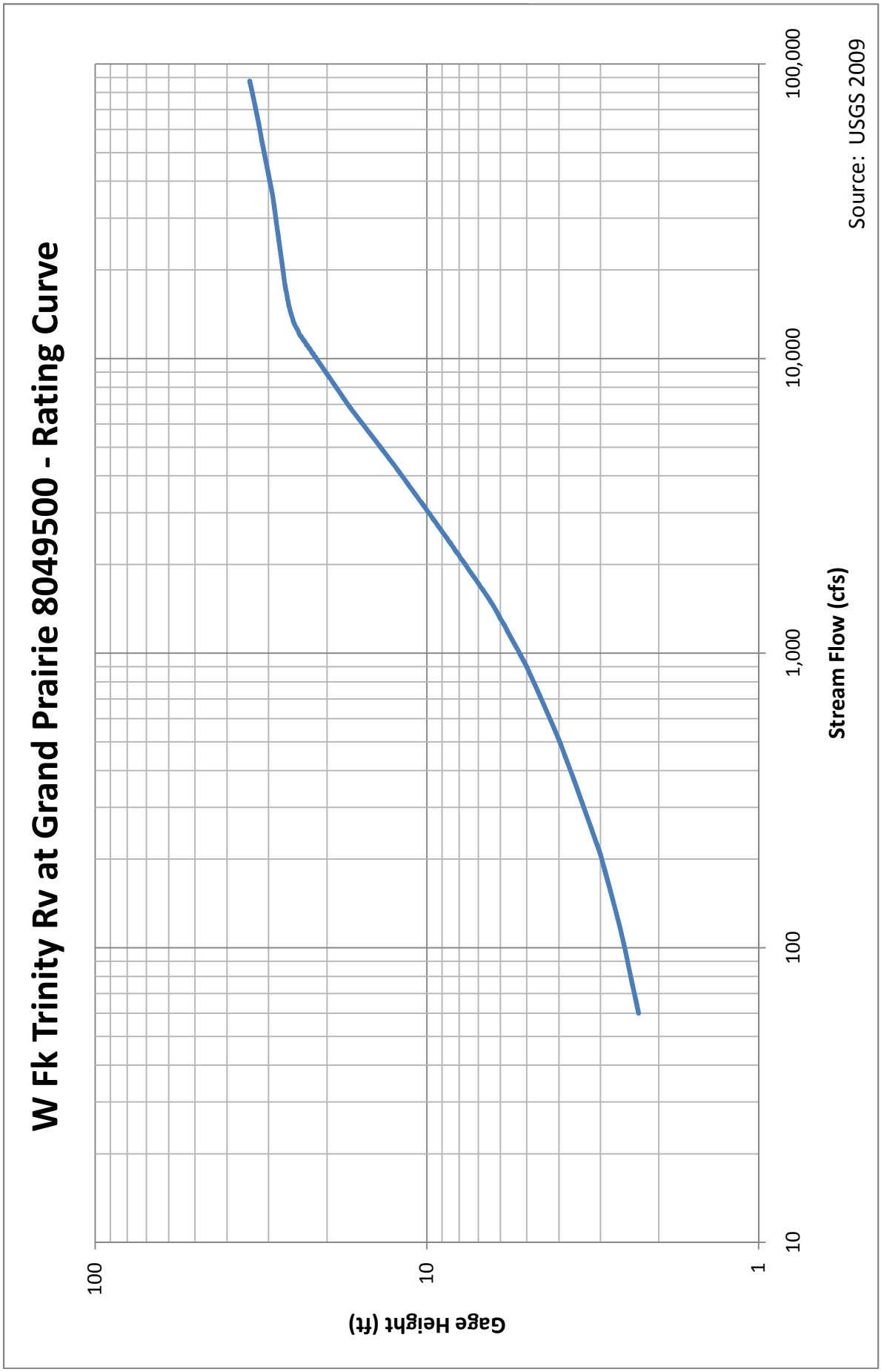
APPENDIX D: OVERBANK FLOW

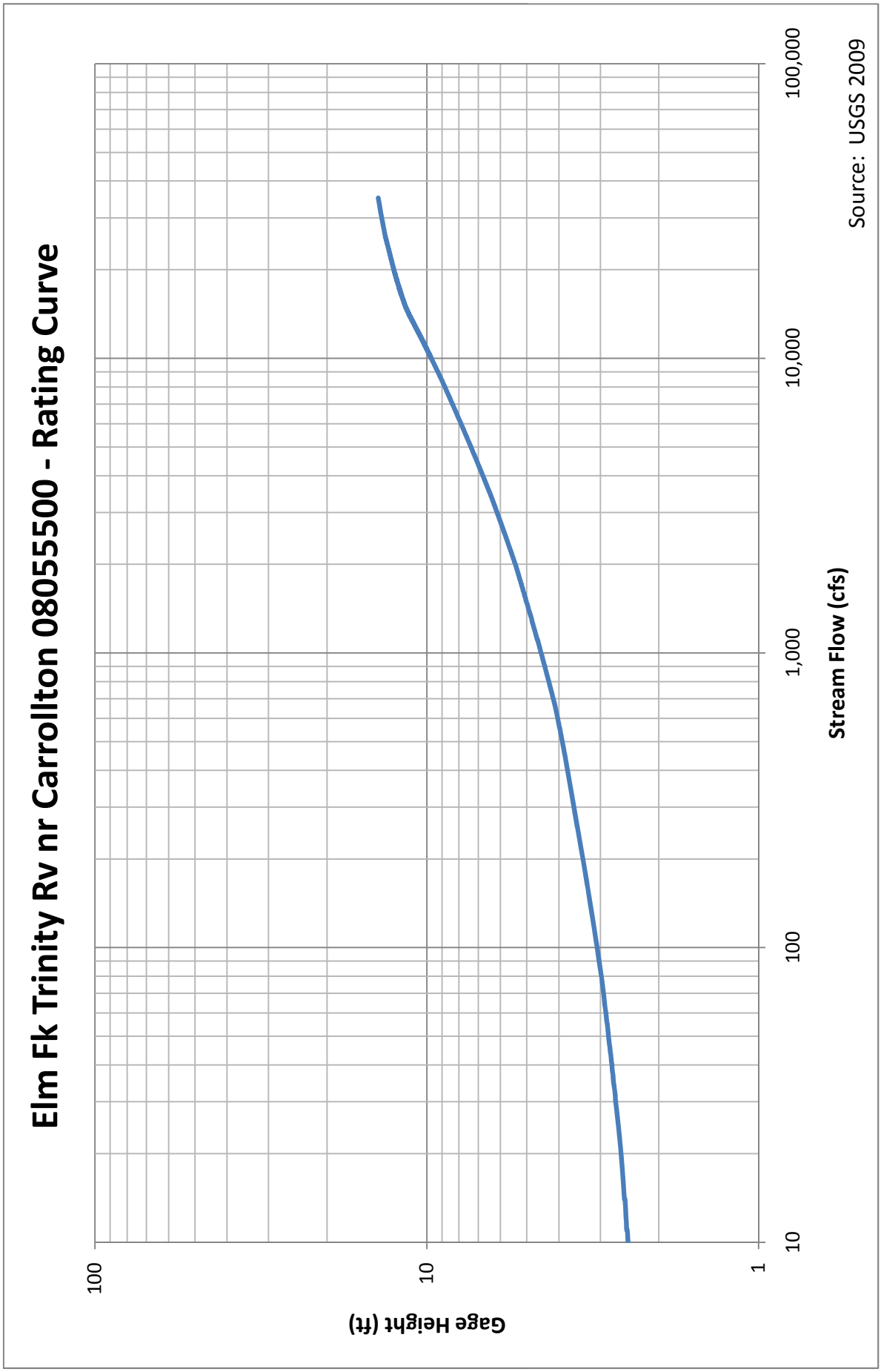
Summary of National Weather Service (NWS) Information

Category	Unit	West Fork Trinity River at Grand Prairie	Elm Fork Trinity River near Carrollton	Trinity River at Dallas	Trinity River near Rosser	Trinity River at Trinidad	Trinity River near Oakwood	Trinity River near Crockett	Trinity River at Romayor
NWS Station Name		West Fork of the Trinity 3 NW Grand Prairie	Elm Fork of the Trinity 2 at Carrollton	Trinity River 2 W Dallas	Trinity River S Rosser	Trinity River at Trinidad	Trinity River 6 NE Long Lake	Trinity River 12 W Crockett	Trinity River 1.9 S Romayor
NWS "Action Stage"*	ft	25	7	29	29	31	30	35	30
NWS "Action Stage" Flow	cfs	13,000	4,400	10,000	36,000	14,000	18,100	31,300	44,600
NWS "Flood Stage"*	ft	27	8	30	31	33	35	41	40
NWS "Flood Stage" Flow	cfs	20,000	6,200	11,100	40,000	17,000	24,600	42,000	94,300
NWS "Flood Stage" Impacts		Major flooding may start to occur at low lying areas near the river in North Grand Prairie.	Minor flooding will occur downstream from the gage.	Minor lowland flooding will begin. The pasture lands near the river will flood.	Minor flooding of farm and ranch land is expected near the river. A few rural roads will be inundated.	Minor flooding will occur along the right bank of river. Low woodlands for one mile along right bank will begin to flood	Minor flooding of numerous ranches along the river is expected. Minor flooding of Coffield Prison farm and ranch lands near the river is to be expected.	For Action Stage: Minor overbank is flow expected. All livestock and equipment should be removed from the flood plain.	Minor lowland flooding begins as livestock and equipment near the river are endangered and communities in Liberty are threatened.

*NWS Flood Stage appears to be the level where actual overbank flooding starts based on descriptions (No flooding is mentioned for Action Stage except for Crockett).

Category	Unit	West Fork San Jacinto near Conroe	Spring Creek near Spring	East Fork San Jacinto River near Cleveland	Brays Bayou at Houston	Buffalo Bayou at Piney Point
NWS Station Name		West Fork San Jacinto 4.2 S Conroe	Spring Creek 1.1 NE Spring	East Fork San Jacinto River 12 W Cleveland	Brays Bayou at South Main Street	Buffalo Bayou at Piney Point Village
NWS "Action Stage"*	ft	19	14	13	51	49
NWS "Action Stage" Flow	cfs	16,800	5000	2000	Not Available	3000
NWS "Flood Stage"*	ft	20	21	19	52.1	52
NWS Overbank Flow	cfs	19,100	8,500	16,000	Not Available	3,700
NWS "Flood Stage" Impacts		Minor lowland flooding begins.	94.6 MSL...minor lowland flooding begins as flow escapes into secondary channels.	Minor lowland flooding begins	No impact provided	At levels above 52 feet minor lowland flooding begins as pool decks, tennis courts, and lower garage area are inundated.


W Fk Trinity Rv at Grand Prairie 8049500 - Rating Curve
Gage Height (ft)
100
10
1
10
100
1,000
10,000
100,000
Stream Flow (cfs)
Source: USGS 2009


Elm Fk Trinity Rv nr Carrollton 08055500 - Rating Curve
Gage Height (ft)
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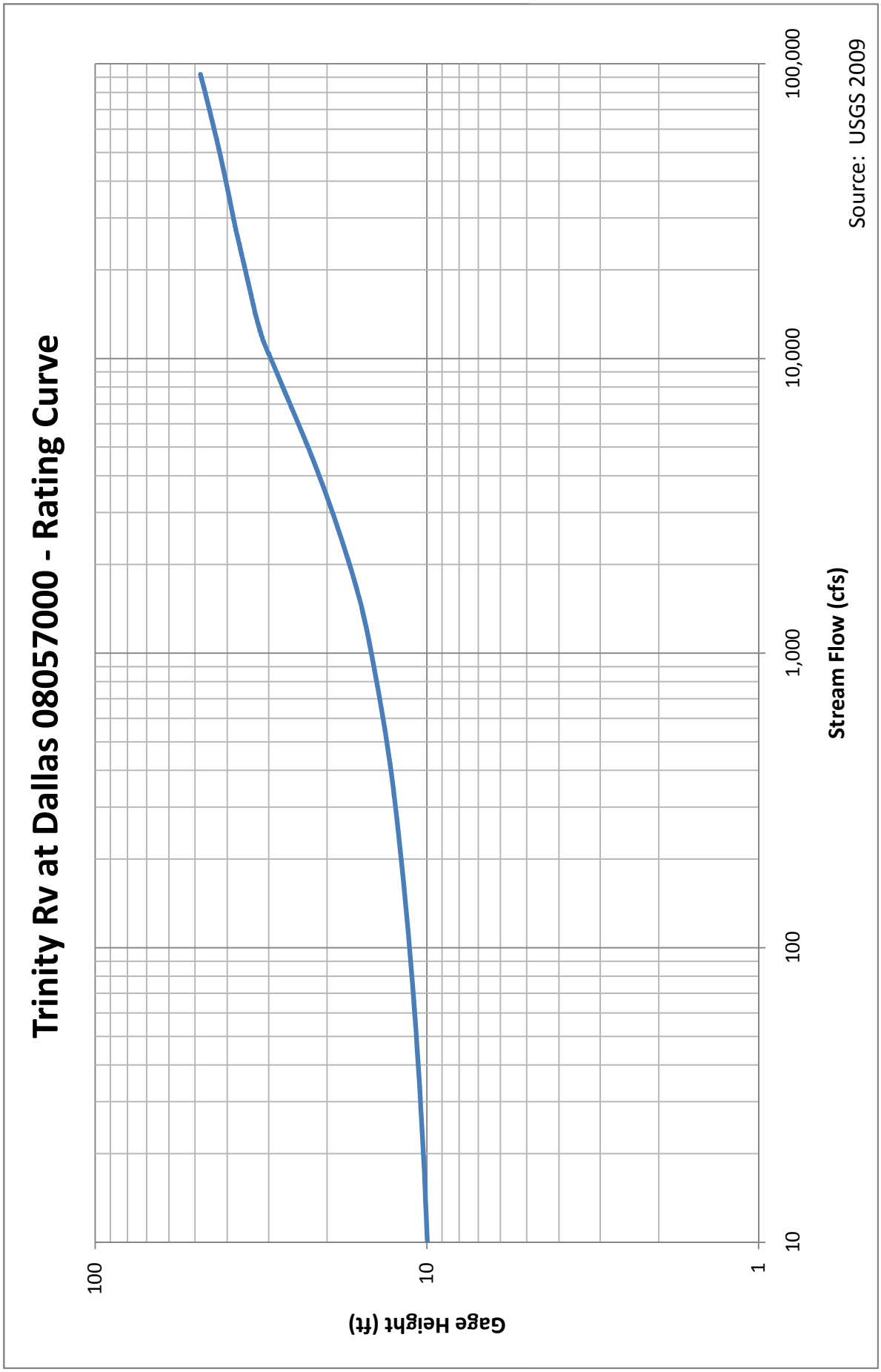
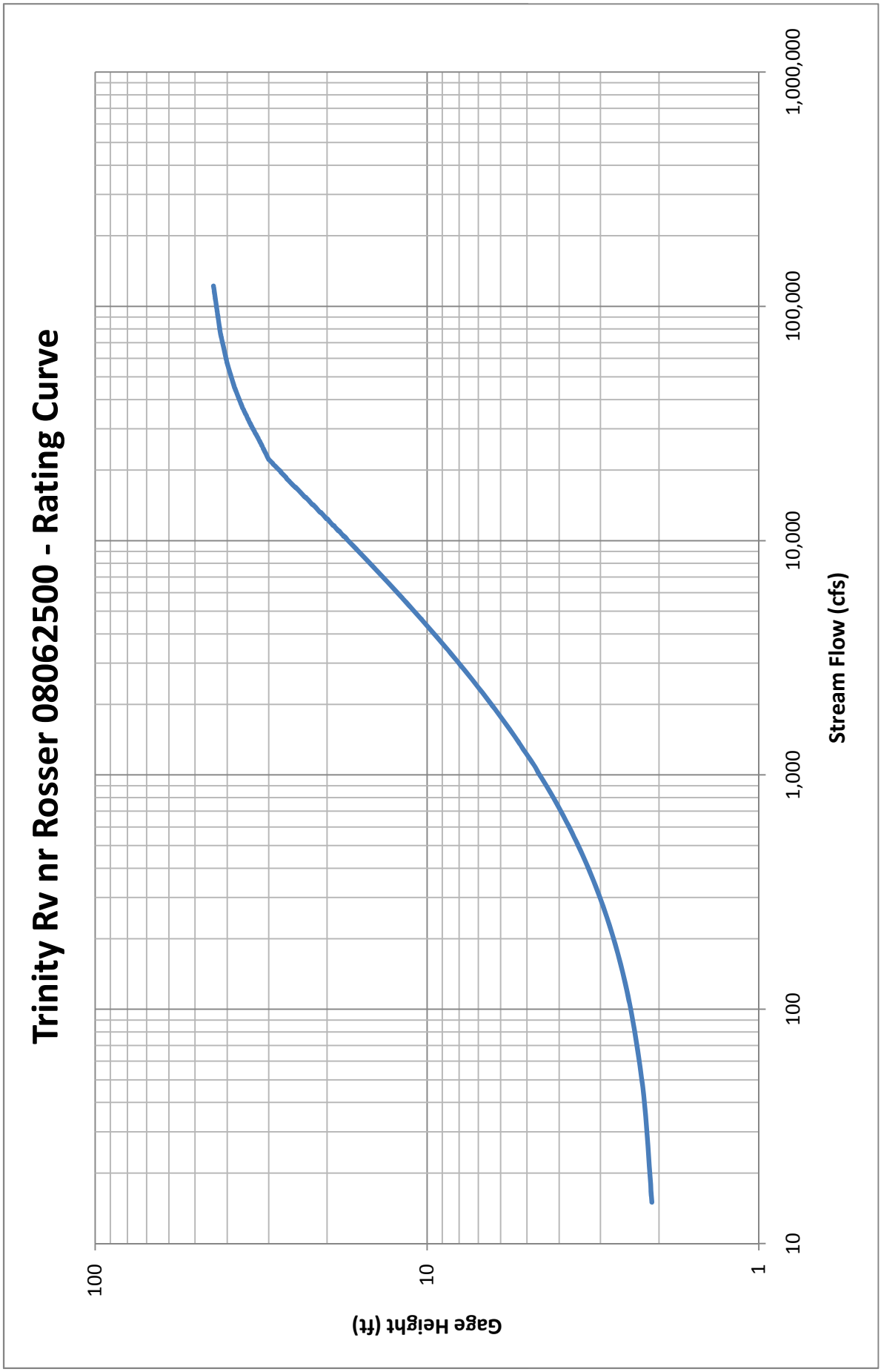
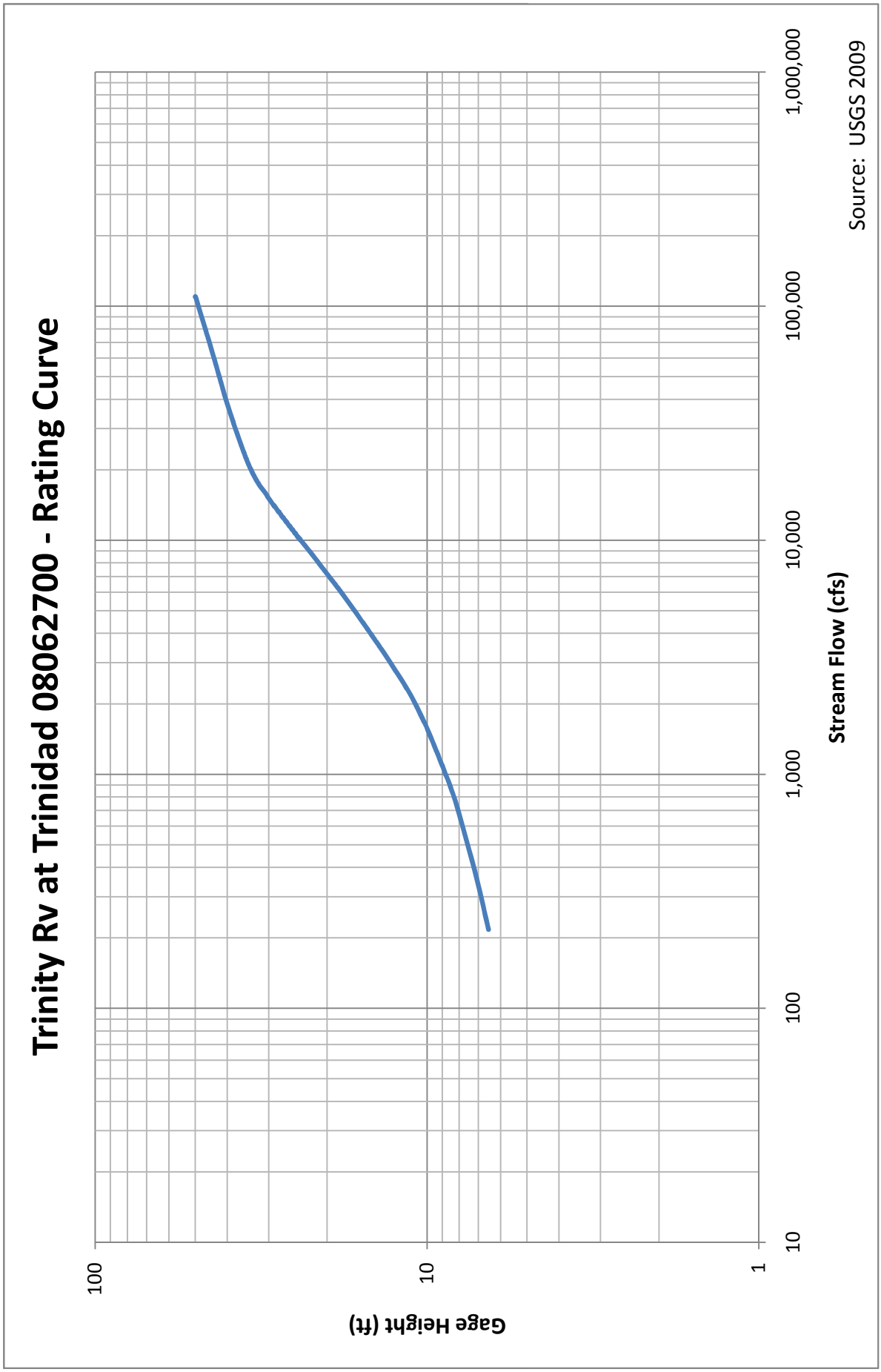
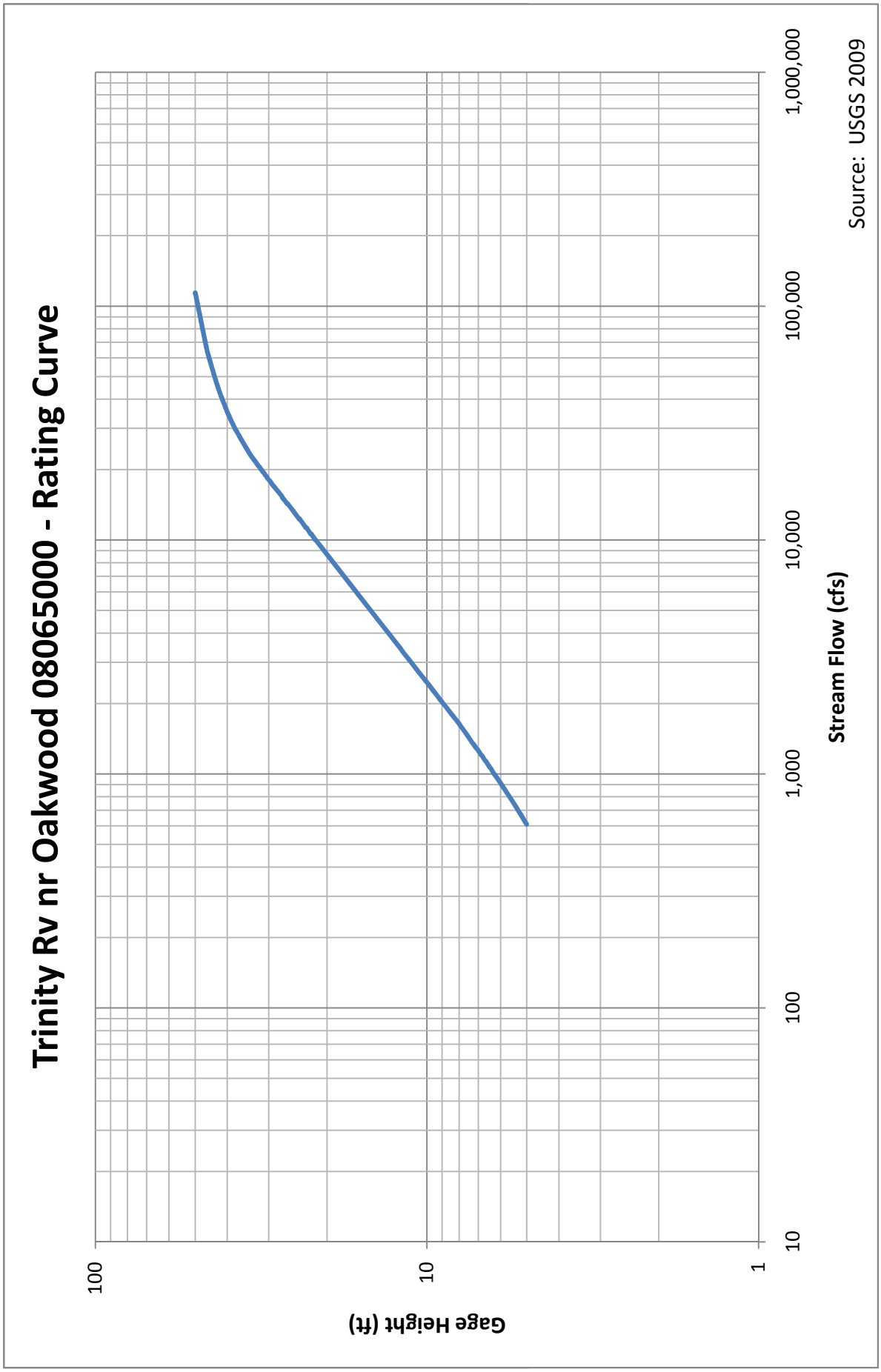
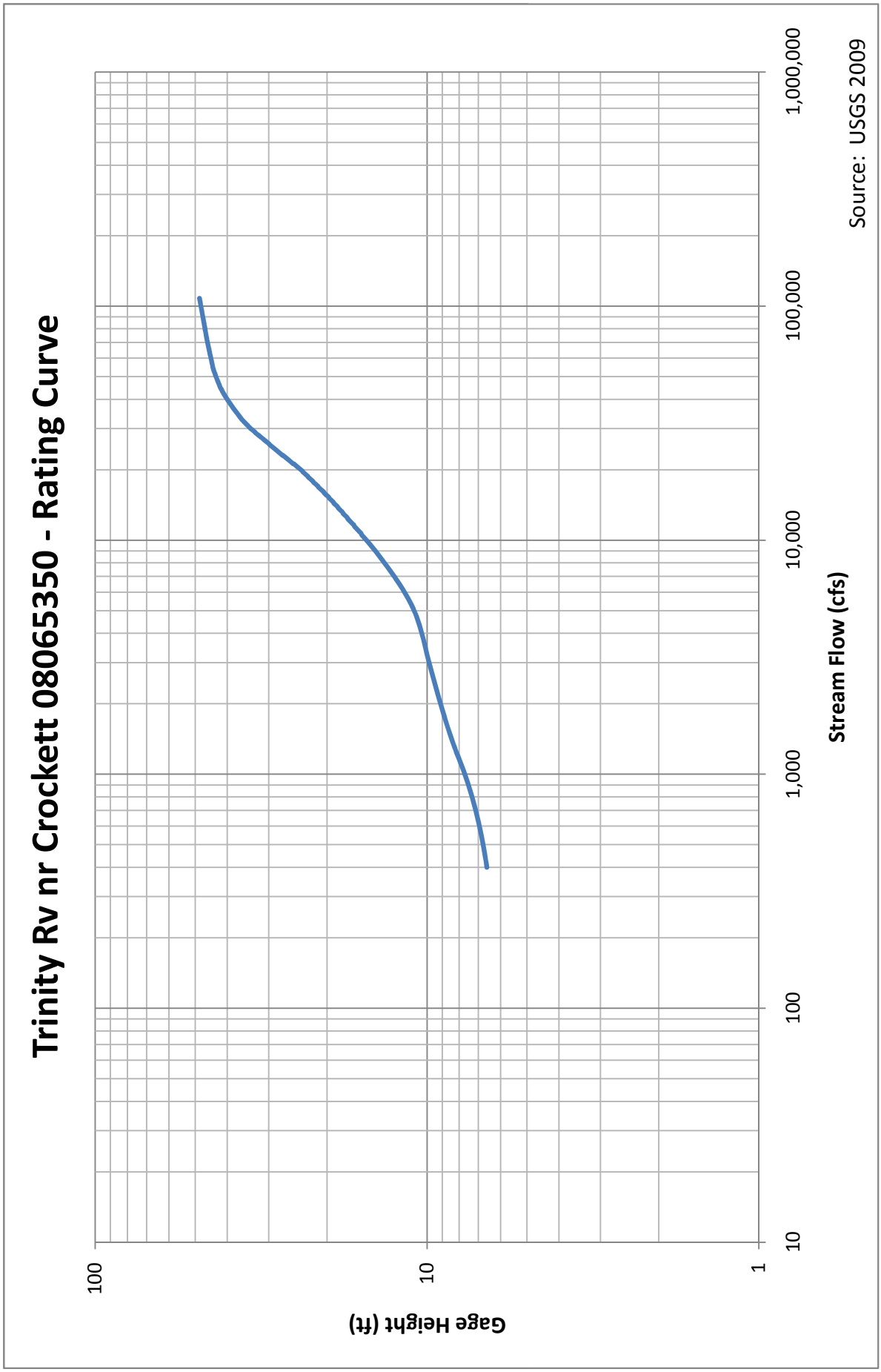
10
1
10
100
1,000
10,000
100,000
Stream Flow (cfs)
Source: USGS 2009

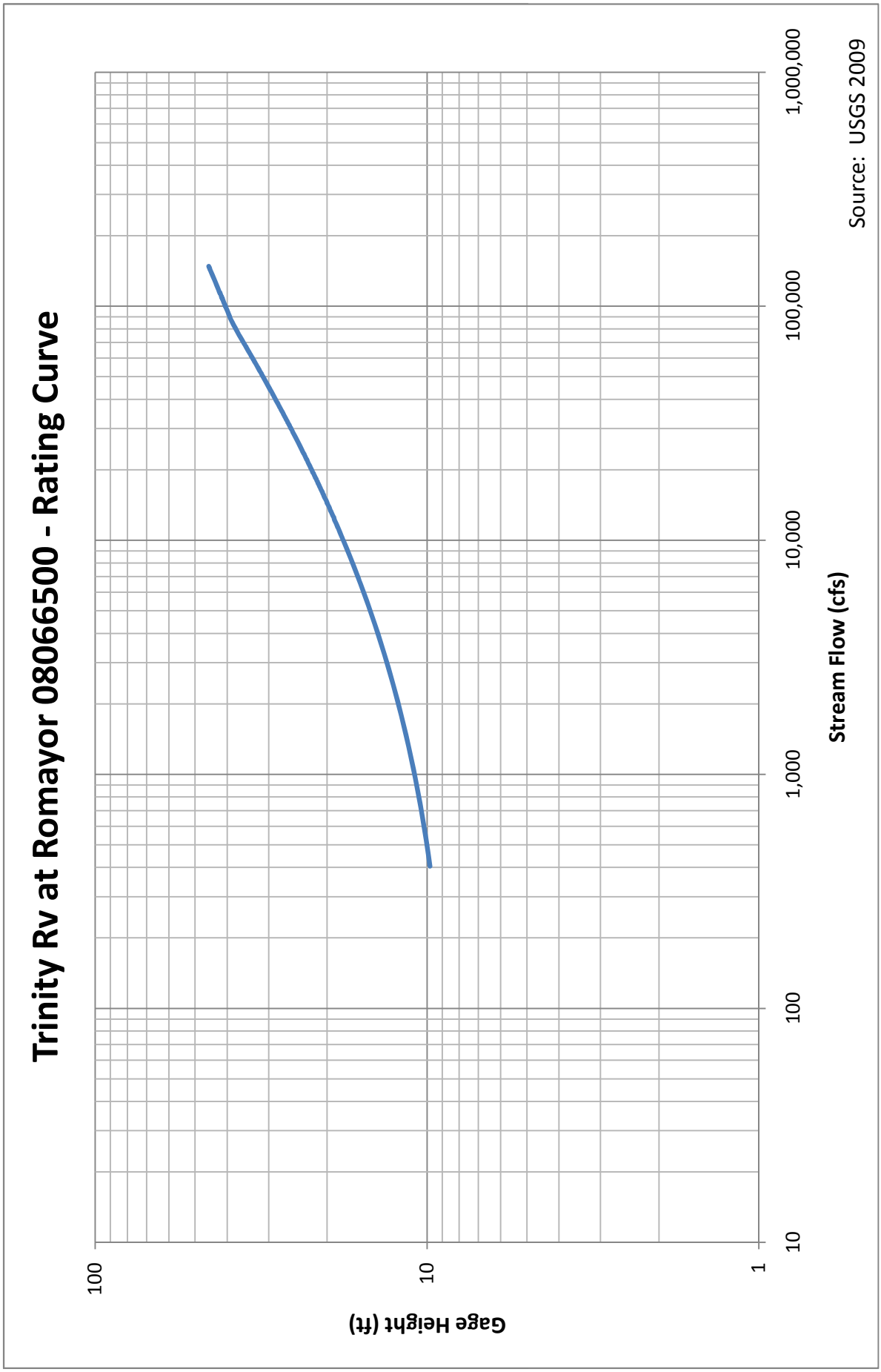

Trinity Rv at Dallas 08057000 - Rating Curve
Gage Height (ft)
100
10
1
10
100
1,000
10,000
100,000
Stream Flow (cfs)
Source: USGS 2009

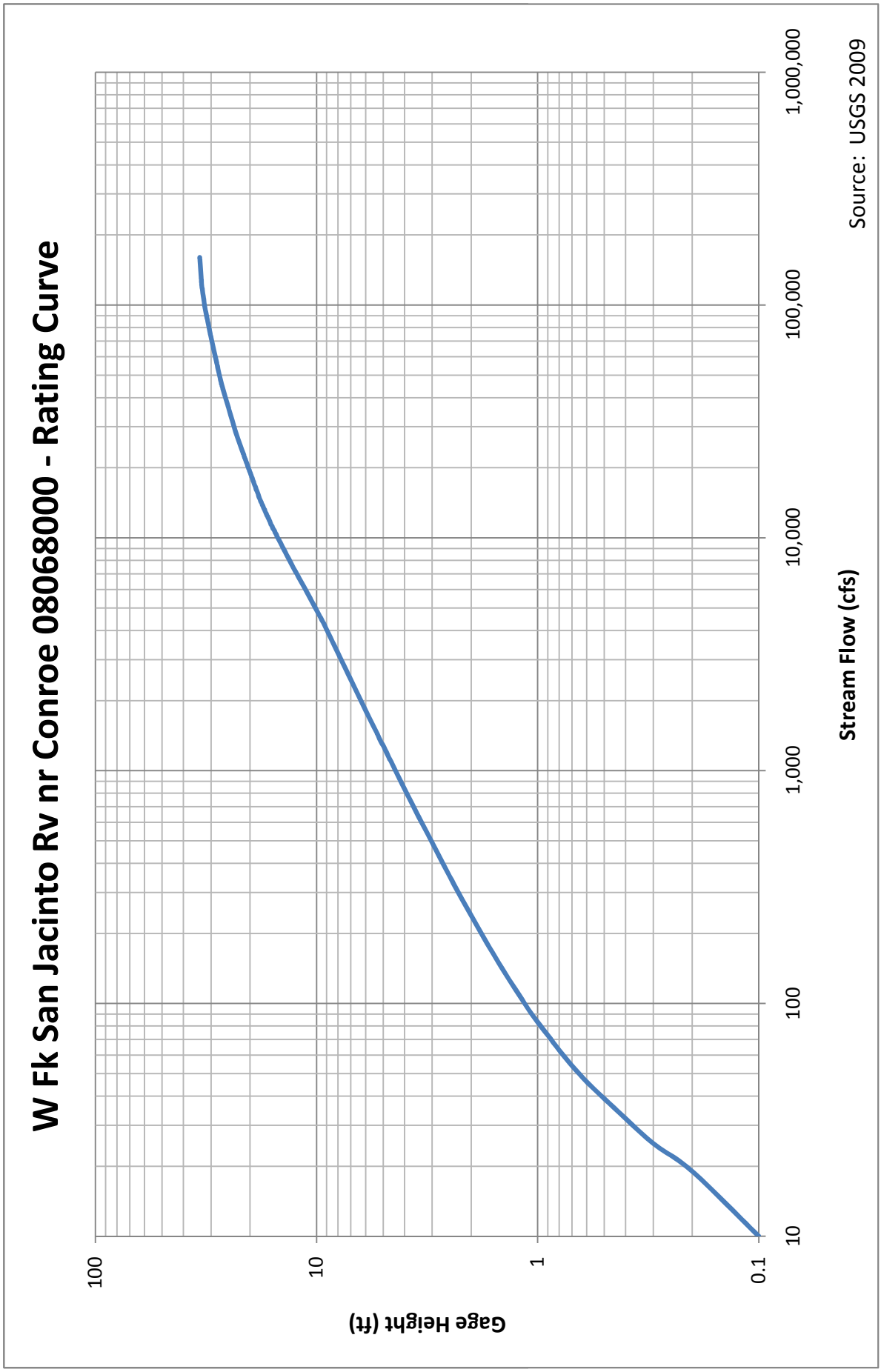

Trinity Rv nr Rosser 08062500 - Rating Curve
Gage Height (ft)
100
10
1
10
100
1,000
10,000
100,000
1,000,000
Stream Flow (cfs)

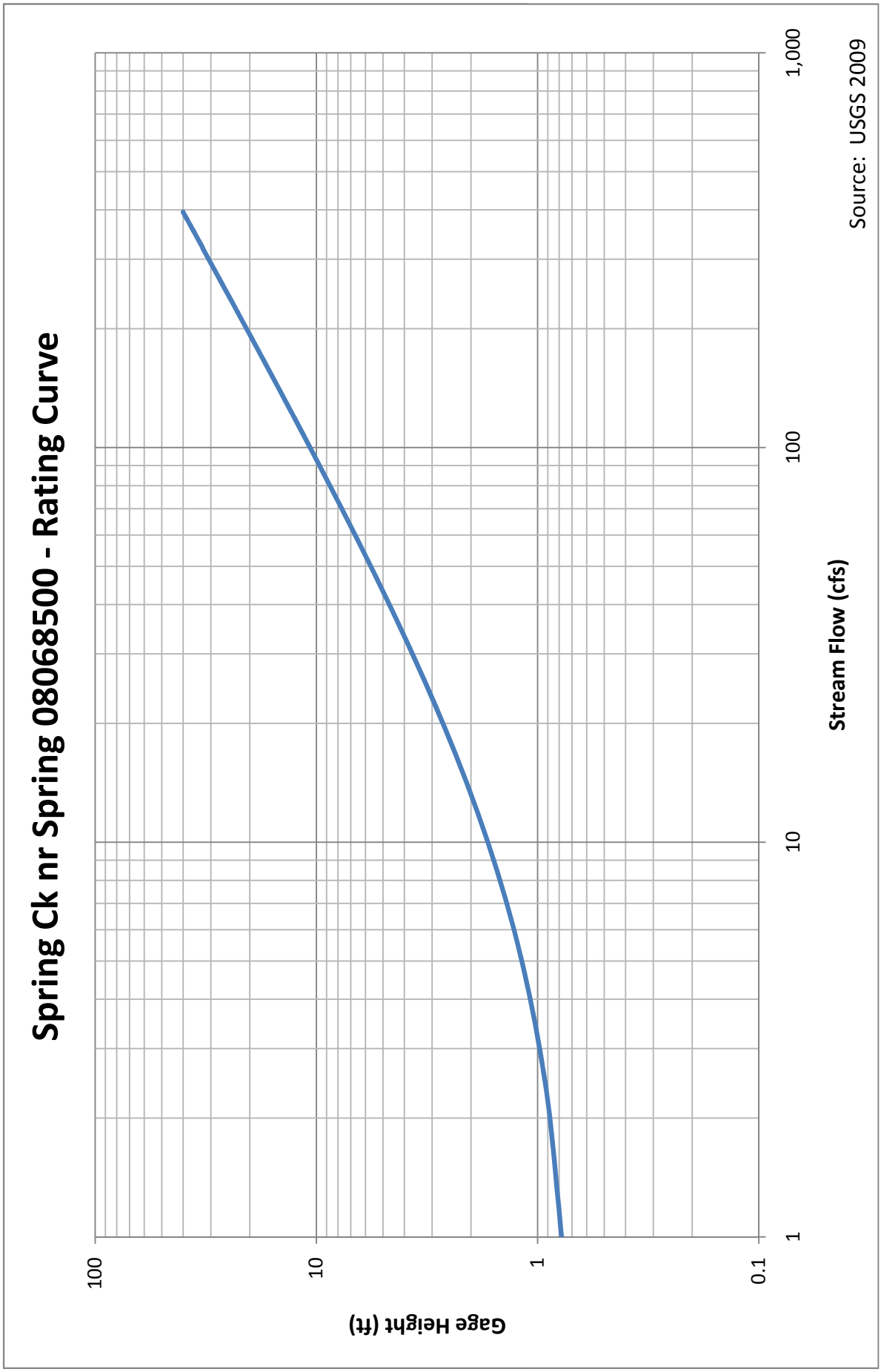

Trinity Rv at Trinidad 08062700 - Rating Curve
Gage Height (ft)
100
10
1
10
100
1,000
10,000
100,000
1,000,000
Stream Flow (cfs)
Source: USGS 2009

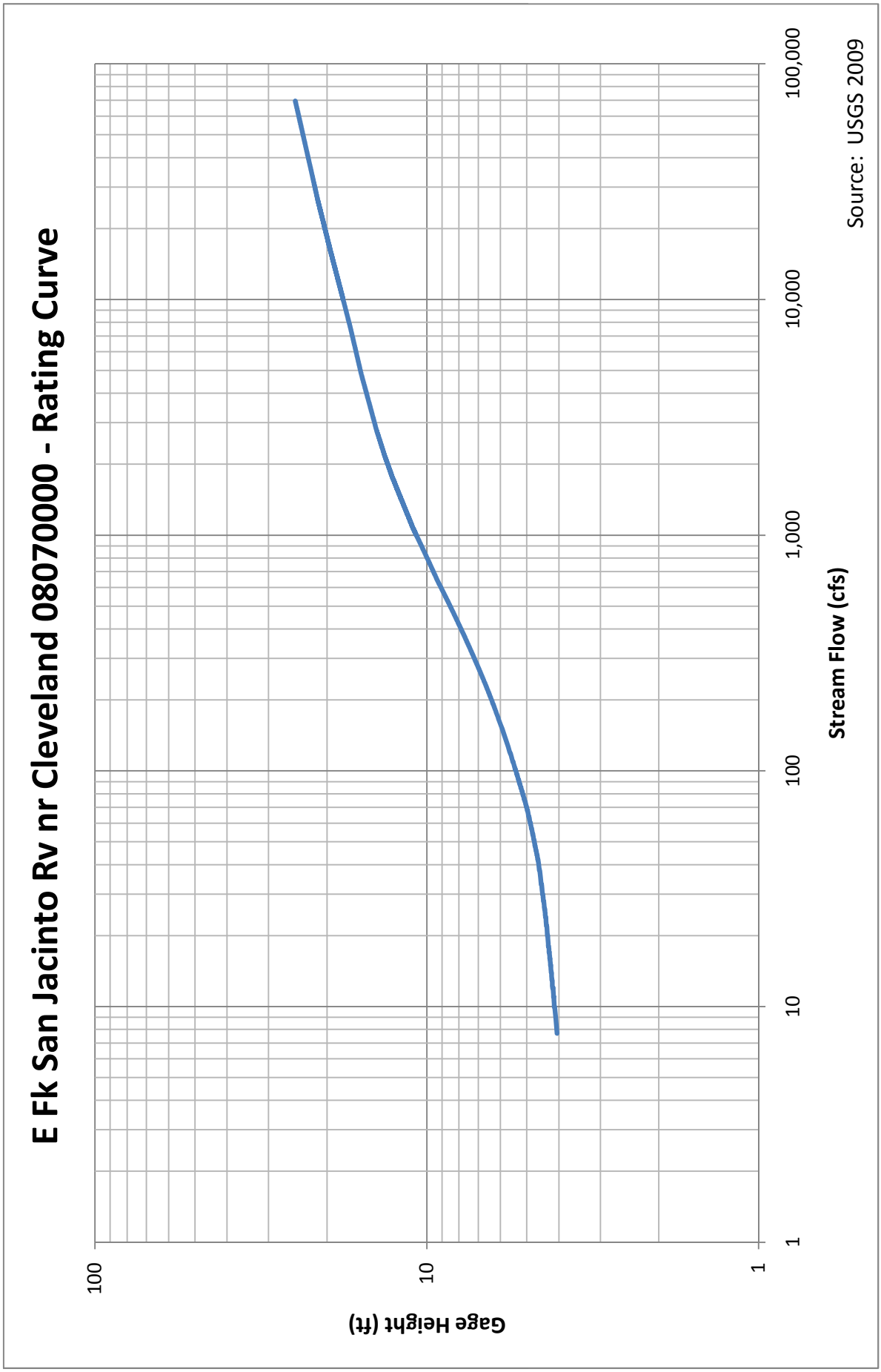

Trinity Rv nr Oakwood 08065000 - Rating Curve
Gage Height (ft)
100
10
1
10
100
1,000
10,000
100,000
1,000,000
Stream Flow (cfs)
Source: USGS 2009

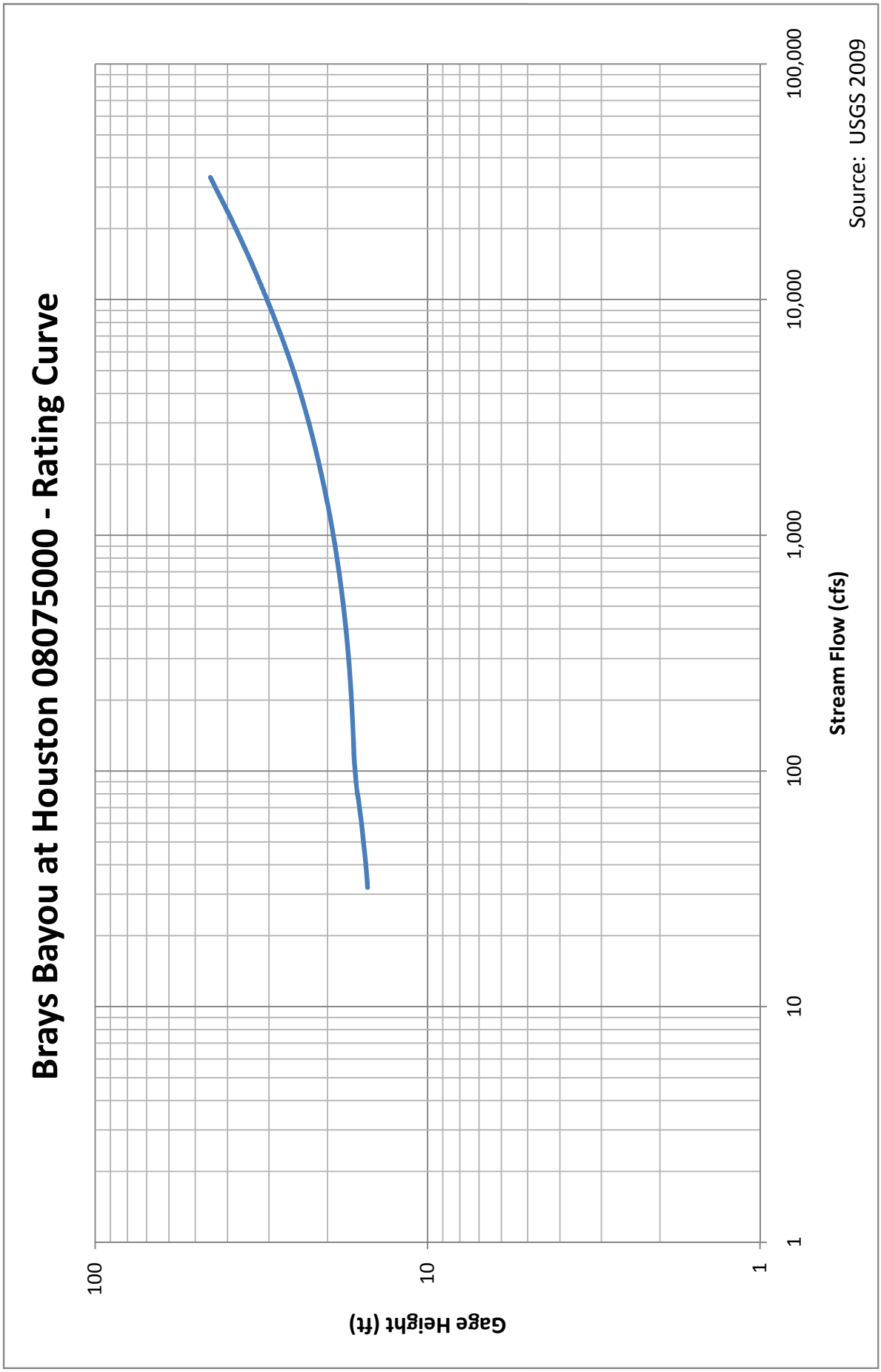

Trinity Rv nr Crockett 08065350 - Rating Curve
Gage Height (ft)
100
10
1
10
100
1,000
10,000
100,000
1,000,000
Stream Flow (cfs)
Source: USGS 2009

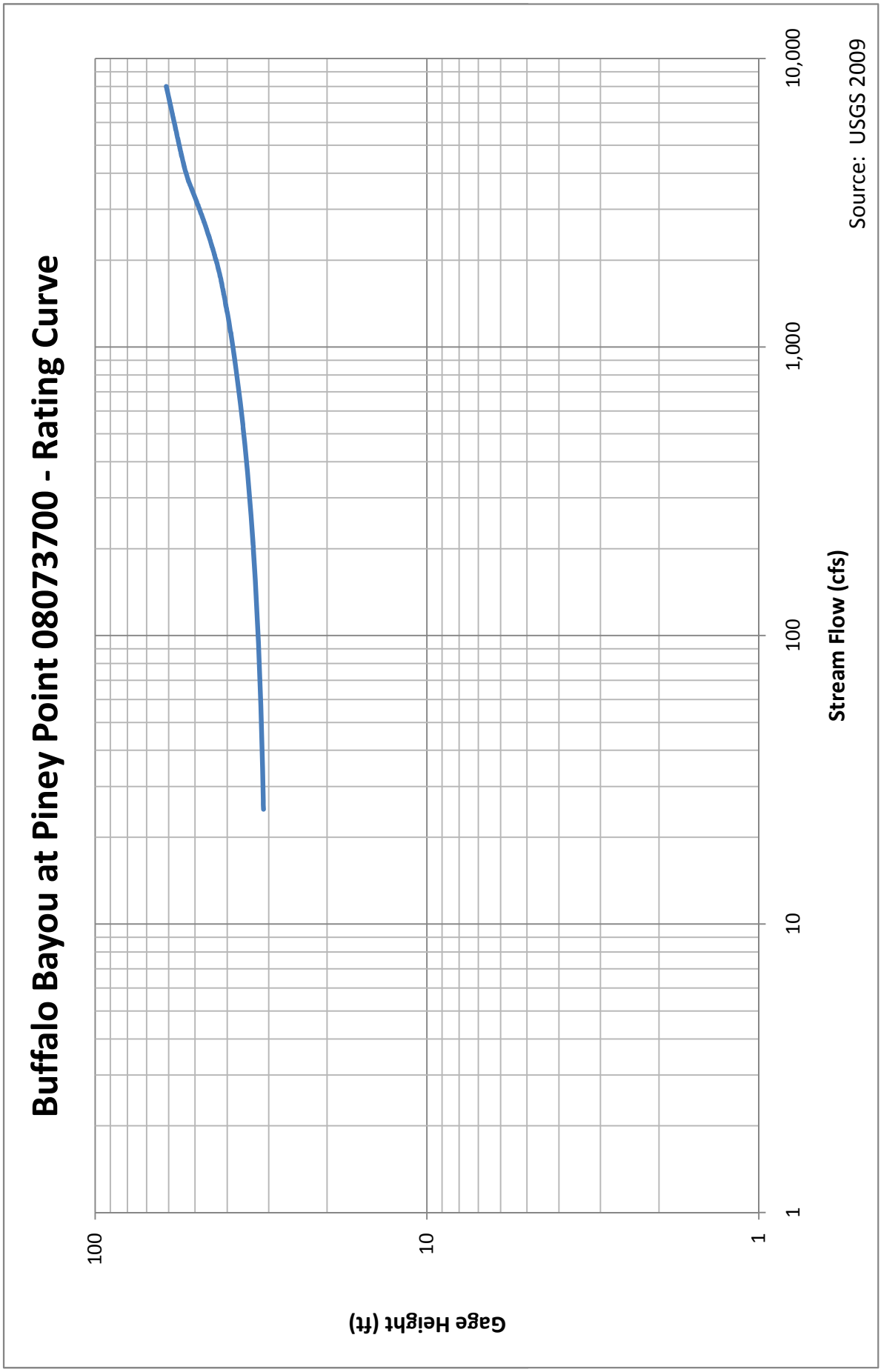

Trinity Rv at Romayor 08066500 - Rating Curve
Gage Height (ft)
100
10
1
10
100
1,000
10,000
100,000
1,000,000
Stream Flow (cfs)
Source: USGS 2009


W Fk San Jacinto Rv nr Conroe 08068000 - Rating Curve
Gage Height (ft)
100
10
1
0.1
10
100
1,000
10,000
100,000
1,000,000
Stream Flow (cfs)
Source: USGS 2009


Spring Ck nr Spring 08068500 - Rating Curve
Gage Height (ft)
100
10
1
0.1
1
10
100
1,000
Stream Flow (cfs)
Source: USGS 2009


E Fk San Jacinto Rv nr Cleveland 08070000 - Rating Curve
Gage Height (ft)
100
10
1
1
10
100
1,000
10,000
100,000
Stream Flow (cfs)
Source: USGS 2009


Brays Bayou at Houston 08075000 - Rating Curve
Gage Height (ft)
100
10
1
1
10
100
1,000
10,000
100,000
Stream Flow (cfs)
Source: USGS 2009


Buffalo Bayou at Piney Point 08073700 - Rating Curve
Gage Height (ft)
100
10
1
1
10
100
1,000
10,000
Stream Flow (cfs)
Source: USGS 2009

APPENDIX E – OUTPUT FOR CONROE

E.1 HEFR (PARAMETERIZED WITH MBFIT) E-1

E.2 HEFR (PARAMETERIZED WITH IHA) E-2

APPENDIX E: OUTPUT FOR CONROE

West Fork San Jacinto River near Conroe

MBFIT/HEFR Parameterization Results and Input Parameters

Original Approach

Overbank Flows	Return Period (R) : 4.1 (years)		Duration (D) : 24 (days)	
	Volume (V) : 134131 (ac-ft)		Peak Flow (Q) : 14000 (cfs)	
High Flow Pulses	F: 6	F: 6	F: 5	F: 6
	D: 14	D: 14	D: 11	D: 10
	Q: 1438	Q: 1500	Q: 266	Q: 509
	V: 14529	V: 12824	V: 2820	V: 4211
	F: 0	F: 0	F: 0	F: 0
	D: 8	D: 8	D: 5	D: 6
	Q: 329	Q: 284	Q: 89	Q: 143
	V: 2655	V: 2652	V: 691	V: 1135
	F: 0	F: 0	F: 0	F: 0
	D: 4	D: 4	D: 2	D: 2
	Q: 103	Q: 98	Q: 49	Q: 64
	V: 763	V: 562	V: 186	V: 269
Base Flows (cfs)	104	104	32	31
	50	60	24	24
	33	40	17	16
Subsistence Flows (cfs)	10	N/A	10	10
	Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
	Winter	Spring	Summer	Fall

Alternative Approach

Overbank Flows	Qp: 6,170 cfs with Frequency 2 per 3 years Volume is 39,384 to 72,472 (55,928) Duration is 13 to 44 (24)			
High Flow Pulses	Qp: 5,450 cfs with Frequency 1 per 2 seasons Volume is 66,586 to 106,044 (86,315) Duration is 14 to 44 (25)	Qp: 6,920 cfs with Frequency 1 per 2 seasons Volume is 62,039 to 89,399 (75,719) Duration is 13 to 41 (23)	Qp: 1,730 cfs with Frequency 1 per 2 seasons Volume is 10,419 to 19,061 (14,740) Duration is 7 to 27 (14)	Qp: 1,930 cfs with Frequency 1 per 2 seasons Volume is 10,808 to 23,764 (17,286) Duration is 8 to 26 (14)
	Qp: 2,290 cfs with Frequency 1 per season Volume is 22,267 to 61,514 (41,890) Duration is 9 to 29 (17)	Qp: 2,720 cfs with Frequency 1 per season Volume is 17,580 to 44,835 (31,208) Duration is 9 to 27 (15)	Qp: 424 cfs with Frequency 1 per season Volume is #N/A to 7,857 (3,536) Duration is 4 to 14 (7)	Qp: 570 cfs with Frequency 1 per season Volume is #N/A to 11,051 (4,572) Duration is 4 to 14 (8)
	Qp: 420 cfs with Frequency 2 per season Volume is #N/A to 24,577 (4,946) Duration is 4 to 13 (7)	Qp: 839 cfs with Frequency 2 per season Volume is #N/A to 22,722 (9,092) Duration is 5 to 17 (9)	Qp: 91 cfs with Frequency 2 per season Volume is #N/A to 4,949 (627) Duration is 2 to 7 (3)	Qp: 147 cfs with Frequency 2 per season Volume is #N/A to 7,098 (619) Duration is 2 to 7 (4)
Base Flows (cfs)	104	104	32	31
	50	60	24	24
	33	40	17	16
Subsistence Flows (cfs)	10	N/A	10	10
	Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov
	Winter	Spring	Summer	Fall

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

MBFI Parameters for Pre-processing

		Thresholds		Code3 Thresholds	
			Percentile		Percentile
N	3				
f	0.9	high flow upper	0.75	extreme low flow	0.1
Runoff Fraction	0.2	high flow lower	0.35	small flood	2.5
				large flood	99.99

APPENDIX E: OUTPUT FOR CONROE

West Fork San Jacinto River near Conroe

IHA/HEFR Parameterization Results and Input Parameters

Original Approach

Overbank Flows	Return Period (R) : 2.4 (years)		Duration (D) : 35 (days)	
	Volume (V) : 146120 (ac-ft)		Peak Flow (Q) : 14000 (cfs)	
High Flow Pulses	F: 1	F: 1	F: 1	F: 2
	D: 17	D: 22	D: 12	D: 11
	Q: 1760	Q: 2395	Q: 500	Q: 538
	V: 25091	V: 30210	V: 4069	V: 3930
	F: 2	F: 2	F: 2	F: 3
	D: 10	D: 12	D: 6	D: 6
	Q: 468	Q: 696	Q: 138	Q: 190
	V: 4766	V: 7431	V: 876	V: 1284
	F: 3	F: 3	F: 3	F: 3
	D: 7	D: 7	D: 3	D: 3
	Q: 215	Q: 245	Q: 63	Q: 64
	V: 2015	V: 1994	V: 254	V: 276
Base Flows (cfs)	104	97	39	35
	55	62	26	25
	35	44	18	16
Subsistence Flows (cfs)	10	N/A	10	10
	Dec Jan Feb	Mar Apr May	Jun Jul Aug	Sep Oct Nov
	Winter	Spring	Summer	Fall

Alternative Approach

Overbank Flows	Qp: 8,510 cfs with Frequency 1 per year Volume is 64,923 to 109,819 (87,371) Duration is 21 to 56 (34)			
High Flow Pulses	Qp: 9,570 cfs with Frequency 1 per 5 seasons Volume is 107,244 to 156,989 (132,117) Duration is 25 to 67 (41)	Qp: 11,700 cfs with Frequency 1 per 5 seasons Volume is 107,591 to 150,086 (128,839) Duration is 22 to 54 (34)	Qp: 4,280 cfs with Frequency 1 per 5 seasons Volume is 31,064 to 49,377 (40,221) Duration is 14 to 40 (23)	Qp: 7,920 cfs with Frequency 1 per 5 seasons Volume is 75,587 to 95,806 (85,697) Duration is 20 to 54 (33)
	Qp: 4,140 cfs with Frequency 3 per 5 seasons Volume is 24,563 to 151,653 (88,108) Duration is 2 to 395 (27)	Qp: 4,920 cfs with Frequency 3 per 5 seasons Volume is #N/A to 124,796 (60,267) Duration is 2 to 364 (24)	Qp: 714 cfs with Frequency 3 per 5 seasons Volume is #N/A to 55,991 (6,437) Duration is 1 to 86 (10)	Qp: 1,000 cfs with Frequency 3 per 5 seasons Volume is #N/A to 106,644 (9,635) Duration is 1 to 90 (11)
	Qp: 300 cfs with Frequency 2 per season Volume is #N/A to 63,974 (418) Duration is 1 to 107 (7)	Qp: 490 cfs with Frequency 2 per season Volume is #N/A to 69,804 (5,223) Duration is 1 to 138 (9)	Qp: 42 cfs with Frequency 2 per season Volume is #N/A to 49,384 (#N/A) Duration is 0 to 23 (3)	Qp: 113 cfs with Frequency 2 per season Volume is #N/A to 96,780 (#N/A) Duration is 0 to 30 (4)
Base Flows (cfs)	104	97	39	35
	55	62	26	25
	35	44	18	16
Subsistence Flows (cfs)	10	N/A	10	10
	Dec Jan Feb	Mar Apr May	Jun Jul Aug	Sep Oct Nov
	Winter	Spring	Summer	Fall

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

IHA Parameters for Pre-processing

HFP upper	75%	small flood	2 years
HFP lower	25%	large flood	99 years
HFP rise rate	50% per day	extreme low flow	10%
HFP fall rate	5% per day		

APPENDIX F – FLOW MATRICES (HEFR RESULTS)

F.1	TRINITY BASIN	F-1
F.2	SAN JACINTO BASIN	F-21

Elm Fork Trinity River near Carrollton
Pre-impact - IHA (Adjusted)

	Winter	Spring	Summer	Fall
Overbank Flows	Qp: 9,000 cfs with Frequency 2 per 3 years Volume is 9 to 802,386,366 (86,247) Duration is 2 to 154 (18)			
High Flow Pulses	Qp: 7,900 cfs with Frequency 1 per 2 seasons Volume is 5 to 1,130,633,751 (76,329) Duration is 2 to 192 (18)	Qp: 9,610 cfs with Frequency 1 per 2 seasons Volume is 6 to 1,527,754,914 (93,026) Duration is 2 to 181 (18)	Qp: 5,340 cfs with Frequency 1 per 2 seasons Volume is 7 to 336,734,036 (49,309) Duration is 2 to 109 (15)	Qp: 3,490 cfs with Frequency 1 per 2 seasons Volume is 4 to 167,273,259 (25,358) Duration is 1 to 82 (11)
	Qp: 2,420 cfs with Frequency 1 per season Volume is 1 to 284,839,464 (20,034) Duration is 1 to 114 (11)	Qp: 5,280 cfs with Frequency 1 per season Volume is 25,332 to 84,582 (46,289) Duration is 8 to 24 (14)	Qp: 2,460 cfs with Frequency 1 per season Volume is 10,827 to 33,525 (19,052) Duration is 6 to 18 (10)	Qp: 1,390 cfs with Frequency 1 per season Volume is 4,568 to 17,840 (9,027) Duration is 4 to 15 (7)
	Qp: 372 cfs with Frequency 2 per season Volume is 1,277 to 4,552 (2,411) Duration is 3 to 9 (5)	Qp: 1,490 cfs with Frequency 2 per season Volume is 5,804 to 19,342 (10,595) Duration is 5 to 14 (8)	Qp: 540 cfs with Frequency 2 per season Volume is 1,686 to 5,213 (2,965) Duration is 3 to 8 (5)	Qp: 306 cfs with Frequency 2 per season Volume is 836 to 3,267 (1,652) Duration is 2 to 8 (4)
Base Flows (cfs)	180	205	235	192
	102	118	112	102
	60	62	41	45
Subsistence Flows (cfs)	0	0	0	0

Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Winter			Spring			Summer			Fall		

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Trinity River at Dallas
Pre-impact - IHA (adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 12,100 cfs with Frequency 2 per 3 years Volume is 12 to 1,614,608,764 (137,433) Duration is 11 to 34 (20)			
High Flow Pulses	Qp: 8,980 cfs with Frequency 1 per 2 seasons Volume is 7 to 1,338,054,291 (96,551) Duration is 2 to 151 (17)	Qp: 14,200 cfs with Frequency 1 per 2 seasons Volume is 7 to 3,548,961,316 (157,251) Duration is 2 to 218 (21)	Qp: 7,760 cfs with Frequency 1 per 2 seasons Volume is 8 to 872,952,771 (82,901) Duration is 2 to 131 (16)	Qp: 5,860 cfs with Frequency 1 per 2 seasons Volume is 8 to 485,113,786 (63,201) Duration is 2 to 122 (16)
	Qp: 3,300 cfs with Frequency 1 per season Volume is 2 to 402,181,892 (29,882) Duration is 1 to 98 (11)	Qp: 7,820 cfs with Frequency 1 per season Volume is 3 to 1,689,195,351 (76,057) Duration is 1 to 163 (15)	Qp: 2,740 cfs with Frequency 1 per season Volume is 2 to 243,014,776 (23,867) Duration is 1 to 83 (10)	Qp: 1,930 cfs with Frequency 1 per season Volume is 2 to 117,985,400 (15,887) Duration is 1 to 69 (9)
	Qp: 680 cfs with Frequency 2 per season Volume is 0 to 62,842,858 (4,696) Duration is 1 to 50 (6)	Qp: 2,380 cfs with Frequency 2 per season Volume is 1 to 391,364,636 (17,869) Duration is 1 to 91 (9)	Qp: 688 cfs with Frequency 2 per season Volume is 0 to 46,143,856 (4,570) Duration is 1 to 46 (6)	Qp: 520 cfs with Frequency 2 per season Volume is 0 to 22,965,037 (3,111) Duration is 1 to 36 (5)
Base Flows (cfs)	297	352	270	205
	128	139	105	88
	43	55	44	40
Subsistence Flows (cfs)	0	0	0	0

Hydrologic Conditions	
	Wet (0th %ile)
	Average (0th %ile)
	Dry (0th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

West Fork Trinity River at Grand Prairie
Pre-impact - IHA (Adjusted)

	Winter	Spring	Summer	Fall
Overbank Flows	Qp: 4,680 cfs with Frequency 2 per 3 years Volume is 12 to 255,893,208 (56,288) Duration is 12 to 36 (21)			
High Flow Pulses	Qp: 4,350 cfs with Frequency 1 per 2 seasons Volume is 9 to 300,879,825 (52,506) Duration is 2 to 157 (19)	Qp: 5,330 cfs with Frequency 1 per 2 seasons Volume is 8 to 430,093,584 (58,733) Duration is 2 to 181 (21)	Qp: 1,920 cfs with Frequency 1 per 2 seasons Volume is 5 to 85,591,807 (20,143) Duration is 2 to 105 (14)	Qp: 2,000 cfs with Frequency 1 per 2 seasons Volume is 6 to 77,216,440 (21,049) Duration is 2 to 121 (16)
	Qp: 1,380 cfs with Frequency 1 per season Volume is 2 to 66,883,554 (12,371) Duration is 1 to 84 (10)	Qp: 2,120 cfs with Frequency 1 per season Volume is 3 to 129,561,150 (18,433) Duration is 1 to 106 (12)	Qp: 867 cfs with Frequency 1 per season Volume is 2 to 29,054,603 (7,129) Duration is 1 to 66 (9)	Qp: 620 cfs with Frequency 1 per season Volume is 1 to 15,936,915 (4,578) Duration is 1 to 58 (8)
	Qp: 415 cfs with Frequency 2 per season Volume is 1 to 14,529,477 (2,725) Duration is 1 to 44 (6)	Qp: 917 cfs with Frequency 2 per season Volume is 3,672 to 11,255 (6,428) Duration is 4 to 13 (8)	Qp: 346 cfs with Frequency 2 per season Volume is 1,186 to 3,886 (2,147) Duration is 3 to 10 (5)	Qp: 206 cfs with Frequency 2 per season Volume is 595 to 1,995 (1,090) Duration is 2 to 7 (4)
Base Flows (cfs)	127	167	87	76
	85	89	53	51
	50	53	37	37
Subsistence Flows (cfs)	19	18	17	16
	Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov

Hydrologic Conditions	
	Wet (0th %ile)
	Average (0th %ile)
	Dry (0th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Trinity River near Oakwood
Pre-impact - IHA (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 17,900 cfs with Frequency 2 per 3 years Volume is 249,841 to 562,083 (374,742) Duration is 14 to 33 (21)			
High Flow Pulses	Qp: 16,700 cfs with Frequency 1 per 2 seasons Volume is 216,323 to 510,695 (332,378) Duration is 12 to 30 (19)	Qp: 25,800 cfs with Frequency 1 per 2 seasons Volume is 435,672 to 975,372 (651,876) Duration is 17 to 43 (28)	Qp: 12,100 cfs with Frequency 1 per 2 seasons Volume is 6 to 8,722,037,707 (226,495) Duration is 2 to 170 (18)	Qp: 11,600 cfs with Frequency 1 per 2 seasons Volume is 5 to 6,801,761,816 (191,228) Duration is 2 to 147 (16)
	Qp: 11,200 cfs with Frequency 1 per season Volume is 3 to 14,222,928,029 (189,617) Duration is 1 to 169 (15)	Qp: 13,600 cfs with Frequency 1 per season Volume is 2 to 32,156,053,186 (255,706) Duration is 1 to 255 (18)	Qp: 4,500 cfs with Frequency 1 per season Volume is 1 to 1,952,127,787 (53,370) Duration is 1 to 90 (10)	Qp: 4,960 cfs with Frequency 1 per season Volume is 2 to 2,023,514,429 (59,731) Duration is 1 to 92 (10)
	Qp: 3,200 cfs with Frequency 2 per season Volume is 0 to 2,404,677,789 (32,621) Duration is 1 to 85 (8)	Qp: 5,500 cfs with Frequency 2 per season Volume is 1 to 8,458,975,836 (68,093) Duration is 1 to 141 (10)	Qp: 1,370 cfs with Frequency 2 per season Volume is 0 to 345,433,555 (9,387) Duration is 1 to 43 (5)	Qp: 1,830 cfs with Frequency 2 per season Volume is 0 to 512,706,292 (15,245) Duration is 1 to 54 (6)
Base Flows (cfs)	1355	1770	816	585
	599	914	418	340
	319	473	246	224
Subsistence Flows (cfs)	112	92	86	96

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Trinity River at Romayor
Pre-impact - IHA (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 27,200 cfs with Frequency 2 per 3 years Volume is 366,127 to 1,039,950 (617,052) Duration is 12 to 36 (21)			
High Flow Pulses	Qp: 26,800 cfs with Frequency 1 per 2 seasons Volume is 3 to 95,086,974,963 (570,329) Duration is 2 to 250 (20)	Qp: 35,100 cfs with Frequency 1 per 2 seasons Volume is 4 to 281,997,579,850 (1,022,558) Duration is 2 to 415 (27)	Qp: 15,300 cfs with Frequency 1 per 2 seasons Volume is 2 to 34,051,992,111 (288,343) Duration is 1 to 183 (16)	Qp: 14,000 cfs with Frequency 1 per 2 seasons Volume is 3 to 16,611,064,796 (216,348) Duration is 1 to 130 (14)
	Qp: 19,600 cfs with Frequency 1 per season Volume is 2 to 59,032,811,059 (362,222) Duration is 1 to 205 (17)	Qp: 19,500 cfs with Frequency 1 per season Volume is 2 to 105,593,879,533 (398,678) Duration is 1 to 265 (17)	Qp: 6,460 cfs with Frequency 1 per season Volume is 1 to 9,373,719,153 (83,102) Duration is 1 to 109 (10)	Qp: 7,460 cfs with Frequency 1 per season Volume is 1 to 6,740,196,244 (90,771) Duration is 1 to 90 (10)
	Qp: 8,460 cfs with Frequency 2 per season Volume is 1 to 17,065,584,387 (107,041) Duration is 1 to 122 (10)	Qp: 8,680 cfs with Frequency 2 per season Volume is 0 to 28,754,639,924 (108,976) Duration is 1 to 144 (10)	Qp: 1,280 cfs with Frequency 2 per season Volume is 0 to 1,042,351,903 (8,040) Duration is 0 to 43 (4)	Qp: 2,460 cfs with Frequency 2 per season Volume is 0 to 1,483,413,106 (19,642) Duration is 1 to 48 (5)
Base Flows (cfs)	2930	3500	1925	1310
	1400	1990	980	765
	825	1180	600	525
Subsistence Flows (cfs)	276	N/A	232	257

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Trinity River near Rosser
Pre-impact - IHA (Adjusted)

Overbank Flows	Qp: 17,600 cfs with Frequency 2 per 3 years Volume is 189,406 to 519,521 (313,688) Duration is 12 to 36 (21)			
High Flow Pulses	Qp: 12,600 cfs with Frequency 1 per 2 seasons Volume is 111,144 to 403,266 (211,709) Duration is 9 to 33 (17)	Qp: 17,600 cfs with Frequency 1 per 2 seasons Volume is 189,142 to 432,619 (286,053) Duration is 12 to 31 (20)	Qp: 15,300 cfs with Frequency 1 per 2 seasons Volume is 160,639 to 440,950 (266,146) Duration is 12 to 34 (20)	Qp: 5,200 cfs with Frequency 1 per 2 seasons Volume is 38,380 to 103,572 (63,048) Duration is 7 to 19 (11)
	Qp: 5,400 cfs with Frequency 1 per season Volume is 35,098 to 125,616 (66,399) Duration is 6 to 20 (11)	Qp: 9,440 cfs with Frequency 1 per season Volume is 80,080 to 182,108 (120,761) Duration is 8 to 21 (13)	Qp: 6,620 cfs with Frequency 1 per season Volume is 53,033 to 143,931 (87,367) Duration is 8 to 21 (13)	Qp: 3,280 cfs with Frequency 1 per season Volume is 19,656 to 52,702 (32,186) Duration is 5 to 14 (8)
	Qp: 2,660 cfs with Frequency 2 per season Volume is 13,327 to 47,636 (25,196) Duration is 4 to 14 (7)	Qp: 3,940 cfs with Frequency 2 per season Volume is 23,920 to 54,255 (36,025) Duration is 5 to 12 (8)	Qp: 1,440 cfs with Frequency 2 per season Volume is 0 to 539,985,345 (11,494) Duration is 1 to 59 (6)	Qp: 1,200 cfs with Frequency 2 per season Volume is 0 to 184,583,488 (7,421) Duration is 1 to 33 (4)
Base Flows (cfs)	889	1340	614	500
	446	758	403	304
	228	401	261	199
Subsistence Flows (cfs)	100	111	134	122
	Dec, Jan, Feb Winter	Mar, Apr, May Spring	Jun, Jul, Aug Summer	Sep, Oct, Nov Fall

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Elm Fork Trinity River near Carrollton
Current - IHA (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 4,260 cfs with Frequency 2 per 3 years Volume is 24,841 to 97,891 (49,312) Duration is 7 to 27 (14)			
High Flow Pulses	Qp: 3,780 cfs with Frequency 1 per 2 seasons Volume is 15,121 to 63,062 (30,880) Duration is 4 to 19 (9)	Qp: 4,270 cfs with Frequency 1 per 2 seasons Volume is 29,518 to 136,207 (63,408) Duration is 9 to 35 (17)	Qp: 1,820 cfs with Frequency 1 per 2 seasons Volume is 12,648 to 43,043 (23,333) Duration is 7 to 23 (12)	Qp: 1,640 cfs with Frequency 1 per 2 seasons Volume is 5,414 to 18,088 (9,896) Duration is 3 to 12 (6)
	Qp: 1,930 cfs with Frequency 1 per season Volume is 6,356 to 26,288 (12,927) Duration is 3 to 13 (6)	Qp: 1,860 cfs with Frequency 1 per season Volume is 8,709 to 39,712 (18,597) Duration is 5 to 20 (10)	Qp: 914 cfs with Frequency 1 per season Volume is 4,610 to 15,561 (8,470) Duration is 4 to 14 (8)	Qp: 1,020 cfs with Frequency 1 per season Volume is 3,038 to 10,095 (5,538) Duration is 3 to 9 (5)
	Qp: 650 cfs with Frequency 2 per season Volume is 1,558 to 6,394 (3,156) Duration is 2 to 8 (4)	Qp: 679 cfs with Frequency 2 per season Volume is 1,975 to 8,942 (4,202) Duration is 2 to 10 (5)	Qp: 427 cfs with Frequency 2 per season Volume is 1,507 to 5,069 (2,764) Duration is 3 to 8 (5)	Qp: 617 cfs with Frequency 2 per season Volume is 1,646 to 5,451 (2,996) Duration is 2 to 7 (4)
Base Flows (cfs)	126	165	213	149
	87	103	174	101
	59	75	131	73
Subsistence Flows (cfs)	10	9	11	15

Hydrologic Conditions
Wet (75th %ile)
Average (50th %ile)
Dry (25th %ile)
Subsistence

High Flow Pulse Characteristics
F = Frequency (per season)
D = Duration (days)
Q = Peak Flows (cfs)
V = Volume (ac-ft)

Trinity River at Dallas
Current - IHA (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 14,500 cfs with Frequency 2 per 3 years Volume is 87,449 to 241,273 (145,255) Duration is 8 to 23 (14)			
High Flow Pulses	Qp: 14,400 cfs with Frequency 1 per 2 seasons Volume is 79,006 to 232,379 (135,497) Duration is 7 to 22 (13)	Qp: 13,600 cfs with Frequency 1 per 2 seasons Volume is 94,070 to 261,057 (156,708) Duration is 9 to 26 (15)	Qp: 10,100 cfs with Frequency 1 per 2 seasons Volume is 63,789 to 173,184 (105,106) Duration is 7 to 21 (13)	Qp: 10,200 cfs with Frequency 1 per 2 seasons Volume is 46,471 to 121,578 (75,165) Duration is 6 to 17 (10)
	Qp: 7,820 cfs with Frequency 1 per season Volume is 2 to 1,628,304,614 (61,005) Duration is 1 to 59 (9)	Qp: 6,700 cfs with Frequency 1 per season Volume is 2 to 1,699,727,815 (56,028) Duration is 1 to 63 (9)	Qp: 3,880 cfs with Frequency 1 per season Volume is 1 to 565,978,651 (28,586) Duration is 1 to 44 (7)	Qp: 6,180 cfs with Frequency 1 per season Volume is 2 to 804,002,195 (40,503) Duration is 1 to 46 (8)
	Qp: 4,160 cfs with Frequency 2 per season Volume is 1 to 690,577,770 (26,735) Duration is 1 to 40 (6)	Qp: 3,950 cfs with Frequency 2 per season Volume is 1 to 771,915,532 (26,002) Duration is 1 to 42 (6)	Qp: 1,680 cfs with Frequency 2 per season Volume is 0 to 178,913,634 (9,149) Duration is 1 to 26 (4)	Qp: 3,590 cfs with Frequency 2 per season Volume is 1 to 398,797,110 (20,720) Duration is 1 to 34 (6)
Base Flows (cfs)	714	853	581	522
	538	665	481	453
	458	525	440	416
Subsistence Flows (cfs)	356	342	359	354

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

West Fork Trinity River at Grand Prairie
Current - IHA (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 6,380 cfs with Frequency 2 per 3 years Volume is 33,902 to 87,828 (54,567) Duration is 9 to 23 (14)			
High Flow Pulses	Qp: 5,920 cfs with Frequency 1 per 2 seasons Volume is 32,590 to 92,030 (54,766) Duration is 10 to 27 (16)	Qp: 7,130 cfs with Frequency 1 per 2 seasons Volume is 4 to 984,139,647 (65,171) Duration is 2 to 121 (16)	Qp: 4,660 cfs with Frequency 1 per 2 seasons Volume is 5 to 389,334,794 (44,431) Duration is 2 to 81 (13)	Qp: 5,020 cfs with Frequency 1 per 2 seasons Volume is 4 to 248,046,504 (29,539) Duration is 2 to 52 (9)
	Qp: 3,710 cfs with Frequency 1 per season Volume is 3 to 344,936,601 (30,308) Duration is 2 to 86 (12)	Qp: 3,460 cfs with Frequency 1 per season Volume is 2 to 367,418,585 (26,282) Duration is 1 to 75 (10)	Qp: 1,880 cfs with Frequency 1 per season Volume is 2 to 107,275,205 (13,330) Duration is 1 to 45 (7)	Qp: 2,910 cfs with Frequency 1 per season Volume is 2 to 127,167,165 (16,058) Duration is 1 to 40 (7)
	Qp: 1,530 cfs with Frequency 2 per season Volume is 1 to 107,428,195 (9,874) Duration is 1 to 46 (6)	Qp: 1,730 cfs with Frequency 2 per season Volume is 1 to 149,672,164 (11,004) Duration is 1 to 48 (6)	Qp: 980 cfs with Frequency 2 per season Volume is 1 to 44,447,517 (5,618) Duration is 1 to 29 (5)	Qp: 1,580 cfs with Frequency 2 per season Volume is 1 to 62,168,919 (8,113) Duration is 1 to 29 (5)
Base Flows (cfs)	326	358	337	255
	243	267	217	194
	200	224	182	174
Subsistence Flows (cfs)	152	140	140	148

Hydrologic Conditions	
	Wet (0th %ile)
	Average (0th %ile)
	Dry (0th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Trinity River near Oakwood
Current - IHA (Adjusted)

	Winter	Spring	Summer	Fall
Overbank Flows	Qp: 23,000 cfs with Frequency 2 per 3 years Volume is 334,664 to 721,863 (491,509) Duration is 13 to 30 (20)			
High Flow Pulses	Qp: 26,300 cfs with Frequency 1 per 2 seasons Volume is 387,196 to 756,578 (541,243) Duration is 13 to 28 (19)	Qp: 26,900 cfs with Frequency 1 per 2 seasons Volume is 471,653 to 1,209,017 (755,140) Duration is 17 to 43 (27)	Qp: 11,900 cfs with Frequency 1 per 2 seasons Volume is 143,041 to 299,116 (206,847) Duration is 10 to 21 (14)	Qp: 10,900 cfs with Frequency 1 per 2 seasons Volume is 89,530 to 169,095 (123,041) Duration is 7 to 14 (10)
	Qp: 15,700 cfs with Frequency 1 per season Volume is 2 to 40,991,351,023 (252,994) Duration is 1 to 156 (14)	Qp: 12,800 cfs with Frequency 1 per season Volume is 1 to 37,426,126,863 (219,882) Duration is 1 to 186 (14)	Qp: 6,940 cfs with Frequency 1 per season Volume is 1 to 4,959,210,413 (85,590) Duration is 1 to 71 (9)	Qp: 8,220 cfs with Frequency 1 per season Volume is 2 to 4,074,982,216 (81,783) Duration is 1 to 55 (8)
	Qp: 7,180 cfs with Frequency 2 per season Volume is 1 to 12,570,524,545 (79,845) Duration is 1 to 94 (8)	Qp: 7,490 cfs with Frequency 2 per season Volume is 1 to 15,131,050,328 (90,273) Duration is 1 to 119 (9)	Qp: 2,890 cfs with Frequency 2 per season Volume is 0 to 1,168,719,980 (20,410) Duration is 1 to 35 (5)	Qp: 4,640 cfs with Frequency 2 per season Volume is 1 to 1,724,633,298 (35,743) Duration is 1 to 39 (6)
Base Flows (cfs)	2133	3440	2043	1250
	1370	1670	1140	1010
	1060	1250	936	892
Subsistence Flows (cfs)	793	786	745	763

	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
	Winter			Spring			Summer			Fall		

Hydrologic Conditions	
	Wet (0th %ile)
	Average (0th %ile)
	Dry (0th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Trinity River at Romayor
Current - IHA (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 38,700 cfs with Frequency 2 per 3 years Volume is 523,596 to 1,979,242 (1,018,000) Duration is 12 to 45 (23)			
High Flow Pulses	Qp: 40,800 cfs with Frequency 1 per 2 seasons Volume is 574,135 to 2,206,040 (1,125,418) Duration is 13 to 48 (25)	Qp: 34,900 cfs with Frequency 1 per 2 seasons Volume is 598,909 to 1,953,008 (1,081,515) Duration is 13 to 46 (25)	Qp: 15,700 cfs with Frequency 1 per 2 seasons Volume is 141,273 to 668,108 (307,222) Duration is 7 to 30 (14)	Qp: 22,600 cfs with Frequency 1 per 2 seasons Volume is 172,547 to 662,301 (338,050) Duration is 7 to 27 (14)
	Qp: 24,800 cfs with Frequency 1 per season Volume is 278,375 to 1,061,544 (543,606) Duration is 9 to 35 (18)	Qp: 19,700 cfs with Frequency 1 per season Volume is 237,913 to 768,287 (427,534) Duration is 8 to 30 (16)	Qp: 7,880 cfs with Frequency 1 per season Volume is 55,598 to 264,584 (121,286) Duration is 5 to 21 (10)	Qp: 8,350 cfs with Frequency 1 per season Volume is 45,756 to 173,782 (89,172) Duration is 4 to 15 (8)
	Qp: 7,330 cfs with Frequency 2 per season Volume is 46,848 to 178,810 (91,526) Duration is 4 to 17 (8)	Qp: 6,310 cfs with Frequency 2 per season Volume is 0 to 39,204,973,826 (67,383) Duration is 0 to 112 (7)		
Base Flows (cfs)	4310	6270	2993	1950
	2050	2795	2120	1330
	1270	1900	1368	1120
Subsistence Flows (cfs)	928	835	905	846

Hydrologic Conditions	
	Wet (0th %ile)
	Average (0th %ile)
	Dry (0th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Trinity River near Rosser
Current - IHA (Adjusted)

Overbank Flows	Qp: 19,700 cfs with Frequency 2 per 3 years Volume is 154,262 to 374,417 (240,330) Duration is 9 to 23 (14)			
High Flow Pulses	Qp: 19,400 cfs with Frequency 1 per 2 seasons Volume is 146,682 to 384,793 (237,576) Duration is 8 to 24 (14)		Qp: 15,900 cfs with Frequency 1 per 2 seasons Volume is 132,056 to 318,908 (205,217) Duration is 9 to 22 (14)	Qp: 13,200 cfs with Frequency 1 per 2 seasons Volume is 81,965 to 174,082 (119,451) Duration is 7 to 15 (10)
	Qp: 13,400 cfs with Frequency 1 per season Volume is 78,371 to 196,515 (124,101) Duration is 5 to 16 (9)	Qp: 12,100 cfs with Frequency 1 per season Volume is 2 to 9,876,939,925 (135,620) Duration is 1 to 98 (11)	Qp: 6,540 cfs with Frequency 1 per season Volume is 2 to 1,827,436,896 (55,058) Duration is 1 to 44 (7)	Qp: 8,960 cfs with Frequency 1 per season Volume is 2 to 2,688,094,899 (71,152) Duration is 1 to 51 (8)
	Qp: 7,820 cfs with Frequency 2 per season Volume is 1 to 3,419,959,745 (60,000) Duration is 1 to 47 (7)	Qp: 6,390 cfs with Frequency 2 per season Volume is 1 to 3,575,916,375 (50,684) Duration is 1 to 58 (7)	Qp: 4,360 cfs with Frequency 2 per season Volume is 1 to 982,688,200 (30,202) Duration is 1 to 32 (5)	Qp: 5,740 cfs with Frequency 2 per season Volume is 1 to 1,434,488,017 (39,226) Duration is 1 to 38 (6)
Base Flows (cfs)	1610	2080	1290	991
	1070	1290	974	865
	897	1020	853	802
Subsistence Flows (cfs)	703	688	666	678
	Dec, Jan, Feb Winter	Mar, Apr, May Spring	Jun, Jul, Aug Summer	Sep, Oct, Nov Fall

Hydrologic Conditions	
	Wet (0th %ile)
	Average (0th %ile)
	Dry (0th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Trinity River at Dallas
Full Record - IHA (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 11,100 cfs with Frequency 2 per 3 years Volume is 69,020 to 196,200 (116,369) Duration is 9 to 28 (16)			
High Flow Pulses	Qp: 8,440 cfs with Frequency 1 per 2 seasons Volume is 47,554 to 139,362 (81,408) Duration is 8 to 23 (13)	Qp: 13,200 cfs with Frequency 1 per 2 seasons Volume is 91,177 to 251,861 (151,538) Duration is 11 to 32 (18)	Qp: 7,200 cfs with Frequency 1 per 2 seasons Volume is 42,853 to 122,254 (72,381) Duration is 8 to 24 (14)	Qp: 6,350 cfs with Frequency 1 per 2 seasons Volume is 31,699 to 87,817 (52,761) Duration is 7 to 19 (11)
	Qp: 4,000 cfs with Frequency 1 per season Volume is 18,870 to 55,224 (32,281) Duration is 5 to 16 (9)	Qp: 6,460 cfs with Frequency 1 per season Volume is 35,251 to 97,264 (58,555) Duration is 7 to 21 (12)	Qp: 2,860 cfs with Frequency 1 per season Volume is 13,058 to 37,184 (22,036) Duration is 5 to 14 (8)	Qp: 3,570 cfs with Frequency 1 per season Volume is 15,829 to 43,801 (26,331) Duration is 5 to 14 (8)
	Qp: 1,350 cfs with Frequency 2 per season Volume is 4,915 to 14,376 (8,406) Duration is 3 to 9 (5)	Qp: 2,760 cfs with Frequency 2 per season Volume is 11,372 to 31,360 (18,885) Duration is 4 to 12 (7)	Qp: 1,010 cfs with Frequency 2 per season Volume is 3,417 to 9,727 (5,765) Duration is 3 to 8 (5)	Qp: 1,340 cfs with Frequency 2 per season Volume is 4,853 to 13,420 (8,070) Duration is 3 to 9 (5)
Base Flows (cfs)	446	484	407	381
	247	247	240	230
	118	112	114	115
Subsistence Flows (cfs)	15	0	2	13

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Elm Fork Trinity River near Carrollton
Full Record - IHA (Adjusted)

	Winter	Spring	Summer	Fall
Overbank Flows	Qp: 5,190 cfs with Frequency 2 per 3 years Volume is 20 to 161,044,360 (56,781) Duration is 3 to 95 (16)			
High Flow Pulses	Qp: 3,890 cfs with Frequency 1 per 2 seasons Volume is 12 to 112,673,294 (37,387) Duration is 2 to 84 (14)	Qp: 5,910 cfs with Frequency 1 per 2 seasons Volume is 15 to 315,167,577 (68,654) Duration is 3 to 121 (18)	Qp: 3,350 cfs with Frequency 1 per 2 seasons Volume is 12 to 111,479,346 (36,307) Duration is 2 to 85 (14)	Qp: 2,390 cfs with Frequency 1 per 2 seasons Volume is 11 to 34,477,581 (19,303) Duration is 2 to 47 (10)
	Qp: 1,280 cfs with Frequency 1 per season Volume is 3 to 27,723,438 (9,343) Duration is 1 to 47 (8)	Qp: 3,270 cfs with Frequency 1 per season Volume is 7 to 145,797,732 (32,015) Duration is 2 to 88 (13)	Qp: 998 cfs with Frequency 1 per season Volume is 3 to 23,953,191 (7,946) Duration is 1 to 45 (8)	Qp: 830 cfs with Frequency 1 per season Volume is 3 to 9,127,077 (5,182) Duration is 1 to 27 (6)
	Qp: 318 cfs with Frequency 2 per season Volume is 1 to 4,854,513 (1,645) Duration is 1 to 23 (4)	Qp: 704 cfs with Frequency 2 per season Volume is 1 to 19,938,820 (4,422) Duration is 1 to 39 (6)	Qp: 344 cfs with Frequency 2 per season Volume is 1 to 6,267,834 (2,088) Duration is 1 to 26 (4)	Qp: 316 cfs with Frequency 2 per season Volume is 1 to 2,734,387 (1,560) Duration is 1 to 17 (4)
Base Flows (cfs)	123	159	212	153
	79	96	141	91
	38	47	73	48
Subsistence Flows (cfs)	0	0	0	0

Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Winter			Spring			Summer			Fall		

Hydrologic Conditions	
	Wet (0th %ile)
	Average (0th %ile)
	Dry (0th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Trinity River Near Crockett
Full Record - IHA (Adjusted)

Overbank Flows	Qp: 21,500 cfs with Frequency 2 per 3 years Volume is 310,064 to 715,480 (471,004) Duration is 12 to 30 (19)			
High Flow Pulses	Qp: 21,300 cfs with Frequency 1 per 2 seasons Volume is 294,962 to 627,054 (430,066) Duration is 12 to 26 (17)	Qp: 25,000 cfs with Frequency 1 per 2 seasons Volume is 4 to 97,648,379,147 (655,800) Duration is 2 to 262 (23)	Qp: 14,900 cfs with Frequency 1 per 2 seasons Volume is 4 to 19,936,935,134 (292,617) Duration is 2 to 145 (17)	Qp: 12,700 cfs with Frequency 1 per 2 seasons Volume is 4 to 8,434,599,770 (184,451) Duration is 2 to 88 (13)
	Qp: 14,100 cfs with Frequency 1 per season Volume is 2 to 31,169,079,149 (223,919) Duration is 1 to 137 (13)	Qp: 15,900 cfs with Frequency 1 per season Volume is 2 to 44,028,149,765 (305,353) Duration is 1 to 179 (16)	Qp: 7,110 cfs with Frequency 1 per season Volume is 1 to 5,623,362,725 (86,555) Duration is 1 to 79 (9)	Qp: 7,620 cfs with Frequency 1 per season Volume is 2 to 3,752,480,213 (85,317) Duration is 1 to 61 (9)
	Qp: 5,750 cfs with Frequency 2 per season Volume is 0 to 7,517,161,385 (54,174) Duration is 1 to 70 (7)	Qp: 7,780 cfs with Frequency 2 per season Volume is 1 to 12,965,457,266 (91,305) Duration is 1 to 98 (9)	Qp: 2,580 cfs with Frequency 2 per season Volume is 0 to 1,073,580,203 (16,311) Duration is 0 to 34 (4)	Qp: 3,960 cfs with Frequency 2 per season Volume is 1 to 1,376,504,254 (31,768) Duration is 1 to 39 (6)
Base Flows (cfs)	2490	3130	2040	1490
	1580	1770	1160	1070
	1100	1250	903	855
Subsistence Flows (cfs)	593	578	508	551
	Dec, Jan, Feb Winter	Mar, Apr, May Spring	Jun, Jul, Aug Summer	Sep, Oct, Nov Fall

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

West Fork Trinity River at Grand Prairie
Full Record - IHA (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 4,850 cfs with Frequency 2 per 3 years Volume is 26,876 to 77,244 (45,563) Duration is 9 to 27 (16)			
High Flow Pulses	Qp: 3,830 cfs with Frequency 1 per 2 seasons Volume is 22,420 to 63,539 (37,744) Duration is 9 to 26 (16)	Qp: 5,360 cfs with Frequency 1 per 2 seasons Volume is 31,833 to 91,181 (53,875) Duration is 11 to 30 (18)	Qp: 2,860 cfs with Frequency 1 per 2 seasons Volume is 14,406 to 41,490 (24,448) Duration is 7 to 20 (12)	Qp: 3,320 cfs with Frequency 1 per 2 seasons Volume is 13,874 to 39,709 (23,471) Duration is 7 to 19 (11)
	Qp: 1,730 cfs with Frequency 1 per season Volume is 8,131 to 22,995 (13,673) Duration is 6 to 16 (9)	Qp: 2,820 cfs with Frequency 1 per season Volume is 13,879 to 39,698 (23,473) Duration is 7 to 20 (12)	Qp: 1,210 cfs with Frequency 1 per season Volume is 4,841 to 13,910 (8,206) Duration is 4 to 12 (7)	Qp: 1,730 cfs with Frequency 1 per season Volume is 6,360 to 18,174 (10,751) Duration is 5 to 13 (8)
	Qp: 691 cfs with Frequency 2 per season Volume is 2,518 to 7,116 (4,233) Duration is 3 to 9 (5)	Qp: 1,140 cfs with Frequency 2 per season Volume is 1 to 52,506,580 (7,273) Duration is 1 to 51 (7)	Qp: 530 cfs with Frequency 2 per season Volume is 1 to 11,059,443 (2,878) Duration is 1 to 25 (4)	Qp: 769 cfs with Frequency 2 per season Volume is 1 to 16,598,449 (4,071) Duration is 1 to 29 (5)
Base Flows (cfs)	214	233	175	169
	140	151	116	122
	93	96	79	77
Subsistence Flows (cfs)	25	25	21	21

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Trinity River near Oakwood
Full Record - IHA (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 18,400 cfs with Frequency 2 per 3 years Volume is 248,746 to 551,443 (370,363) Duration is 13 to 29 (19)			
High Flow Pulses	Qp: 18,400 cfs with Frequency 1 per 2 seasons Volume is 236,170 to 516,396 (349,223) Duration is 12 to 27 (18)	Qp: 25,800 cfs with Frequency 1 per 2 seasons Volume is 441,126 to 1,012,839 (668,424) Duration is 17 to 42 (26)	Qp: 11,500 cfs with Frequency 1 per 2 seasons Volume is 121,204 to 264,395 (179,013) Duration is 9 to 21 (14)	
	Qp: 12,200 cfs with Frequency 1 per season Volume is 130,827 to 285,818 (193,372) Duration is 9 to 21 (14)	Qp: 12,900 cfs with Frequency 1 per season Volume is 151,306 to 346,913 (229,107) Duration is 10 to 25 (16)	Qp: 5,950 cfs with Frequency 1 per season Volume is 48,646 to 105,672 (71,697) Duration is 6 to 14 (10)	Qp: 6,320 cfs with Frequency 1 per season Volume is 47,025 to 101,203 (68,986) Duration is 6 to 14 (9)
	Qp: 5,470 cfs with Frequency 2 per season Volume is 1 to 5,924,714,043 (60,990) Duration is 1 to 91 (8)	Qp: 6,020 cfs with Frequency 2 per season Volume is 1 to 7,917,658,130 (70,589) Duration is 1 to 113 (9)	Qp: 2,010 cfs with Frequency 2 per season Volume is 0 to 592,564,275 (13,403) Duration is 1 to 37 (4)	Qp: 2,930 cfs with Frequency 2 per season Volume is 1 to 871,832,927 (23,035) Duration is 1 to 44 (6)
Base Flows (cfs)	1640	2090	1150	960
	993	1200	735	676
	585	730	483	447
Subsistence Flows (cfs)	153	137	123	124

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

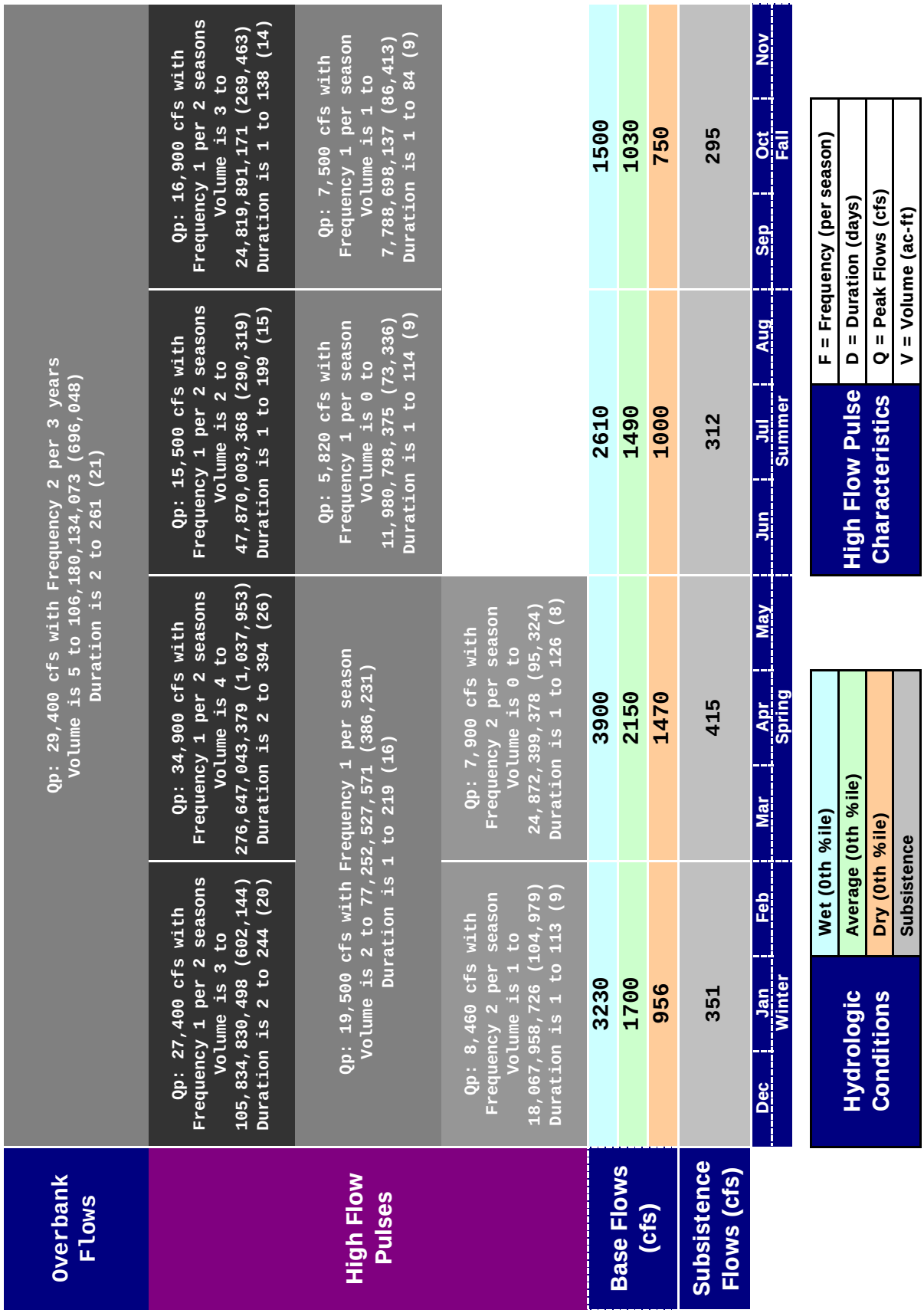
Trinity River at Trinidad
Full Record - IHA (Adjusted)

	Winter			Spring			Summer			Fall		
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Overbank Flows	Qp: 18,300 cfs with Frequency 2 per 3 years Volume is 7 to 11,523,923,403 (292,403) Duration is 11 to 27 (17)											
High Flow Pulses	Qp: 21,600 cfs with Frequency 1 per 2 seasons Volume is 6 to 19,667,450,664 (333,525) Duration is 2 to 134 (17)			Qp: 22,200 cfs with Frequency 1 per 2 seasons Volume is 7 to 34,317,019,118 (484,094) Duration is 2 to 243 (25)			Qp: 9,740 cfs with Frequency 1 per 2 seasons Volume is 4 to 3,847,606,498 (120,866) Duration is 2 to 75 (11)			Qp: 10,400 cfs with Frequency 1 per 2 seasons Volume is 4 to 3,028,330,172 (104,949) Duration is 2 to 62 (10)		
	Qp: 10,100 cfs with Frequency 1 per season Volume is 2 to 6,254,018,506 (110,917) Duration is 1 to 80 (10)			Qp: 11,700 cfs with Frequency 1 per season Volume is 3 to 11,701,828,956 (171,401) Duration is 1 to 140 (14)			Qp: 5,770 cfs with Frequency 1 per season Volume is 2 to 1,681,346,744 (54,465) Duration is 1 to 51 (8)			Qp: 6,590 cfs with Frequency 1 per season Volume is 2 to 1,562,753,080 (55,645) Duration is 1 to 46 (8)		
	Qp: 6,010 cfs with Frequency 2 per season Volume is 1 to 2,915,086,994 (52,298) Duration is 1 to 56 (7)			Qp: 5,740 cfs with Frequency 2 per season Volume is 1 to 3,634,074,643 (54,035) Duration is 1 to 76 (8)			Qp: 2,470 cfs with Frequency 2 per season Volume is 0 to 458,752,262 (14,967) Duration is 1 to 27 (4)			Qp: 4,040 cfs with Frequency 2 per season Volume is 1 to 781,160,986 (28,178) Duration is 1 to 34 (6)		
Base Flows (cfs)	1320			1670			1060			934		
	959			1070			835			784		
	707			775			659			639		
Subsistence Flows (cfs)	415			412			415			418		

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Trinity River at Romayor
Full Record - IHA (Adjusted)



Trinity River near Rosser
Full Record - IHA (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 14,300 cfs with Frequency 2 per 3 years Volume is 7 to 5,649,017,029 (193,022) Duration is 2 to 117 (16)			
High Flow Pulses	Qp: 12,600 cfs with Frequency 1 per 2 seasons Volume is 4 to 5,474,530,411 (151,598) Duration is 2 to 101 (13)	Qp: 15,500 cfs with Frequency 1 per 2 seasons Volume is 5 to 10,843,822,780 (231,990) Duration is 2 to 163 (18)	Qp: 8,950 cfs with Frequency 1 per 2 seasons Volume is 5 to 2,481,681,409 (107,392) Duration is 2 to 84 (12)	Qp: 9,270 cfs with Frequency 1 per 2 seasons Volume is 4 to 2,328,461,827 (96,706) Duration is 2 to 76 (11)
	Qp: 6,510 cfs with Frequency 1 per season Volume is 2 to 2,229,188,240 (63,064) Duration is 1 to 68 (9)	Qp: 9,050 cfs with Frequency 1 per season Volume is 2 to 4,829,105,478 (105,115) Duration is 1 to 109 (12)	Qp: 4,360 cfs with Frequency 1 per season Volume is 2 to 859,547,569 (38,046) Duration is 1 to 50 (8)	Qp: 5,730 cfs with Frequency 1 per season Volume is 2 to 1,175,286,316 (49,679) Duration is 1 to 55 (8)
	Qp: 3,150 cfs with Frequency 2 per season Volume is 1 to 845,084,947 (24,046) Duration is 1 to 45 (6)	Qp: 3,940 cfs with Frequency 2 per season Volume is 1 to 1,409,538,608 (30,926) Duration is 1 to 59 (7)	Qp: 1,820 cfs with Frequency 2 per season Volume is 0 to 243,113,133 (10,786) Duration is 1 to 27 (4)	Qp: 3,100 cfs with Frequency 2 per season Volume is 1 to 497,610,470 (21,221) Duration is 1 to 37 (6)
Base Flows (cfs)	1100	1240	876	831
	775	820	613	586
	443	490	430	388
Subsistence Flows (cfs)	147	158	140	133

Hydrologic Conditions
Wet (75th %ile)
Average (50th %ile)
Dry (25th %ile)
Subsistence

High Flow Pulse Characteristics
F = Frequency (per season)
D = Duration (days)
Q = Peak Flows (cfs)
V = Volume (ac-ft)

Brays Bayou at Houston
Pre-impact - IHA (Default)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 1,730 cfs with Frequency 2 per 3 years Volume is 7,773 to 17,948 (11,811) Duration is 13 to 36 (22)			
High Flow Pulses	Qp: 1,430 cfs with Frequency 1 per 2 seasons Volume is 7,364 to 18,217 (11,582) Duration is 15 to 46 (26)	Qp: 1,550 cfs with Frequency 1 per 2 seasons Volume is 6,235 to 13,169 (9,061) Duration is 11 to 26 (17)	Qp: 1,190 cfs with Frequency 1 per 2 seasons Volume is 12 to 4,263,213 (7,205) Duration is 2 to 113 (17)	Qp: 1,470 cfs with Frequency 1 per 2 seasons Volume is 14 to 6,364,842 (9,545) Duration is 3 to 141 (19)
	Qp: 707 cfs with Frequency 1 per season Volume is 3 to 8,780,291 (5,091) Duration is 1 to 225 (18)	Qp: 437 cfs with Frequency 1 per season Volume is 4 to 1,448,037 (2,272) Duration is 1 to 71 (10)	Qp: 310 cfs with Frequency 1 per season Volume is 3 to 909,981 (1,615) Duration is 1 to 62 (9)	Qp: 325 cfs with Frequency 1 per season Volume is 1,116 to 2,769 (1,758) Duration is 6 to 16 (10)
	Qp: 195 cfs with Frequency 2 per season Volume is 1 to 1,907,116 (1,132) Duration is 1 to 116 (10)	Qp: 82 cfs with Frequency 2 per season Volume is 1 to 227,396 (365) Duration is 1 to 36 (5)	Qp: 78 cfs with Frequency 2 per season Volume is 1 to 193,098 (348) Duration is 1 to 33 (5)	Qp: 67 cfs with Frequency 2 per season Volume is 0 to 186,130 (299) Duration is 1 to 35 (5)
Base Flows (cfs)	11	10	10	10
	8	7	7	7
	5	4	4	4
Subsistence Flows (cfs)	1	1	1	1

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Buffalo Bayou at Piney Point
Pre-impact - IHA (Default)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 1,550 cfs with Frequency 2 per 3 years Volume is 16,817 to 45,315 (27,605) Duration is 12 to 37 (21)			
High Flow Pulses	Qp: 1,110 cfs with Frequency 1 per 2 seasons Volume is 10,057 to 25,828 (16,117) Duration is 10 to 29 (17)	Qp: 1,280 cfs with Frequency 1 per 2 seasons Volume is 10,836 to 30,908 (18,300) Duration is 11 to 29 (18)	Qp: 812 cfs with Frequency 1 per 2 seasons Volume is 7,124 to 17,567 (11,187) Duration is 8 to 23 (13)	Qp: 1,270 cfs with Frequency 1 per 2 seasons Volume is 13,089 to 40,764 (23,099) Duration is 10 to 39 (20)
	Qp: 783 cfs with Frequency 1 per season Volume is 6,003 to 15,327 (9,592) Duration is 8 to 23 (13)	Qp: 826 cfs with Frequency 1 per season Volume is 5,780 to 16,355 (9,723) Duration is 8 to 22 (13)	Qp: 434 cfs with Frequency 1 per season Volume is 2,729 to 6,670 (4,266) Duration is 5 to 15 (9)	Qp: 868 cfs with Frequency 1 per season Volume is 6,951 to 21,448 (12,210) Duration is 7 to 28 (14)
	Qp: 405 cfs with Frequency 2 per season Volume is 2,259 to 5,735 (3,599) Duration is 5 to 14 (8)	Qp: 377 cfs with Frequency 2 per season Volume is 1,867 to 5,255 (3,133) Duration is 5 to 13 (8)	Qp: 329 cfs with Frequency 2 per season Volume is 1 to 8,673,388 (2,786) Duration is 1 to 54 (7)	Qp: 378 cfs with Frequency 2 per season Volume is 1 to 14,942,735 (3,033) Duration is 1 to 68 (7)
Base Flows (cfs)	43	40	106	93
	29	29	57	50
	22	20	33	32
Subsistence Flows (cfs)	10	11	8	12

Hydrologic Conditions
Wet (75th %ile)
Average (50th %ile)
Dry (25th %ile)
Subsistence

High Flow Pulse Characteristics
F = Frequency (per season)
D = Duration (days)
Q = Peak Flows (cfs)
V = Volume (ac-ft)

West Fork San Jacinto near Conroe
Pre-impact - MBFIT (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 6,170 cfs with Frequency 2 per 3 years Volume is 42,488 to 123,278 (72,373) Duration is 13 to 44 (24)			
High Flow Pulses	Qp: 5,450 cfs with Frequency 1 per 2 seasons Volume is 45,720 to 126,923 (76,177) Duration is 14 to 44 (25)	Qp: 6,920 cfs with Frequency 1 per 2 seasons Volume is 14 to 389,851,931 (73,931) Duration is 2 to 214 (23)	Qp: 1,730 cfs with Frequency 1 per 2 seasons Volume is 9 to 22,911,522 (14,169) Duration is 2 to 93 (14)	Qp: 1,930 cfs with Frequency 1 per 2 seasons Volume is 7 to 37,494,771 (16,683) Duration is 2 to 102 (14)
	Qp: 2,290 cfs with Frequency 1 per season Volume is 5 to 149,278,250 (26,900) Duration is 2 to 161 (17)	Qp: 2,720 cfs with Frequency 1 per season Volume is 5 to 132,755,118 (25,993) Duration is 2 to 144 (15)	Qp: 424 cfs with Frequency 1 per season Volume is 2 to 4,301,013 (2,776) Duration is 1 to 47 (7)	Qp: 570 cfs with Frequency 1 per season Volume is 2 to 8,385,345 (3,874) Duration is 1 to 55 (8)
	Qp: 420 cfs with Frequency 2 per season Volume is 1 to 18,969,634 (3,511) Duration is 1 to 71 (7)	Qp: 839 cfs with Frequency 2 per season Volume is 1 to 34,830,429 (6,967) Duration is 1 to 88 (9)	Qp: 91 cfs with Frequency 2 per season Volume is 0 to 720,425 (466) Duration is 1 to 23 (3)	Qp: 147 cfs with Frequency 2 per season Volume is 0 to 1,648,235 (765) Duration is 1 to 28 (4)
Base Flows (cfs)	104	104	32	31
	50	60	24	24
	33	40	17	16
Subsistence Flows (cfs)	10	N/A	10	10

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

East Fork San Jacinto River near Cleveland
Pre-impact - MBFIT (Adjusted)

	Winter			Spring			Summer			Fall		
	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Overbank Flows	Qp: 2,130 cfs with Frequency 2 per 3 years Volume is 18 to 20,072,115 (18,877) Duration is 3 to 110 (18)											
High Flow Pulses	Qp: 1,740 cfs with Frequency 1 per 2 seasons Volume is 13 to 30,699,635 (19,947) Duration is 3 to 151 (21)			Qp: 3,310 cfs with Frequency 1 per 2 seasons Volume is 15 to 52,991,633 (28,450) Duration is 3 to 145 (20)			Qp: 950 cfs with Frequency 1 per 2 seasons Volume is 10 to 4,479,185 (6,584) Duration is 2 to 57 (11)			Qp: 680 cfs with Frequency 1 per 2 seasons Volume is 6 to 3,140,116 (4,371) Duration is 2 to 51 (10)		
	Qp: 625 cfs with Frequency 1 per season Volume is 4 to 8,322,321 (5,597) Duration is 2 to 84 (12)			Qp: 1,120 cfs with Frequency 1 per season Volume is 5 to 15,315,949 (8,496) Duration is 2 to 88 (12)			Qp: 202 cfs with Frequency 1 per season Volume is 2 to 752,041 (1,160) Duration is 1 to 28 (6)			Qp: 286 cfs with Frequency 1 per season Volume is 2 to 1,156,236 (1,646) Duration is 1 to 34 (7)		
	Qp: 204 cfs with Frequency 2 per season Volume is 1 to 2,040,709 (1,395) Duration is 1 to 44 (6)			Qp: 500 cfs with Frequency 2 per season Volume is 2 to 6,143,642 (3,456) Duration is 1 to 61 (8)			Qp: 70 cfs with Frequency 2 per season Volume is 1 to 227,834 (353) Duration is 1 to 17 (3)			Qp: 73 cfs with Frequency 2 per season Volume is 1 to 245,688 (353) Duration is 1 to 18 (3)		
Base Flows (cfs)	48			57			24			23		
	31			36			17			18		
	22			26			12			12		
Subsistence Flows (cfs)	9			9			7			8		

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Brays Bayou at Houston
Current - IHA (Default)

	Winter	Spring	Summer	Fall
Overbank Flows	Qp: 4,510 cfs with Frequency 2 per 3 years Volume is 13,823 to 30,515 (20,538) Duration is 7 to 17 (11)			
High Flow Pulses	Qp: 3,910 cfs with Frequency 1 per 2 seasons Volume is 12,868 to 26,844 (18,586) Duration is 8 to 18 (12)	Qp: 4,220 cfs with Frequency 1 per 2 seasons Volume is 11,893 to 24,432 (17,046) Duration is 6 to 14 (9)	Qp: 3,310 cfs with Frequency 1 per 2 seasons Volume is 11,379 to 28,294 (17,943) Duration is 7 to 19 (11)	Qp: 4,300 cfs with Frequency 1 per 2 seasons Volume is 12,558 to 26,736 (18,324) Duration is 6 to 14 (9)
	Qp: 2,910 cfs with Frequency 1 per season Volume is 9,434 to 19,645 (13,614) Duration is 7 to 15 (10)	Qp: 2,430 cfs with Frequency 1 per season Volume is 6,800 to 13,926 (9,731) Duration is 5 to 11 (7)	Qp: 1,570 cfs with Frequency 1 per season Volume is 5,107 to 12,630 (8,031) Duration is 4 to 13 (8)	Qp: 2,810 cfs with Frequency 1 per season Volume is 8,172 to 17,356 (11,909) Duration is 5 to 12 (8)
	Qp: 1,290 cfs with Frequency 2 per season Volume is 4,009 to 8,321 (5,776) Duration is 4 to 10 (7)	Qp: 1,450 cfs with Frequency 2 per season Volume is 4,029 to 8,235 (5,760) Duration is 4 to 9 (6)	Qp: 949 cfs with Frequency 2 per season Volume is 2,971 to 7,334 (4,668) Duration is 3 to 10 (6)	Qp: 1,270 cfs with Frequency 2 per season Volume is 3,661 to 7,754 (5,328) Duration is 4 to 9 (6)
Base Flows (cfs)	127	129	130	125
	117	115	114	114
	109	108	106	106
Subsistence Flows (cfs)	96	96	98	97
	Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Buffalo Bayou at Piney Point
Current - IHA (Default)

	Winter	Spring	Summer	Fall
Overbank Flows	Qp: 2,040 cfs with Frequency 2 per 3 years Volume is 17,422 to 48,271 (28,999) Duration is 10 to 29 (17)			
High Flow Pulses	Qp: 1,720 cfs with Frequency 1 per 2 seasons Volume is 14,568 to 38,751 (23,760) Duration is 9 to 26 (15)	Qp: 2,030 cfs with Frequency 1 per 2 seasons Volume is 16,539 to 50,788 (28,982) Duration is 9 to 30 (17)	Qp: 1,810 cfs with Frequency 1 per 2 seasons Volume is 14,304 to 38,285 (23,401) Duration is 9 to 27 (16)	Qp: 1,990 cfs with Frequency 1 per 2 seasons Volume is 16,452 to 44,491 (27,055) Duration is 10 to 28 (16)
	Qp: 1,440 cfs with Frequency 1 per season Volume is 11,228 to 29,800 (18,292) Duration is 8 to 23 (14)	Qp: 1,720 cfs with Frequency 1 per season Volume is 12,714 to 38,970 (22,259) Duration is 8 to 26 (15)	Qp: 1,280 cfs with Frequency 1 per season Volume is 8,597 to 22,922 (14,038) Duration is 7 to 21 (12)	Qp: 1,470 cfs with Frequency 1 per season Volume is 10,447 to 28,170 (17,155) Duration is 8 to 22 (13)
	Qp: 631 cfs with Frequency 2 per season Volume is 3,342 to 8,824 (5,430) Duration is 5 to 13 (8)	Qp: 900 cfs with Frequency 2 per season Volume is 4,543 to 13,857 (7,934) Duration is 5 to 15 (8)	Qp: 718 cfs with Frequency 2 per season Volume is 3,671 to 9,751 (5,983) Duration is 5 to 13 (8)	Qp: 724 cfs with Frequency 2 per season Volume is 3,607 to 9,689 (5,912) Duration is 4 to 13 (8)
Base Flows (cfs)	110	97	103	94
	82	79	79	71
	67	62	66	61
Subsistence Flows (cfs)	47	44	45	46
	Dec, Jan, Feb	Mar, Apr, May	Jun, Jul, Aug	Sep, Oct, Nov

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Spring Creek near Spring
Pre-impact - MBFIT (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 2,670 cfs with Frequency 2 per 3 years Volume is 21 to 29,593,212 (25,096) Duration is 3 to 138 (21)			
High Flow Pulses	Qp: 2,180 cfs with Frequency 1 per 2 seasons Volume is 15,216 to 39,401 (24,485) Duration is 13 to 42 (24)	Qp: 3,130 cfs with Frequency 1 per 2 seasons Volume is 18,082 to 47,800 (29,399) Duration is 12 to 37 (21)	Qp: 850 cfs with Frequency 1 per 2 seasons Volume is 3,555 to 9,928 (5,941) Duration is 6 to 19 (11)	Qp: 1,200 cfs with Frequency 1 per 2 seasons Volume is 5,815 to 14,217 (9,092) Duration is 8 to 21 (13)
	Qp: 786 cfs with Frequency 1 per season Volume is 4,517 to 11,649 (7,254) Duration is 8 to 24 (14)	Qp: 860 cfs with Frequency 1 per season Volume is 4,085 to 10,750 (6,627) Duration is 7 to 20 (11)	Qp: 280 cfs with Frequency 1 per season Volume is 1,023 to 2,846 (1,707) Duration is 4 to 11 (7)	Qp: 408 cfs with Frequency 1 per season Volume is 1,717 to 4,182 (2,680) Duration is 5 to 13 (8)
	Qp: 200 cfs with Frequency 2 per season Volume is 884 to 2,275 (1,418) Duration is 4 to 12 (7)	Qp: 259 cfs with Frequency 2 per season Volume is 1,025 to 2,691 (1,661) Duration is 4 to 11 (6)	Qp: 82 cfs with Frequency 2 per season Volume is 258 to 716 (430) Duration is 2 to 7 (4)	Qp: 116 cfs with Frequency 2 per season Volume is 413 to 1,006 (645) Duration is 3 to 8 (5)
Base Flows (cfs)	40	46	26	24
	22	29	16	16
	16	18	11	11
Subsistence Flows (cfs)	4	6	5	5

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

West Fork San Jacinto near Conroe
Current - MBFIT (Adjusted)

	Winter	Spring	Summer	Fall
Overbank Flows	Qp: 5,230 cfs with Frequency 2 per 3 years Volume is 21 to 222,396,646 (67,735) Duration is 3 to 148 (21)			
High Flow Pulses	Qp: 5,500 cfs with Frequency 1 per 2 seasons Volume is 13 to 558,824,144 (83,777) Duration is 3 to 208 (23)	Qp: 4,900 cfs with Frequency 1 per 2 seasons Volume is 15 to 242,760,716 (59,650) Duration is 3 to 145 (19)	Qp: 1,960 cfs with Frequency 1 per 2 seasons Volume is 9 to 40,664,745 (19,357) Duration is 2 to 87 (14)	Qp: 2,870 cfs with Frequency 1 per 2 seasons Volume is 11 to 66,555,731 (27,017) Duration is 2 to 81 (14)
	Qp: 3,040 cfs with Frequency 1 per season Volume is 25,779 to 59,522 (39,171) Duration is 11 to 26 (17)	Qp: 2,930 cfs with Frequency 1 per season Volume is 20,125 to 48,966 (31,392) Duration is 9 to 25 (15)	Qp: 739 cfs with Frequency 1 per season Volume is 3,469 to 9,436 (5,722) Duration is 5 to 14 (8)	Qp: 1,200 cfs with Frequency 1 per season Volume is 5,359 to 15,507 (9,116) Duration is 5 to 16 (9)
	Qp: 1,080 cfs with Frequency 2 per season Volume is 6,846 to 15,774 (10,392) Duration is 6 to 15 (10)	Qp: 997 cfs with Frequency 2 per season Volume is 5,246 to 12,733 (8,173) Duration is 5 to 15 (9)	Qp: 205 cfs with Frequency 2 per season Volume is 699 to 1,899 (1,153) Duration is 3 to 7 (4)	Qp: 346 cfs with Frequency 2 per season Volume is 1,139 to 3,290 (1,936) Duration is 3 to 8 (5)
Base Flows (cfs)	109	69	44	61
	64	46	32	36
	34	36	26	28
Subsistence Flows (cfs)	21	19	18	19

Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Winter			Spring			Summer			Fall		

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

East Fork San Jacinto River near Cleveland
Current - MBFIT (Adjusted)

	Winter	Spring	Summer	Fall
Overbank Flows	Qp: 3,410 cfs with Frequency 2 per 3 years Volume is 15 to 76,494,163 (34,250) Duration is 3 to 122 (18)			
High Flow Pulses	Qp: 3,270 cfs with Frequency 1 per 2 seasons Volume is 10 to 138,232,045 (36,849) Duration is 2 to 152 (19)	Qp: 3,060 cfs with Frequency 1 per 2 seasons Volume is 11 to 76,676,225 (28,552) Duration is 2 to 109 (16)	Qp: 1,600 cfs with Frequency 1 per 2 seasons Volume is 8 to 20,166,648 (12,357) Duration is 2 to 77 (13)	Qp: 1,760 cfs with Frequency 1 per 2 seasons Volume is 8 to 26,818,087 (15,026) Duration is 2 to 84 (14)
	Qp: 1,910 cfs with Frequency 1 per season Volume is 5 to 70,502,717 (19,135) Duration is 2 to 113 (14)	Qp: 1,640 cfs with Frequency 1 per season Volume is 5 to 37,023,942 (14,070) Duration is 2 to 83 (12)	Qp: 645 cfs with Frequency 1 per season Volume is 3 to 6,870,392 (4,342) Duration is 1 to 50 (8)	Qp: 689 cfs with Frequency 1 per season Volume is 3 to 8,432,105 (4,859) Duration is 1 to 52 (8)
	Qp: 822 cfs with Frequency 2 per season Volume is 2 to 24,786,192 (6,848) Duration is 1 to 72 (9)	Qp: 668 cfs with Frequency 2 per season Volume is 2 to 13,120,053 (5,078) Duration is 1 to 56 (8)	Qp: 191 cfs with Frequency 2 per season Volume is 1 to 1,669,597 (1,070) Duration is 1 to 28 (5)	Qp: 247 cfs with Frequency 2 per season Volume is 1 to 2,423,745 (1,414) Duration is 1 to 31 (5)
Base Flows (cfs)	104	81	36	36
	70	53	28	28
	37	38	22	22
Subsistence Flows (cfs)	N/A	13	14	14

Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Winter			Spring			Summer			Fall		

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Spring Creek near Spring
Current - MBFIT (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 3,950 cfs with Frequency 2 per 3 years Volume is 16 to 84,849,752 (37,304) Duration is 11 to 29 (18)			
High Flow Pulses	Qp: 3,060 cfs with Frequency 1 per 2 seasons Volume is 9 to 118,606,402 (32,512) Duration is 2 to 135 (17)	Qp: 3,810 cfs with Frequency 1 per 2 seasons Volume is 11 to 112,022,182 (34,917) Duration is 2 to 120 (16)	Qp: 1,980 cfs with Frequency 1 per 2 seasons Volume is 11 to 25,577,921 (16,804) Duration is 2 to 82 (14)	Qp: 3,740 cfs with Frequency 1 per 2 seasons Volume is 14 to 57,439,089 (28,114) Duration is 2 to 90 (15)
	Qp: 1,980 cfs with Frequency 1 per season Volume is 5 to 69,027,611 (19,253) Duration is 2 to 109 (14)	Qp: 2,240 cfs with Frequency 1 per season Volume is 6 to 60,247,410 (19,148) Duration is 2 to 96 (13)	Qp: 923 cfs with Frequency 1 per season Volume is 5 to 9,953,948 (6,733) Duration is 2 to 56 (10)	Qp: 1,500 cfs with Frequency 1 per season Volume is 5 to 19,672,801 (9,927) Duration is 2 to 61 (10)
	Qp: 757 cfs with Frequency 2 per season Volume is 2 to 21,184,471 (6,053) Duration is 1 to 68 (9)	Qp: 780 cfs with Frequency 2 per season Volume is 2 to 17,831,374 (5,807) Duration is 1 to 62 (9)	Qp: 289 cfs with Frequency 2 per season Volume is 1 to 2,421,886 (1,675) Duration is 1 to 31 (5)	Qp: 376 cfs with Frequency 2 per season Volume is 1 to 3,978,284 (2,052) Duration is 1 to 33 (5)
Base Flows (cfs)	80	67	38	39
	49	45	29	29
	31	33	22	23
Subsistence Flows (cfs)	15	16	14	14

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Brays Bayou at Houston
Full Record - MBFIT (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 3,390 cfs with Frequency 2 per 3 years Volume is 11,302 to 26,161 (17,195) Duration is 5 to 16 (9)			
High Flow Pulses	Qp: 2,450 cfs with Frequency 1 per 2 seasons Volume is 8,404 to 18,859 (12,590) Duration is 5 to 16 (9)	Qp: 2,480 cfs with Frequency 1 per 2 seasons Volume is 7,373 to 16,366 (10,985) Duration is 4 to 12 (7)	Qp: 2,290 cfs with Frequency 1 per 2 seasons Volume is 8,012 to 19,694 (12,562) Duration is 5 to 15 (8)	Qp: 3,400 cfs with Frequency 1 per 2 seasons Volume is 10 to 25,322,711 (15,864) Duration is 2 to 33 (8)
	Qp: 1,460 cfs with Frequency 1 per season Volume is 4 to 11,147,828 (6,926) Duration is 2 to 30 (7)	Qp: 1,630 cfs with Frequency 1 per season Volume is 4 to 10,526,745 (6,824) Duration is 2 to 22 (6)	Qp: 1,260 cfs with Frequency 1 per season Volume is 5 to 8,010,405 (6,251) Duration is 2 to 25 (6)	Qp: 1,500 cfs with Frequency 1 per season Volume is 4 to 10,079,565 (6,394) Duration is 1 to 23 (6)
	Qp: 782 cfs with Frequency 2 per season Volume is 2 to 5,386,636 (3,368) Duration is 1 to 22 (5)	Qp: 786 cfs with Frequency 2 per season Volume is 2 to 4,568,455 (2,983) Duration is 1 to 16 (4)	Qp: 562 cfs with Frequency 2 per season Volume is 2 to 3,096,218 (2,434) Duration is 1 to 17 (4)	Qp: 813 cfs with Frequency 2 per season Volume is 2 to 5,076,589 (3,239) Duration is 1 to 18 (4)
Base Flows (cfs)	106	105	105	106
	43	42	36	51
	17	15	16	16
Subsistence Flows (cfs)	3	3	2	2

Hydrologic Conditions
Wet (75th %ile)
Average (50th %ile)
Dry (25th %ile)
Subsistence

High Flow Pulse Characteristics
F = Frequency (per season)
D = Duration (days)
Q = Peak Flows (cfs)
V = Volume (ac-ft)

Buffalo Bayou at Piney Point
Full Record - MBFIT (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 1,920 cfs with Frequency 2 per 3 years Volume is 21,398 to 65,961 (37,569) Duration is 14 to 47 (26)			
High Flow Pulses	Qp: 1,610 cfs with Frequency 1 per 2 seasons Volume is 7 to 136,249,593 (30,982) Duration is 2 to 229 (24)	Qp: 1,990 cfs with Frequency 1 per 2 seasons Volume is 9 to 135,009,573 (34,524) Duration is 3 to 189 (22)	Qp: 1,780 cfs with Frequency 1 per 2 seasons Volume is 10 to 145,337,345 (38,395) Duration is 3 to 308 (30)	Qp: 1,750 cfs with Frequency 1 per 2 seasons Volume is 8 to 128,889,256 (31,123) Duration is 2 to 232 (24)
	Qp: 1,220 cfs with Frequency 1 per season Volume is 5 to 86,100,839 (19,850) Duration is 2 to 181 (19)	Qp: 1,570 cfs with Frequency 1 per season Volume is 6 to 91,876,267 (23,751) Duration is 2 to 156 (18)	Qp: 1,100 cfs with Frequency 1 per season Volume is 5 to 67,174,189 (18,165) Duration is 2 to 206 (20)	Qp: 1,260 cfs with Frequency 1 per season Volume is 5 to 76,798,087 (18,806) Duration is 2 to 178 (18)
	Qp: 575 cfs with Frequency 2 per season Volume is 1 to 25,168,257 (5,935) Duration is 1 to 95 (10)	Qp: 512 cfs with Frequency 2 per season Volume is 1 to 15,244,962 (4,054) Duration is 1 to 63 (7)	Qp: 458 cfs with Frequency 2 per season Volume is 1 to 16,804,957 (4,650) Duration is 1 to 99 (10)	Qp: 594 cfs with Frequency 2 per season Volume is 1 to 23,765,759 (5,935) Duration is 1 to 98 (10)
Base Flows (cfs)	84	71	73	74
	62	53	59	59
	44	39	45	49
Subsistence Flows (cfs)	14	14	16	14

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

West Fork San Jacinto near Conroe
Full Record - MBFIT (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 6,200 cfs with Frequency 2 per 3 years Volume is 23 to 244,735,334 (75,402) Duration is 3 to 162 (22)			
High Flow Pulses	Qp: 6,240 cfs with Frequency 1 per 2 seasons Volume is 14 to 525,554,348 (86,806) Duration is 2 to 200 (22)	Qp: 5,830 cfs with Frequency 1 per 2 seasons Volume is 15 to 281,699,857 (65,932) Duration is 3 to 167 (21)	Qp: 2,290 cfs with Frequency 1 per 2 seasons Volume is 12 to 35,997,090 (20,830) Duration is 2 to 92 (15)	Qp: 2,640 cfs with Frequency 1 per 2 seasons Volume is 10 to 55,421,006 (23,831) Duration is 2 to 87 (13)
	Qp: 3,090 cfs with Frequency 1 per season Volume is 6 to 220,273,524 (36,862) Duration is 2 to 144 (16)	Qp: 2,950 cfs with Frequency 1 per season Volume is 7 to 124,814,251 (29,533) Duration is 2 to 123 (15)	Qp: 673 cfs with Frequency 1 per season Volume is 3 to 8,076,189 (4,771) Duration is 1 to 50 (8)	Qp: 972 cfs with Frequency 1 per season Volume is 3 to 16,190,938 (7,072) Duration is 1 to 54 (8)
	Qp: 958 cfs with Frequency 2 per season Volume is 1 to 52,231,173 (8,847) Duration is 1 to 83 (9)	Qp: 1,000 cfs with Frequency 2 per season Volume is 2 to 34,497,726 (8,249) Duration is 1 to 76 (9)	Qp: 155 cfs with Frequency 2 per season Volume is 0 to 1,371,640 (815) Duration is 1 to 24 (4)	Qp: 257 cfs with Frequency 2 per season Volume is 1 to 3,191,287 (1,403) Duration is 1 to 29 (4)
Base Flows (cfs)	113	86	38	42
	60	52	28	29
	34	37	22	23
Subsistence Flows (cfs)	10	14	11	11

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

East Fork San Jacinto River near Cleveland
Full Record - MBFIT (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 3,010 cfs with Frequency 2 per 3 years Volume is 18 to 46,031,936 (29,027) Duration is 3 to 122 (19)			
High Flow Pulses	Qp: 2,940 cfs with Frequency 1 per 2 seasons Volume is 14 to 85,824,064 (34,389) Duration is 3 to 164 (21)	Qp: 3,010 cfs with Frequency 1 per 2 seasons Volume is 13 to 56,061,041 (26,687) Duration is 2 to 117 (17)	Qp: 1,080 cfs with Frequency 1 per 2 seasons Volume is 8 to 7,739,003 (8,023) Duration is 2 to 64 (12)	Qp: 1,190 cfs with Frequency 1 per 2 seasons Volume is 7 to 10,800,978 (8,926) Duration is 2 to 70 (12)
	Qp: 1,470 cfs with Frequency 1 per season Volume is 6 to 36,357,622 (14,752) Duration is 2 to 113 (15)	Qp: 1,480 cfs with Frequency 1 per season Volume is 6 to 25,013,519 (12,041) Duration is 2 to 86 (12)	Qp: 396 cfs with Frequency 1 per season Volume is 3 to 2,394,318 (2,521) Duration is 1 to 39 (7)	Qp: 473 cfs with Frequency 1 per season Volume is 3 to 3,703,228 (3,100) Duration is 1 to 45 (8)
	Qp: 529 cfs with Frequency 2 per season Volume is 2 to 10,326,964 (4,236) Duration is 1 to 65 (9)	Qp: 600 cfs with Frequency 2 per season Volume is 2 to 9,010,177 (4,376) Duration is 1 to 58 (8)	Qp: 130 cfs with Frequency 2 per season Volume is 1 to 658,468 (697) Duration is 1 to 23 (4)	Qp: 136 cfs with Frequency 2 per season Volume is 1 to 882,747 (743) Duration is 1 to 26 (4)
Base Flows (cfs)	84	70	29	29
	40	45	23	22
	28	30	17	18
Subsistence Flows (cfs)	10	10	10	10

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Spring Creek near Spring
Full Record - MBFIT (Adjusted)

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May)	Summer (Jun, Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 3,500 cfs with Frequency 2 per 3 years Volume is 21,081 to 52,701 (33,332) Duration is 12 to 33 (20)			
High Flow Pulses	Qp: 2,850 cfs with Frequency 1 per 2 seasons Volume is 20,204 to 49,163 (31,517) Duration is 13 to 34 (21)	Qp: 3,720 cfs with Frequency 1 per 2 seasons Volume is 21,980 to 51,853 (33,760) Duration is 11 to 30 (19)	Qp: 1,360 cfs with Frequency 1 per 2 seasons Volume is 6,603 to 17,770 (10,833) Duration is 8 to 23 (13)	Qp: 2,700 cfs with Frequency 1 per 2 seasons Volume is 13,336 to 31,935 (20,637) Duration is 9 to 24 (15)
	Qp: 1,500 cfs with Frequency 1 per season Volume is 9,351 to 22,724 (14,577) Duration is 9 to 25 (15)	Qp: 1,810 cfs with Frequency 1 per season Volume is 9,746 to 22,963 (14,960) Duration is 8 to 22 (14)	Qp: 450 cfs with Frequency 1 per season Volume is 1,774 to 4,763 (2,907) Duration is 5 to 13 (8)	Qp: 734 cfs with Frequency 1 per season Volume is 3,091 to 7,384 (4,778) Duration is 5 to 14 (9)
	Qp: 403 cfs with Frequency 2 per season Volume is 1,930 to 4,683 (3,006) Duration is 5 to 13 (8)	Qp: 469 cfs with Frequency 2 per season Volume is 2,121 to 4,990 (3,253) Duration is 5 to 12 (8)	Qp: 147 cfs with Frequency 2 per season Volume is 469 to 1,258 (768) Duration is 3 to 7 (4)	Qp: 209 cfs with Frequency 2 per season Volume is 754 to 1,800 (1,165) Duration is 3 to 8 (5)
Base Flows (cfs)	58	55	30	29
	31	37	23	21
	20	23	16	15
Subsistence Flows (cfs)	6	8	6	6

Hydrologic Conditions	
	Wet (75th %ile)
	Average (50th %ile)
	Dry (25th %ile)
	Subsistence

High Flow Pulse Characteristics	
	F = Frequency (per season)
	D = Duration (days)
	Q = Peak Flows (cfs)
	V = Volume (ac-ft)

Trinity River Basin BBEST
Instream Flow Study

Ecological Overlay for the Trinity River for support of Development of Instream Flow Recommendations for Environmental Flows:

Prepared for:
Trinity River Authority and
Texas Water Development Board

Prepared by:
Environmental Institute of Houston, University of Houston Clear Lake
In Cooperation with the Trinity River Authority

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Executive Summary

This report summarizes available ecological information on the Trinity River and provides an "Ecological Overlay" document for future development of instream flow recommendations for the Trinity River. This summary report includes graphical representations and tabular information revealing key relationships between flow variation and the ecological indicators. This also include a species occurrence matrix indicating, when available, the location of various fish and aquatic species within the basin by river mile, TCEQ waterbody code, HUC code and latitude and longitude. This was developed in coordination with San Jacinto River Authority and other investigators in Texas who are conducting similar studies. Supporting graphical and tabular data are included and attached both in hard copy format and are available in digital format from the Trinity River Authority and/or Texas Water Development Board

Data used in the preparation was extracted from various sources including published peer reviewed articles, agency reports, federal aid progress reports, conference proceedings, and regional, state and federal environmental databases. The focus of this study was on development of ecological information on the occurrence and relationship of instream living resources and hydrology. However, an attempt was made to evaluate the concentrations and fluctuation of important water quality variables (water temperature, conductivity, dissolved oxygen, selected nutrients and suspended solids) in relation to flow. In addition we reviewed pertinent literature and data and generated estimates of downstream loading of suspended solids and nutrients to the lower river and estuary. These loads were evaluated for potential impacts on geomorphology and aquatic life.

We found that historically degraded water quality (anoxia, hypoxia and fish kills) had reduced or eliminated aquatic communities in the upper basin below Dallas Fort Worth. Today although many segments are still listed for violations of dissolved oxygen criteria, fish communities have recovered. One of the primary factors limiting full recovery of riverine/fluvial specialist fish species and reintroduction of highly migratory fishes is the high number of dams and reservoirs in the Trinity River basin which have fragmented the river and reduced connectivity. Based on recent studies the Trinity River watershed was classified as the most fragmented watershed in Texas. In addition, this network of reservoirs affects the ability of the river to transport nutrients and sediment to downstream areas. The cumulative extent of this impact is however unknown. The lowest reservoir on the river, Lake Livingston, has since its construction reduced sediment and nutrient loading to the lower river and/or Galveston Bay. The impacts of sediment reductions are however localized below the dam and do not appear to be affecting Galveston Bay due to the sediment load regeneration below the dam. Nitrogen and phosphorus loads have also been reduced below Lake Livingston in comparison to inputs from the upper watershed. However the phosphorus deficit has slowly been reduced in recent years. The effects of nutrient load reduction are unknown. During the period after dam construction chlorophyll-a levels declined rapidly in Galveston Bay. However, there are few pre-dam data and during this period point source loading sources in the lower basin were also reduced.

Two major products produced from this study include a species occurrence matrix which utilized data compiled from surveys of the literature including agency reports, and summarization of ecological relationships of candidate "focal species" previously suggested by TPWD. These focal species were compared, based on their life history attributes, to other members of the fish community to determine if they can serve as indicator species representing larger ecological fish

guilds. Finally using these indicator species generic and specific recommendations on possible instream flow targets and metrics are presented. These data can be used to inform, validate and modify current and future hydrological analysis generated by IHA/HEFR/MBFIT to recommend environmental instream flow regimes for conservation and protection of the ecological health of the river. Although data on other biological communities exist for the Trinity River, there is, based on our literature survey, much more information on the fish communities of the Trinity River basin. This is due in part to their cultural and economic importance as a food and game resource, relative ease of identification, and the longer history of research and monitoring by state agencies and university researchers. Comparatively few long term data sets and studies exist on invertebrate and wildlife resources.

Introduction

This report summarizes available ecological information on the Trinity River and provides an "Ecological Overlay" document for future development of instream flow recommendations for the Trinity River. This summary report includes graphical representations and tabular information revealing key relationships between flow variation and the ecological indicators. This also include a species occurrence matrix indicating, when available, the location of various fish and aquatic species within the basin by river mile, TCEQ waterbody code, HUC code and latitude and longitude. This was developed in coordination with San Jacinto River Authority and other investigators in Texas who are conducting similar studies. Supporting graphical and tabular data are available in digital format from the Trinity River Authority and/or Texas Water Development Board with a copy of the full summary report.

Data used in the preparation was extracted from various sources including published peer reviewed articles, agency reports, federal aid progress reports, conference proceedings, and regional, state and federal environmental databases. The focus of this study was on development of ecological information on the occurrence and relationship of instream living resources and hydrology. However, two related study objectives were also included in the scope of work. This included developing background data on important variables processes needed to understand the influence of changing hydrology on water quality and the physical transport of sediments. Therefore an attempt was made to evaluate the fluctuation of important water quality parameters (water temperature, conductivity, dissolved oxygen, selected nutrients and suspended solids in relation to flow, including loading estimates at selected priority gages. In addition we have provided estimates of downstream loading of nutrients and suspended solids to the estuary from the Trinity River. Two major products produced from this study include a species occurrence matrix which utilized data compiled from surveys of the literature including agency reports, and summarization of ecological relationships of candidate "focal species" previously suggested by TPWD. These focal species were compared, based on their life history attributes, to other members of the fish community to determine if they can serve as indicator species representing larger ecological fish guilds. Finally using these indicator species generic and specific recommendations on possible instream flow regimes is presented. This data can be used to inform current and future hydrological analysis generated by IHA/HEFR/MBFIT to prescribe recommend flow regimes for conservation and protection of the ecological health of the river.

Although other biological data exist on benthic communities and wildlife, by far more information exists on the fish communities of the Trinity River basin. This is due in part to their cultural and economic importance as a fisheries resource and the more extensive history of research and monitoring by state agencies and university researchers. The primary sources of data include fisheries and river fish community studies by Texas Parks and Wildlife Department during the last 40 years and recent investigations by TCEQ and predecessor agencies conducting water quality related permitting studies including receiving water assessments. In addition, EPA and TCEQ have funded additional university studies investigating the effects of water quality on biota. Comparatively few data and studies exist on invertebrate and wildlife resources.

Background

Senate Bill 3 (SB 3), passed by the Texas Legislature in 2007, directed the development of environmental flow recommendations through a regulatory approach using a local stakeholder process and the best available science and culminating in Texas Commission on Environmental Quality (TCEQ) rulemaking. SB 3 directed the use of an environmental flow regime in developing flow standards from the environmental flow recommendations and defined a regime as a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats. Initial flow recommendations by the local basin and bay expert science teams (BBEST) are to be made without regard to the need for the water for other uses.

The Science Advisory Committee (SAC) has published guidance on using hydrologic data as a method to develop initial instream flow recommendations as part of SB 3 efforts (Science Advisory Committee (SAC) 2009). One of the approaches outlined is the Hydrology-Based Environmental Flow Regime (HEFR) methodology which uses hydrologic data to populate an initial flow regime matrix consisting of monthly/seasonal schedules for subsistence flows, base flows, high flow pulses, and overbank flows. The hydrology-based approach represents a critical component in the collaborative process designed to identify flows needed to maintain a sound ecological environment in Texas Rivers and streams. However, completion of the process requires input from other scientific disciplines including biology, geomorphology, and water quality to ensure that environmental flow recommendations use the best available scientific information, and are adequate to support all processes and functions that maintain a sound ecological environment. This includes flow sufficient to maintain water quality, sediment transport, and provide habitat needs for aquatic life. To facilitate the use of other disciplines to inform, confirm, or modify the hydrology-based initial flow regime matrix, the SAC has produced various guidance documents related to the overlay of biologic, geomorphologic, and water quality information. Some of these have been completed, others are still in preparation.

The primary focus of this report is development of a biological overlay to be used in conjunction with ongoing hydrological based methods. Recently the SAC has produced a draft guidance on development of biological overlay information (Instream Biology Workgroup of the Science Advisory Committee (SAC) 2009). Many of the suggested approaches and recommended procedures in that document are included in this report and are outlined below.

The recommended steps as outlined in draft recommendations include:

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.

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

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

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

STEP 5. Evaluate and refine the initial flow matrix

Our study and report provides information needed to immediately complete steps 2 and 3. Furthermore the information provided in this report can be used to assist the BBEST complete the remaining steps.

The SAC draft guidance also provided other general recommendations on use of biological data.

They are paraphrased and listed below.

1. Quantification of biology based flow parameters

The BBEST should examine sources from the literature review, assess them for relevance and identify any statements, data, or graphs that specifically link aspects of the flow regime with biota or key ecological processes. It is important to document key habitat requirements and preferences of target biological species and assemblages.

2. Causal connections based on available data and known relationships

It is recommended that the BBEST portray the flow-ecology relationships and ecological processes in a conceptual model. Conceptual models provide a concise way to portray ecological knowledge and show hypothesized linkages between flow and various aspects of ecosystem health, or a species' dependence upon certain flow conditions to complete a particular life history stage.

3. If there is existing data that links aspects of the flow regime with biological information, this information should be used to parameterize the flow regime analysis, e.g. HEFR

Based on the quantification of flow parameters, development of causal connections and geospatial information, information may be available that specifically links biological information to aspects of the flow regime. Even if specific biological information is not available to inform all decision points in the hydrographic separation, any available information should be used.

4. Subsistence flows should maintain water quality and key habitat considerations

Subsistence flows need to be sufficient to support key habitats and habitat needs for focal species, populations, or guilds of representative flowing-water organisms and adjustments should be made to minimize or avoid loss of key habitats and needs, to the extent possible. Flows should be evaluated and adjusted to ensure water quality parameters (e.g. DO and temperature) are maintained in a suitable range to ensure aquatic life persists/endures.

5. Base flows should be identified that provide suitable and diverse habitat conditions and support the survival, growth, and reproduction of aquatic organisms

To the extent available, information on focal species can be used to confirm and refine base flow estimates. Specifically, quantified flow-ecology relationships discovered in literature reviews can be used directly by comparing statistical (e.g. HEFR-derived) estimates with specific flow requirements. Qualitative life history information and conceptual models of species' life cycles can also be used. A variety of tools can be used to evaluate suitable habitat. Desktop methods can be used where limited information is available.

6. High flow pulses have important roles in maintaining water quality, physical processes, connectivity, and biological processes.

Pulse characteristics (such as the magnitude, timing, duration, and frequency) should be evaluated and refined relative to life history information for focal species, to the extent available. Approaches to address lateral connectivity to oxbows or other riparian habitats include reviewing available life history information, conducting targeted sampling and hydraulic modeling to identify flow levels needed to provide connections.

7. Overbanking flows support geomorphic processes, provide lateral connectivity, and maintain the balance and diversity of riparian areas.

Our study and report provides information needed to immediately evaluate and attain recommendations 1-3 and 5. Furthermore the information provided in this report can be used to assist the BBEST evaluate attainment of the remaining recommendations.

Data summarized in this report will need to be coupled with existing and future information generated by the hydrological analysis of the Trinity River basin. A separate related project conducted concurrently during this study was the hydrological analysis utilizing various tools including IHA, HEFR and/or MBFIT. The primary objective of that study entitled "*Use of Hydrologic Data in the Development of Instream Flow Recommendations for the Environmental Flows*" conducted by Crespo Consulting Services, Inc. was to study the flow regime at specific locations within the Trinity/San Jacinto River Basin (Crespo Consulting Services Inc. 2009). Their study included development of preliminary flow matrices for 8 locations on the Trinity River (along with qualifications about the meaning, limitations, and uses thereof), and recommendations on how these preliminary flows might ultimately be developed into environmental flow recommendations using biological overlay data, supplemental evaluation tools, and improvements in computational methodologies. Part of our effort involved comparing the distribution of biological resources in relation to these hydrological gages (potential control points) for future instream flow recommendations to insure complementary flow and biological data sets exist.

This report contains graphical representations and tabular information revealing key relationships between flow variation and the ecological indicators. Included in this report is a fish and aquatic invertebrate (mussel) species occurrence matrix. This was done in coordination with San Jacinto River Authority to facilitate use of the information by the Trinity and San Jacinto BBEST. The report includes graphical and tabular data including compiled summary biological data in electronic spreadsheet format. This report and analysis is an attempt to provide generic and where possible specific biological criteria that can be used to provide guidance to future hydrological analyses for development of instream flow criteria in the Trinity River.

Methodology

Hydrology Summary

In order to understand the potential biological responses to the hydrology in the basin it is necessary to provide some background on the historical hydrology in the basin. Eight priority USGS gage sites were selected from a list of 119 historical sites by the BBEST instream flow workgroup as potential control points in the Trinity River basin. The primary criteria used included having a sufficiently long period of record, and a strategic location which facilitates characterization of a significant percentage of the basin hydrology. These sites are listed and displayed in Table 1 and Figures 1 and 2. A separate but related project conducted concurrently during this study was the hydrological analysis utilizing various tools including IHA, HEFR and/or MBFIT. The primary objective of that study entitled "*Use of Hydrologic Data in the Development of Instream Flow Recommendations for the Environmental Flows*" conducted by Crespo Consulting Services, Inc. was to study the flow regime at specific locations within the Trinity/San Jacinto River Basin (Crespo Consulting Services Inc. 2009). Their study lays the groundwork for subsequent development of the hydrologic analysis. Their study included the development of preliminary flow matrices for eight priority gage locations (along with qualifications about the meaning, limitations, and uses thereof) on the Trinity River, and recommendations on how these preliminary flows might ultimately be developed into environmental flow recommendations using biological overlay data.

We also provided a very basic summary of the historical hydrology in the basin using the previously identified priority gages as control points. These data and related discussion are not intended to replace the more in-depth analysis provided through the Crespo Consulting report (IHA-HEFR/MBFIT analysis) but instead to provide a general description of long-term patterns in hydrology in the basin within the historical period of record. This may be helpful in understanding the possible relationships between hydrology, water quality, and life history adaptations and requirements of organisms within the river. Daily average discharge data during the period of record through December 2008, was obtained for the eight priority gage sites: (http://nwis.waterdata.usgs.gov/nwis/monthly/?search_site_no=08066500&agency_cd=USGS&referred_module=sw&format=sites_selection_links). Monthly mean daily average flow was generated for all months including periods with missing daily values. In addition, we computed average differences in flow (between adjacent days) as a means of characterizing daily variations in flow and ramping rates. The IHA software package was also used to preprocess and organize the daily mean average daily values and generate daily discharge graphs. The Minitab© software package was used to construct summary graphics.

Table 1. Location of priority gage sites on the Trinity River utilized for hydrological analysis project (Crespo Consulting 2009).

USGS Gage #	Gage Site Description	lat	long	TCEQ Segment #	HUC Code	River Mile	Watershed	Flow Data	
							sq. miles	begin date	end date
08055500	Elm Fork Trinity River near Carrollton, TX	32.96583	-96.94417	0822	12030103	18.2	2459	1907	2008
08049500	West Fork Tiniry River at Grand Prairie, TX	32.76250	-96.99444	0841	12030102	514.6	3065	1926	2008
08057000	Trinity River at Dallas, TX	32.77472	-96.82167	0805	12030105	500.3	6106	1904	2008
08062500	Trinity River near Rosser, TX	32.42639	-96.46278	0805	12030105	451.4	8147	1939	2008
08062700	Trinity River at Trinidad, TX	32.14750	-96.10222	0804	12030105	390.3	8538	1965	2008
08065000	Trinity River near Oakwood, TX	31.64833	-95.78917	0804	12030201	313.4	12833	1924	2008
08065350	Trinity River near Crockett, TX	31.33833	-95.65611	0804	12030201	265.4	13911	1964	2008
08066500	Trinity River @ Romayor, TX	30.42500	-94.85056	0802	12030202	94.3	171186	1925	2008

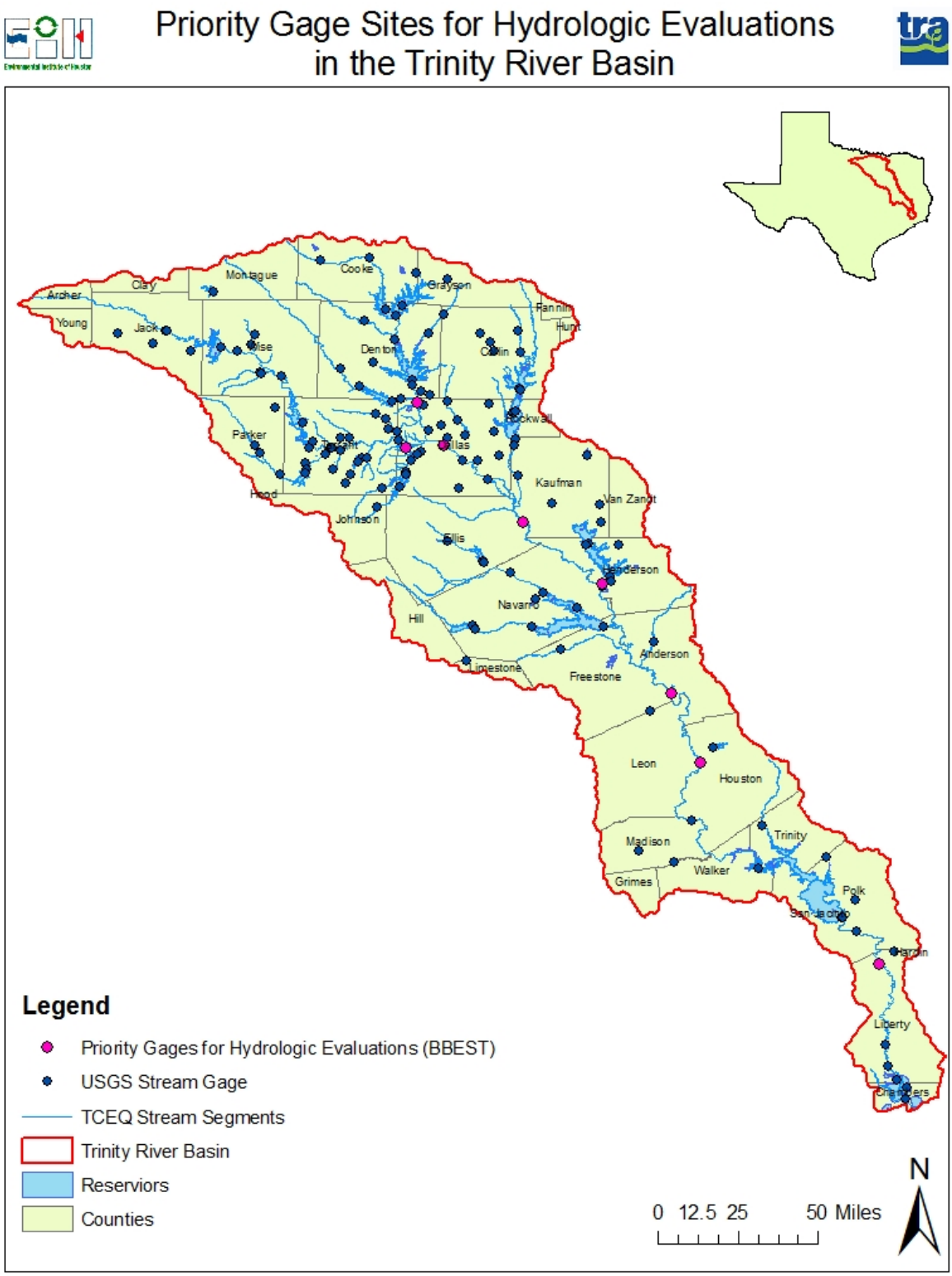


Figure 1. Distribution of USGS gage sites in Trinity River.

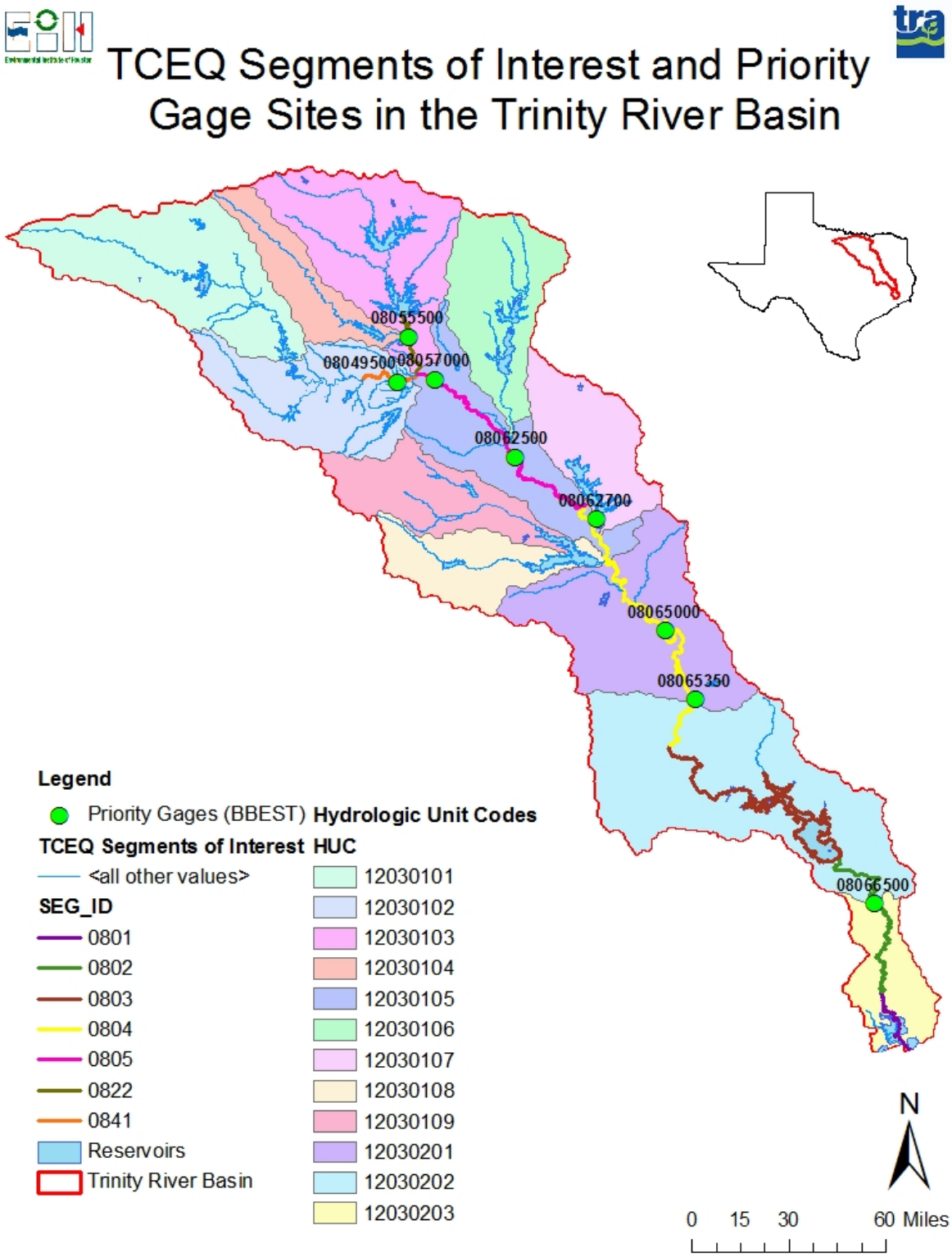


Figure 2. Distribution of USGS priority gage sites in relation to TCEQ segments and hydrologic units of the Trinity River.

Water Quality and Geomorphology

Recent and archived historical digital water quality and hydrology data within the Trinity River basin was compiled from both USGS, TCEQ and the Clear Rivers Program (CRP) partner TRA and are included in the comprehensive database compiled by EIH prior to this project. In order to evaluate the potential relationship between hydrology and water quality we queried several databases including the USGS, Clean Rivers Program and TCEQ surface water quality monitoring database. In order to evaluate the relationship between streamflow and water quality and geomorphology (i.e. sediment transport) we focused our efforts on the eight USGS priority gage sites and associated TCEQ river segments on the Trinity River utilized by the hydrological analysis study (Crespo Consulting Services Inc. 2009)(Figures 1 and 2). The preferred data sets in order of priority include USGS, TCEQ, and Clean Rivers Program (CRP). Data collected by USGS at priority gage sites were specifically targeted for characterization. In all cases we utilized paired water quality data collected near the gage site and upstream of any major downstream tributaries. Water quality data collected by TCEQ and Clean Rivers Program at routine water quality monitoring sites were used to supplement data collected at the USGS gage network to provide broad scale characterizations of selected variables (Figure 3). Since much of the water quality data collected in the state is done for compliance with water quality standards we also provide a list of the current legally defined water body segments in the Trinity River watershed that are used for water quality management (Table 2)(TNRCC 2000).

Graphical plots depicting streamflow, concentrations and loading were constructed when paired water quality and instantaneous flow data were available. We also attempted to develop statistical models of flow versus observed water quality data. In most cases we only plotted data if there was sufficient temporal intensity and coverage. Our decision rule was to only conduct these analyses when at least 10 observations were obtained over a range of flow levels. The period of record was usually shorter then the period of record for only discharge data alone and is reported with each graph. When data was insufficient we did not plot the data. In some cases we evaluated the fit of various statistical models (e.g. linear, log-linear and quadratic) to determine if there were viable predictive models that could be develop predictive discharges loading estimates and key water quality variables that may influence stream productivity and aquatic organisms.

Target parameters included water temperature, specific conductance, suspended solids, and nutrients (nitrates or nitrate+nitrites, total phosphorus, orthophosphates). For water temperature and dissolved oxygen we segregated the data first into seasonal periods and then analyzed these subsets separately. In some cases data were limited and/or lacking and consequently some analyses were not feasible. Another critical factor that should be noted was the frequency and reason for data collection. Matching flow and water quality data sets collected by USGS were collected at various time frequencies including long term monitoring and storm events. Sampling frequency and timing along with prior environmental conditions (e.g. flood, drought) will influence the levels in nutrients etc. For example levels of pollutants are often highly elevated during the initial rising limb of a storm hydrograph following a dry period than comparable flows levels under sustained stream flow conditions during wet periods. The relationship of these parameters would be expected to vary due to the factors. However, our basic analysis does not separate these groups. Therefore potential relationships between parameters during storm versus sustained flows may be obscured. To separate this it would be necessary to go back and reclassify these data sets and analyze them separately.

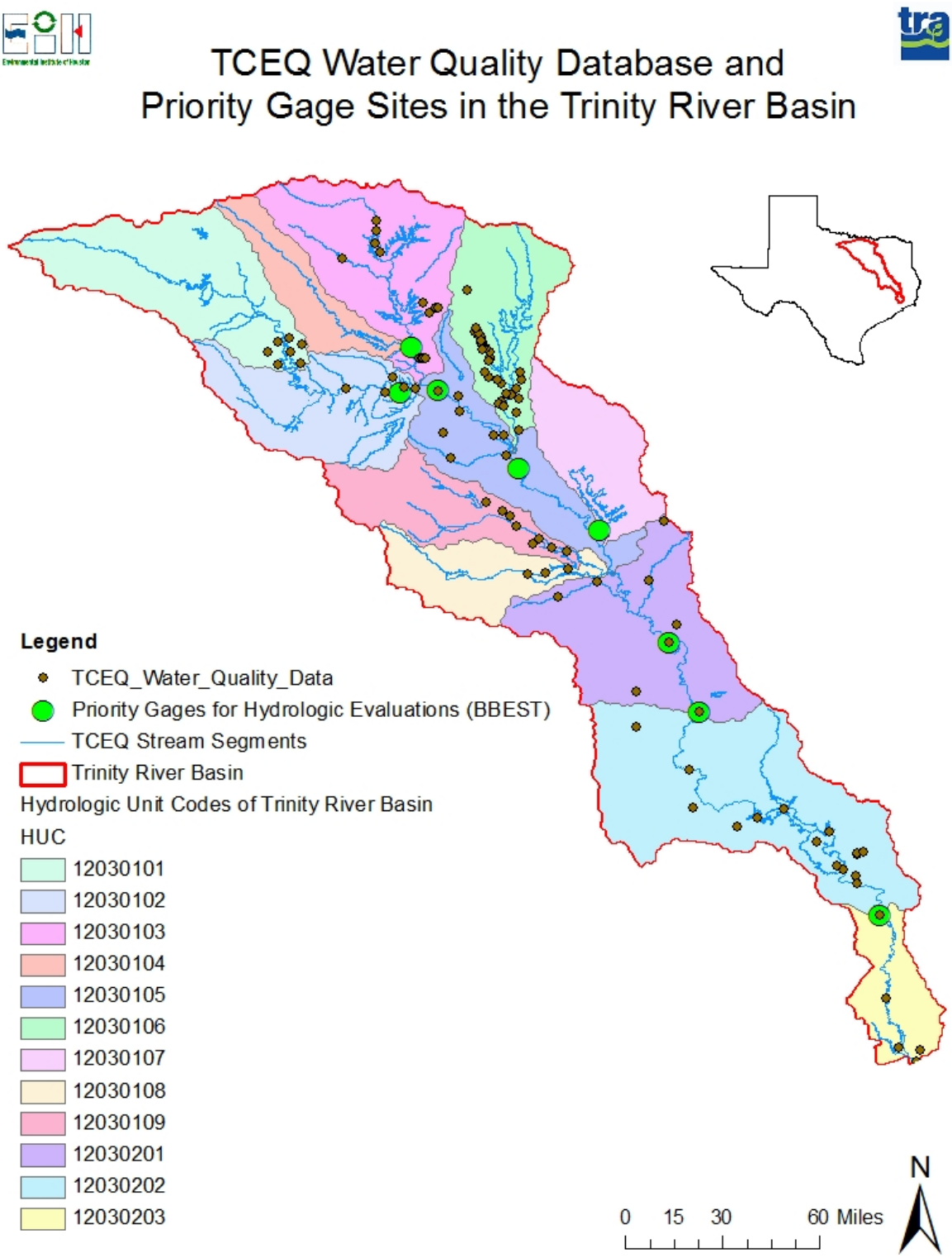


Figure 3. Location of TCEQ/CRP water quality monitoring sites within the Trinity River Basin that were used as data sources.

Table 2. List of legally defined waterbody segments within the Trinity River watershed (TNRCC 2000). Other segments referred to in the text with letter suffixes refer to unclassified tributaries of these main segments.

SEGMENT	DESCRIPTION
0801	Trinity River Tidal - from the confluence with Anahuac Channel in Chambers County to a point 3.1 kilometers (1.9 miles) downstream of US 90 in Liberty County
0802	Trinity River Below Lake Livingston - from a point 3.1 kilometers (1.9 miles) downstream of US 90 in Liberty County to Livingston Dam in Polk/San Jacinto County
0803	Lake Livingston - from Livingston Dam in Polk/San Jacinto County to a point 1.8 kilometers (1.1 miles) upstream of Boggy Creek in Houston/Leon County, up to the normal pool elevation of 131 feet
0804	Trinity River Above Lake Livingston - from a point 1.8 kilometers (1.1 miles) upstream of Boggy Creek in Houston/Leon County to a point immediately upstream of the confluence of the Cedar
0805	Upper Trinity River - from a point immediately upstream of the confluence of the Cedar Creek Reservoir discharge canal in Henderson/Navarro County to a point immediately upstream of the
0806	West Fork Trinity River Below Lake Worth - from a point immediately upstream of the confluence of Village Creek in Tarrant County to Lake Worth Dam in Tarrant County
0807	Lake Worth - from Lake Worth Dam in Tarrant County to a point 4.0 kilometers (2.5 miles) downstream of Eagle Mountain Dam in Tarrant County, up to the normal pool elevation of 594.3 feet
0808	West Fork Trinity River Below Eagle Mountain Reservoir - from a point 4.0 kilometers (2.5 miles) downstream of Eagle Mountain Dam in Tarrant County to Eagle Mountain Dam in Tarrant County
0809	Eagle Mountain Reservoir - from Eagle Mountain Dam in Tarrant County to a point 0.6 kilometer (0.4 mile) downstream of the confluence of Oates Branch in Wise County up to the normal pool
0810	West Fork Trinity River Below Bridgeport Reservoir - from a point 0.6 kilometer (0.4 mile) downstream of the confluence of Oates Branch in Wise County to Bridgeport Dam in Wise County
0811	Bridgeport Reservoir - from Bridgeport Dam in Wise County to a point immediately upstream of the confluence of Bear Hollow in Jack County, up to the normal pool elevation of 836 feet (impounds
0812	West Fork Trinity River Above Bridgeport Reservoir - from a point immediately upstream of the confluence of Bear Hollow in Jack County to SH 79 in Archer County
0813	Houston County Lake - from Houston County Dam in Houston County up to the normal pool
0814	Chambers Creek Above Richland-Chambers Reservoir - from a point 4.0 kilometers (2.5 miles) downstream of Tupelo Branch in Navarro County to the confluence of North Fork Chambers Creek
0815	Bardwell Reservoir - from Bardwell Dam in Ellis County up to the normal pool elevation of 421 feet
0816	Lake Waxahachie - from South Prong Dam in Ellis County up to the normal pool elevation of 531.5
0817	Navarro Mills Lake - from Navarro Mills Dam in Navarro County up to the normal pool elevation of
0818	Cedar Creek Reservoir - from Joe B. Hoggsett Dam in Henderson County up to the normal pool
0819	East Fork Trinity River - from the confluence with the Trinity River in Kaufman County to Rockwall-
0820	Lake Ray Hubbard - from Rockwall-Forney Dam in Kaufman County to Lavon Dam in Collin County, up to the normal pool elevation of 435.5 feet (impounds East Fork Trinity River)
0821	Lavon Lake - from Lavon Dam in Collin County up to the normal pool elevation of 492 feet
0822	Elm Fork Trinity River Below Lewisville Lake - from the confluence with the West Fork Trinity River in Dallas County to Lewisville Dam in Denton County
0823	Lewisville Lake - from Lewisville Dam in Denton County to a point 200 meters (220 yards) upstream of FM 428 in Denton County, up to the normal pool elevation of 522 feet (impounds Elm Fork Trinity
0824	Elm Fork Trinity River Above Ray Roberts Lake - from a point 9.5 kilometers (5.9 miles) downstream of the confluence of Pecan Creek in Cooke County to US 82 in Montague County
0825	Denton Creek - from the confluence with the Elm Fork Trinity River in Dallas County to Grapevine
0826	Grapevine Lake - from Grapevine Dam in Tarrant County up to the normal pool elevation of 535 feet
0827	White Rock Lake - from White Rock Dam in Dallas County up to the normal pool elevation of 458
0828	Lake Arlington - from Arlington Dam in Tarrant County up to the normal pool elevation of 550 feet

Source: (TNRCC 2000).

We also provided estimates of draft 7Q2 estimates obtained from TCEQ for selected USGS gage sites in the basin. We also reviewed the most current TCEQ 303d list of impaired water bodies to determine the causes and extent of impairment within the basin and potential influences on aquatic biota (Texas Commission on Environmental Quality (TCEQ) 2009). Using available data and previous published literature we also provide estimated loads of nutrients and solids to Galveston Bay by utilizing data at the most downstream gage, Trinity River at Rotator (08066500). We have also provided citations in our EndNote® databases on pertinent water quality and geomorphological studies, and in some cases associated data in Excel Spreadsheets and/or Access databases for future analyses. Where appropriate we have cited data extracted data and estimates from these reports. We attempted to compile stream cross-sectional data from known USGS gage sites but were only able to obtain a few from the agency since most of this information is not digital.

Focal Species Matrix

Prior to the August 2009 BBEST meeting, the Texas Parks and Wildlife Department (TPWD) was contacted and asked to provide a preliminary list of "focal" species that should be considered during development of the ecological overlay analysis and report. The focal species included selected finfish and unionid mussels. Some of these recommended species were presented at the Trinity/San Jacinto BBASC meeting in July 2009 (Botros 2009). One of the critical exercises we would conduct is a comparison of the distribution of important species with the distribution of priority gages. Hopefully there would be considerable overlap so that information obtained from the biological analysis could be used with hydrological data collected in the same section of river. Upon receipt we cross referenced these recommended species against our existing Trinity watershed fish species matrix that we had previously developed (Table 3).

The species matrix was initially developed using data compiled from a comprehensive literature review of fisheries and aquatic surveys historically conducted or sponsored by various agencies including EPA, USGS, FWS, TPWD, TCEQ, TRA, and university researchers. Data was obtained from various resources including electronic literature databases, peer reviewed articles, and gray literature (agency reports). In some cases this involved directly contacting regional fisheries and aquatic biologists directly. They would sometimes need to make copies of the original reports and send them to us. This included old Federal Aid Progress (Dingell-Johnson) Reports. The responding biologists knew our primary study emphasis was riverine fish populations. Consequently, it is possible that some reservoir fisheries investigations conducted by TPWD during the mid-1970s through mid-1980s were under reported.

Recent synthesis studies on the distribution and status of Texas freshwater fishes conducted by Dr. Tim Bonner at Texas State University and Dr. Dean Hendrickson from the University of Texas have also generated lists of species found in the Trinity River Basin. The data on occurrences on the Trinity Basin compiled by Dr. Bonner was extracted from his web page: http://www.bio.txstate.edu/~tbonner/txfishes/Trinity.htm. Dr. Hendrickson provided a draft copy of his compilation of Trinity River fish species from the ("Fishes of Texas Project database, Texas Natural History Collections, University of Texas at Austin (http://www.utexas.edu/tmm/tnhc/)"). This was provided to us on August 13, 2009 on an Excel spreadsheet. His data was compiled by various institutions and researchers who contributed data to the project. This included voucher specimens. The list of data donor institutions is maintained on their website.

Table 3. List of fish species previously observed or collected in the Trinity River basin.

SPECIES	COMMON NAME	FAMILY	STATUS	OUR STUDY	BONNNER Web Site	Hendrick Study	Shared	Trophic	Tolerance	BALON Reprod Guild	TPWD Spp Concern	Hubbs Status
Agonostomus monticola	mountain mullet	Mugilidae			1	1	2	O	N	CAT		
Alosa chrysochloris	skipjack herring	Clupeidae	ANA	1	1	1	3	P	N	A14		
Ambloplites rupestris	rock bass	Centrarchidae		1			1	P	I	B22		
Ameirus nebulosus	brown bullhead	Ictaluridae	??	1			1	O	N	B27		
Ameiurus melas	black bullhead	Ictaluridae		1	1	1	3	O	T	B27		
Ameiurus natalis	yellow bullhead	Ictaluridae		1	1	1	3	O	N	B27		
Amia calva	bowfin	Amiidae		1	1	1	3	P	T	B25		
Ammocrypta vivax	scaly sand darter	Percidae		1	1	1	3	IF	N	A16		
Anguilla rostrata	American eel	Anguillidae		1	1	1	3	P	N	CAT		SC
Aphredoderus sayanus	pirate perch	Aphredoderidae		1	1	1	3	IF	N	C14		
Aplondinotus grunniens	freshwater drum	Sciaenidae		1	1	1	3	IF	T	A11	TR	
Astyanax mexicanus	Mexican tetra	Characidae		1	1	1	3	IF	N	A11		
Atractosteus spatula	alligator gar	Lepisosteidae		1	1	1	3	P	T	A15	TR	SC
Campostoma anomalum	central stoneroller	Cyprinidae		1	1	1	3	H	N	A23		
Carassius auratus	goldfish	Cyprinidae	(I)	1	1	1	3	O	T	A15		
Carpiodes carpio	river carpsucker	Catostomidae		1	1	1	3	O	T	A12		
Centrarchus macropterus	flier	Centrarchidae		1	1	1	3	IF	N	B23		
Cichlasoma cyanoguttatum	Rio Grande cichlid	Cichlidae			1	1	2	IF	N	B23		
Ctenopharyngodon idella	grass carp	Cyprinidae	(I)		1		1	H	T	A11		
Cycleptus elongatus	blue sucker	Catostomidae			1		1	IF	I	A12		T
Cyprinella lutrensis	red shiner	Cyprinidae		1	1	1	3	IF	T	A24		
Cyprinella venusta	blacktail shiner	Cyprinidae		1	1	1	3	IF	N	A24		
Cyprinodon rubrofluviatilis	Red River pupfish	Cyprinodontidae				1	1	O	T	B23		
Cyprinodon variegatus	sheepshead minnow	Cyprinodontidae		1	1	1	3	O	T	B23		
Cyprinus carpio	common carp	Cyprinidae	(I)	1	1	1	3	O	T	A14		
Dionda argentosa	Manatial roundnose minnow	Cyprinidae				1	1	O	I	A13		
Dionda episcopa	roundnose minnow	Cyprinidae				1	1	O	I	A13		
Dorosoma cepedianum	gizzard shad	Clupeidae		1	1	1	3	O	T	A12		
Dorosoma petenense	threadfin shad	Clupeidae		1	1	1	3	O	N	A15		
Elassoma zonatum	banded pygmy sunfish	Elassomatidae		1	1	1	3	IF	N	B14		
Erimyzon oblongus	creek chubsucker	Catostomidae		1	1	1	3	O	N	A12	**SJR**	T
Erimyzon sucetta	lake chubsucker	Catostomidae		1	1	1	3	O	N	A14		
Esox americanus	redfin pickerel	Esocidae		1	1	1	3	P	N	A15		
Esox niger	chain pickerel	Esocidae		1			1	P	N	A15		
Etheostoma artesiae	redspot darter	Percidae		1			1	IF	N	B14		
Etheostoma chlorosomum	bluntnose darter	Percidae		1	1	1	3	IF	N	B14		
Etheostoma fusiforme	swamp darter	Percidae				1	1	IF	N	B14		
Etheostoma gracile	slough darter	Percidae		1	1	1	3	IF	N	B14		
Etheostoma histrio	harlequin darter	Percidae		1	1		2	IF	N	B14		
Etheostoma lepidum	greenthroat darter	Percidae		1		1	2	IF	I	B14		
Etheostoma nigrum	johny darter	Percidae				1	1	IF	N	B27		
Etheostoma parvipinne	goldstripe darter	Percidae				1	1	IF	I	B14		
Etheostoma proeliare	cypress darter	Percidae		1	1	1	3	IF	I	B14		
Etheostoma spectabile	orangethroat darter	Percidae		1	1	1	3	IF	N	A23		
Fundulus blairae	western starhead topminnow	Fundulidae			1	1	2	IF	N	A14		
Fundulus chrysotus	golden topminnow	Fundulidae		1	1	1	3	IF	N	A14		
Fundulus cingulatus	Banded topminnow	Fundulidae				1	1	IF	N	A23		
Fundulus diaphanus	banded killifish	Fundulidae		1			1	IF	N	A15		
Fundulus dispar	starhead topminnow	Fundulidae		1		1	2	IF	N	A14		
Fundulus notatus	blackstripe topminnow	Fundulidae		1	1	1	3	IF	N	A15		
Fundulus nottii	bayou topminnow	Fundulidae				1	1	IF	N	A14		
Fundulus olivaceus	blackspotted topminnow	Fundulidae		1	1	1	3	IF	I	A13		
Fundulus zebrinus	plains killifish	Fundulidae			1	1	2	IF	T	A14		
Gambusia affinis	western mosquitofish	Poeciliidae		1	1	1	3	IF	N	C21		
Gambusia geiseri	largespring gambusia	Poeciliidae				1	1	IF	N	C21		
Gambusia speciosa	Tex-Mex gambusia	Poeciliidae				1	1	IF	N	C21		
Hybognathus nuchalis	Mississippi silvery minnow	Cyprinidae		1	1	1	3	O	T	A12		
Hybognathus placitus	plains minnow	Cyprinidae		1	1		2	O	T	A11		
Hybopsis amnis	pallid shiner	Cyprinidae			1	1	2	IF	N	A11	**SJR**	
Ichthyomyzon castaneus	chestnut lamprey	Petromyzontidae		1			1	P	I	A23		
Ichthyomyzon gagei	southern brook lamprey	Petromyzontidae		1	1	1	3	None	I	A23		
Ictalurus furcatus	blue catfish	Ictaluridae		1	1	1	3	P	N	B27	TR	
Ictalurus punctatus	channel catfish	Ictaluridae		1	1	1	3	O	T	B27		
Ictiobus bubalus	smallmouth buffalo	Catostomidae		1	1	1	3	O	N	A12		
Ictiobus cyprinellus	bigmouth buffalo	Catostomidae	?	1			1	IF	T	A12		
Ictiobus niger	black buffalo	Catostomidae		1	1		2	O	N	A12		
Labidesthes sicculus	brook silverside	Atherinopsidae		1	1	1	3	IF	I	A14		
Lepisosteus oculatus	spotted gar	Lepisosteidae		1	1	1	3	P	T	A15		
Lepisosteus osseus	longnose gar	Lepisosteidae		1	1	1	3	P	T	A14	SJR	
Lepisosteus platostomus	shortnose gar	Lepisosteidae		1		1	2	P	T	A15		
Lepomis auritus	redbreast sunfish	Centrarchidae	(I)	1	1	1	3	IF	N	B22		
Lepomis cyanellus	green sunfish	Centrarchidae		1	1	1	3	P	T	B22		
Lepomis gulosus	warmouth	Centrarchidae		1	1	1	3	P	T	B23		
Lepomis humilis	orangespotted sunfish	Centrarchidae		1	1	1	3	IF	N	B23		

Table 3. Continued

SPECIES	COMMON NAME	FAMILY	STATUS	OUR STUDY	BONNNER Web Site	Hendrick Study	Shared	Trophic	Tolerance	BALON Reprod Guild	TPWD Spp Concern	Hubbs Status
Lepomis macrochirus	bluegill	Centrarchidae		1	1	1	3	IF	T	B22		
Lepomis marginatus	dollar sunfish	Centrarchidae		1	1	1	3	IF	N	B22		
Lepomis megalotis	longear sunfish	Centrarchidae		1	1	1	3	IF	N	B22	TR	
Lepomis microlophus	redear sunfish	Centrarchidae		1	1	1	3	IF	N	B22		
Lepomis miniatus	redspotted sunfish.	Centrarchidae		1	1	1	3	IF	N	B22		
Lepomis symmetricus	bantam sunfish	Centrarchidae		1	1	1	3	IF	N	B22		
Luxilus chrysocephalus	striped shiner	Cyprinidae		1		1	2	IF	N	A13		
Lythrurus fumeus	ribbon shiner	Cyprinidae		1	1	1	3	IF	N	A13	**SJR**	
Lythrurus umbratilis	redfin shiner	Cyprinidae		1	1	1	3	IF	N	A13		
Macrhybopsis hyostoma	shoal chub	Cyprinidae			1		1	IF	N	A11		
Membras martinica	rough silverside	Atherinopsidae			1	1	2	IF	N	A14		
Menidia beryllina	inland silverside	Atherinopsidae		1	1	1	3	IF	N	A14		
Menidia peninsulae	tidewater silverside	Atherinopsidae		1			1	IF	N	A14		
Micropterus dolomieui	smallmouth bass	Centrarchidae		1		1	2	P	I	B22		
Micropterus punctulatus	spotted bass	Centrarchidae		1	1	1	3	P	N	B22		
Micropterus salmoides	largemouth bass	Centrarchidae		1	1	1	3	P	N	B22	TR	
Minytrema melanops	spotted sucker	Catostomidae		1	1	1	3	IF	N	A12		
Morone americana	white perch	Moronidae				1	1	P	N	A14		
Morone chrysops	white bass	Moronidae		1	1	1	3	P	N	A14	TR	
Morone mississippiensis	yellow bass	Moronidae		1	1	1	3	P	N	A14		
Morone saxatilis	striped bass	Moronidae	(I)	1	1	1	3	P	N	A14		
Moxostoma congestum	gray redhorse	Catostomidae		1		1	2	IF	N	A13		
Moxostoma poecilurum	blacktail redhorse	Catostomidae		1	1	1	3	IF	N	A13	SJR	
Notemigonus crysoleucas	golden shiner	Cyprinidae		1	1	1	3	IF	T	A15		
Notropis amabilis	Texas shiner	Cyprinidae		1		1	2	IF	N	A11		
Notropis atherinoides	emerald shiner	Cyprinidae		1	1	1	3	IF	N	A11		
Notropis atrocaudalis	blackspot shiner	Cyprinidae		1	1	1	3	IF	N	A11	TR&SJR	SC
Notropis blennius	ghost shiner	Cyprinidae		1	1		2	IF	N	A12		
Notropis buchanani	ghost shiner	Cyprinidae		1		1	2	IF	N	A12		
Notropis chalybaeus	ironcolor shiner	Cyprinidae		1		1	2	IF	I	A12		SC
Notropis chrosomus	rainbow shiner	Cyprinidae	?	1			1	IF	N	A12		
Notropis jemezanus	Rio Grande shiner	Cyprinidae				1	1	IF	N	A11		
Notropis potteri	chub shiner	Cyprinidae			1	1	2	IF	N	A12		SC
Notropis sabinae	Sabine shiner	Cyprinidae		1	1		2	IF	N	A12		SC
Notropis shumardi	silverband shiner	Cyprinidae		1	1	1	3	IF	N	A12	TR	SC
Notropis stramineus	sand shiner	Cyprinidae		1	1	1	3	IF	N	A12		
Notropis texanus	weed shiner	Cyprinidae		1	1	1	3	IF	N	A15		
Notropis volucellus	mimic shiner	Cyprinidae		1	1	1	3	IF	I	A15		
Noturus gyrinus	tadpole madtom	Ictaluridae		1	1	1	3	IF	I	B27		
Noturus nocturnus	freckled madtom	Ictaluridae		1	1	1	3	IF	I	B27	SJR	
Oncorhynchus mykiss	rainbow trout	Salmonidae			1	1	2	IF	I	A23		
Opsopoeodus emiliae	pugnose minnow	Cyprinidae		1	1	1	3	IF	N	B27		
Oreochromis aureus	blue tilapia	Cichlidae	(I)	1		1	2	O	T	B13		
Percina caprodes	logperch	Percidae		1		1	2	IF	I	A23		
Percina carbonaria	Texas logperch	Percidae	?	1			1	IF	I	A23		
Percina macrolepida	bigscale logperch	Percidae		1	1	1	3	IF	I	A23		
Percina sciera	dusky darter	Percidae		1	1	1	3	IF	I	A23	TR	
Percina shumardi	river darter	Percidae			1		1	IF	I	A23		
Phenacobius mirabilis	suckermouth minnow	Cyprinidae		1	1	1	3	IF	N	A12		
Pimephales notatus	bluntnose minnow	Cyprinidae		1			1	IF	N	B27		
Pimephales promelas	fathead minnow	Cyprinidae		1	1	1	3	O	T	B27		
Pimephales vigilax	bullhead minnow	Cyprinidae		1	1	1	3	IF	N	B27		
Poecilia latipinna	sailfin molly	Poeciliidae		1	1	1	3	O	T	C21		
Polyodon spathula	paddlefish	Polyodontidae		1	1		2	O	I	A12	TR	T
Pomoxis annularis	white crappie	Centrarchidae		1	1	1	3	P	N	B25		
Pomoxis nigromaculatus	black crappie	Centrarchidae		1	1	1	3	P	N	B25		
Pygocentrus nattereri	red piranha	Characidae	(I)			1	1	P	N	B14		
Pylodictis olivaris	flathead catfish	Ictaluridae		1	1	1	3	P	N	B27	SJR	
Sander vitreus	walleye	Percidae		1			1	P	N	A12		
Semotilus atromaculatus	creek chub	Cyprinidae		1	1	1	3	P	N	A23		

Explanation for various codes used in Table 3 provided in Table 4. Yellow highlighted rows are for original focal species identified by TPWD and presented at BBEST meeting in August 2009. List compiled from EIH Trinity River fish database, (Bonner 2009), and (Hendrickson 2009; Hendrickson et al. 2008)

All of the data compiled by these various efforts including ours should be considered works in progress since the accuracy of taxonomic identifications and locality data is constantly being reviewed and updated. Dr. Hendrickson agreed to provide his data with the provision that specific collection locations not be revealed. In addition to utilizing data from fishery investigations and aquatic surveys we also reviewed information on the distribution of freshwater fishes from several compilations of freshwater fish distribution within United States and Texas including online electronic databases (e.g. FishBase) (Conner and Suttkus 1986; Froese and Pauly 2000; Hubbs et al. 2008; Lee et al. 1980). The final resulting species matrix list represents the most recent comprehensive compilation of the occurrence of freshwater fish species within the Trinity River basin. We believe our approach is was very thorough and consistent with other large scale efforts to compile comprehensive assessment of freshwater fish species distributions conducted across the world. For example, the author recently attended a technical session, *Symposium 11: Mapping Distributions of North American Freshwater Fishes* which was held at the 2009 national annual meeting of the American Fisheries Society (http://www.fisheries.org/afs09/docs/talks.pdf). At the panel discussion part of the session the moderator reported that the primary databases and literature searched during these large national compilations consisted of state museum collections, state agency collections and published sources such as the *Atlas of North American Freshwater Fishes*, regional fish guides and FishBase (Lee et al. 1980). Our study followed this investigation approach as well.

To facilitate construction of meaningful species guilds we classified species based on published literature into their respective trophic levels, water quality tolerance, and reproductive behavior and early life history classifications (Tables 3 and 4) (Balon 1975; Balon 1981; Linam and Kleinsasser 1998; Simon 1999a). If data were lacking for a species we would utilize information from taxonomically related species that shares similar life history traits.

After compiling the list of fish species, including focal species, and their associated attributes a multivariate cluster analysis technique (Wards algorithm, squared Euclidean distance) was used to classify species (observations) based on shared characteristics. These traits were estimated using indicator variables generated from the suite of life history traits including reproductive behaviour, trophic level and tolerance levels was conducted (Linam and Kleinsasser 1998; Romesburg 1990; Simon 1999a). This process produced a multivariate dendrogram which depicts the similarity of species and species groups based on shared life history attributes. After examination of the output we then classified fish species with highest group affinities into community “guilds”. These guilds, which represent species assemblages with similar life history traits were subsequently examined to determine if at least one candidate “focal” species was present in every guild. Membership in a guild would suggest that the focal species exhibits life history characteristics similar to other members of the group. Furthermore this focal species could theoretically be used as an indicator for that assemblage.

Table 4. Biological codes used in tables 3 and 5.

Guild	Name	Description
A	**Non Guarders**	
A1	**Open Sustratum Spawner**	
A11	Pelagophils	bouyant eggs, open spawners
A12	Lithopelagophils	rock, gravel spawners, pelagic free larvae
A13	Lithophils	rock gravel spawners, benthic larvae
A14	Phytolithophils	nonobligatory plant spawners, benthic larvae
A15	Phytophils	obligatory plant spawners, benthic larvae
A16	Psammophils	sand spawners, benthic larvae
A2	**Brood Hiders**	
A23	Lithophils	rock and gravel spawners, deposit eggs in redd or gravel, not guarded
A24	Speleophils	Cave spawning species, large adhesive eggs
B	**Guarders**	
B1	**Substratum choosers**	**female picks egg deposition site**
B13	Lithophils	rock spawning, adhesive eggs, pelagic larvae
B14	Phytophils	plant spawning, adhesive eggs, pelagic larvae
B2	**Nest Spawners**	**Nests built and guarded**
B22	Polyphils	misc substrate and material nesters
B23	Lithophils	rock and gravel nesters
B24	Ariadnophils	Glue making nesters
B25	Polyphils	plant material nesters
B27	Speleophils	hole nesters
C	**Bearers**	
C1	**External Bearers**	
C13	Mouth Brooders	e.g. tilapia
C14	Gill chamber brooders	e.g. Gill chamber brooders
C2	**Internal Bearers**	
C24	Viviparious	e.g. Viviparous C24

Trophic	**Description**	
IF	Invertivore	
P	Piscivore	
O	Omnivore	
H	Herbivore	
Water Quality Tolerance		
I	intoleranct	
N	neutral or unknown	
T	tolerant	
MISC CODES		
I	introduced	
CAT	Catadromous	
ANA	Anadromous	
TR	Trinity River	
SJR	San Jacinto River	
?	Questionable sighting	
Conservation Status		
SC	Species of concern	
T	Threatened	
E	Endangered	

(Balon 1975; Balon 1981; Hubbs et al. 2008; Linam and Kleinsasser 1998; Simon 1999a)
* Note Balon Level 1 classification used (e.g. A1, A2…C2) for further analysis.

Several published and electronic syntheses on the life history requirements of the candidate focal species were also reviewed (Bonner 2009; Carlander 1969; Carlander 1977; Carlander 1997; Edwards 1997; Froese and Pauly 2000; Graham 1999; Hamilton and Nelson 1984; Hubert et al. 1984; Kuehne and Barbour 1983; Lee et al. 1980; Page 1983; Stuber et al. 1982; Warren 2009; Wilson and McKinley 2004). This additional level of review was conducted to evaluate and identify possible relationships between varying stream discharge and associated variables (e.g. dissolved oxygen, velocity, depth, ramping rates) and local population viability of the focal fish species.. For example, low stream velocities caused by decreased stream flow may result in deposition of fine silt particles on gravel beds which might lead to poor larval recruitment in nest building fishes. In addition, reduction of flooding and overbank flows can result in reduced connectivity with adjacent oxbow lakes and riparian areas and large woody debris recruitment (NRC (National Research Council) 2005).

Fish are highly mobile freshwater fauna that are dependent on healthy populations of invertebrate prey and/or plant material for food, and require cover and habitat provided by wetland/riparian emergent plants and submerged vegetation. Consequently they integrate the effects of stressors, including hydrological alteration, on lower trophic levels. Therefore we feel that they are excellent integrators of stressors, including changes in hydrology, within the watershed (Simon 1999b). Most fish have comparatively longer life spans than invertebrates. Fish are relatively easy to identify in comparison to invertebrates and are a valuable resource easily identified by the public. Although benthic invertebrates can provide excellent information on local conditions, long-term data is generally lacking and identification is often difficult without extensive taxonomic training. This has contributed to the lower amount if information on aquatic invertebrates. Although taxonomy is not as challenging there is a general lack of long-term monitoring data on other aquatic organisms as well. However, there are potentially numerous aquatic or semi-aquatic species (e.g. turtles, beaver, river otter, kingfisher, osprey, and amphibians) that are found in the Trinity River basin that are likely effected by changes in hydrology Sufficient flows are likely needed to maintain their unique habitats (e.g. floodplain forests) and associated forage food base.

Information on other aquatic and riparian species were also compiled, reviewed and cataloged by geographic location (lat, long, TCEQ water code and river mile) for potential future analysis (Figures 4 and 5). In addition, the locations of these studies and recorded sightings or collections were input into the EndNote®, Access and ArcGIS databases. This included aquatic invertebrates, and vertebrates. Data on these groups were generally much more limited than for fish. As previously mentioned TPWD provided us with a list of various invertebrate species of concern for their agency including bivalves (Family Unionidae – mussels) and one crustacean (Table 5). Freshwater mussels represent a unique assemblage of organisms since many species have become endangered at the state or federal levels in areas where streams or lakes have experienced rapid changes in flows and/or water levels. For example, dewatering practices that have been historically used for nuisance vegetation control have often led to local extirpation (Howells 2009). Many of these mussels have documented larval parasitic glochidia stages that utilize various host fish species found in the Trinity River. These larvae attach to the body of the fish or gills until they metamorphose into benthic juveniles. Hence, reductions in the numbers of their host fish species can indirectly and negatively impact mussels. Therefore their population viability in many cases is tied to the viability of their host fish populations. The Texas Parks and Wildlife Department has designated no harvest mussel sanctuary areas in the State.

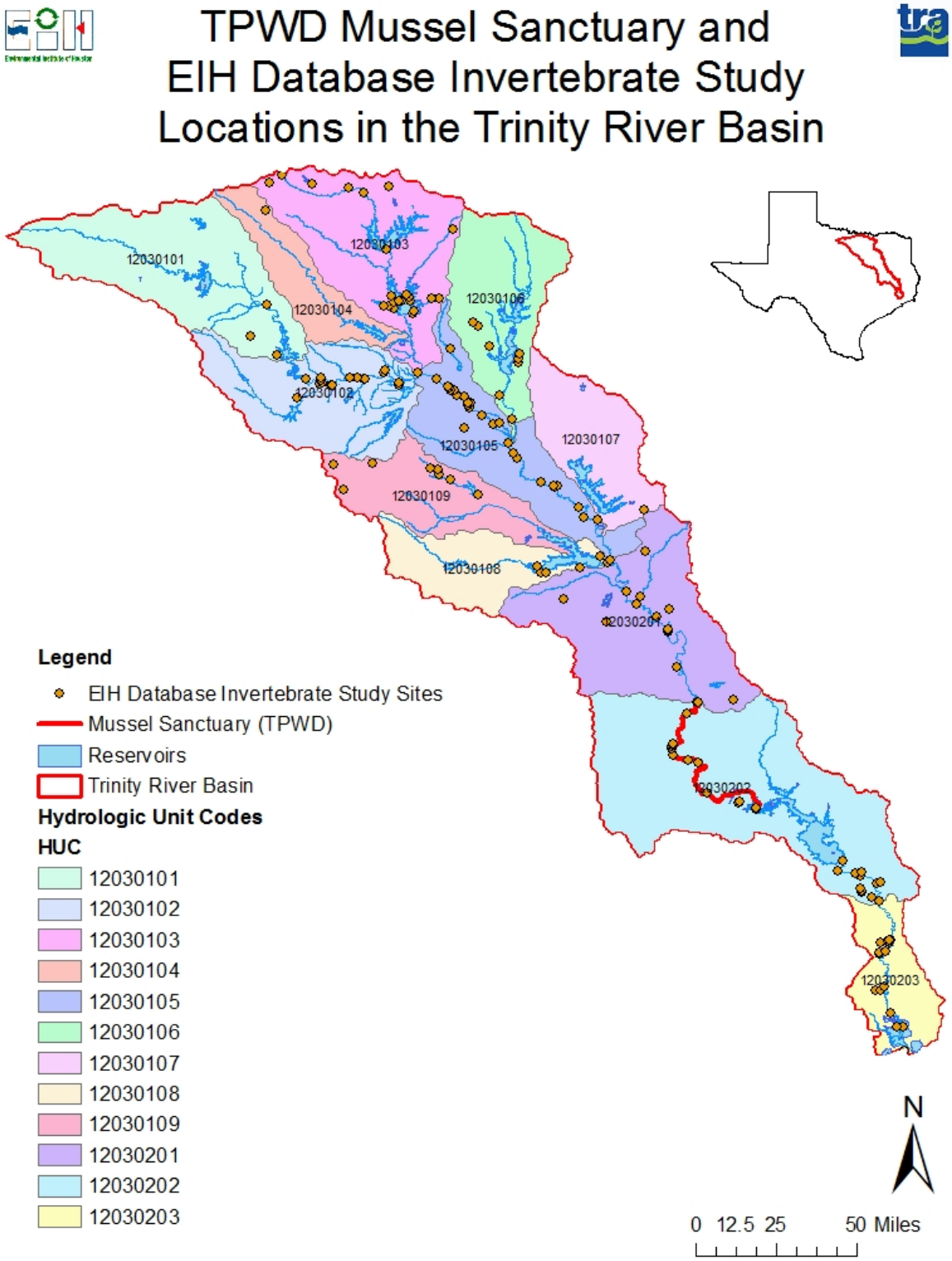


Figure 4. Location of historical invertebrate collection and study sites and TPWD mussel sanctuary within the Trinity River Basin that were used as data sources.

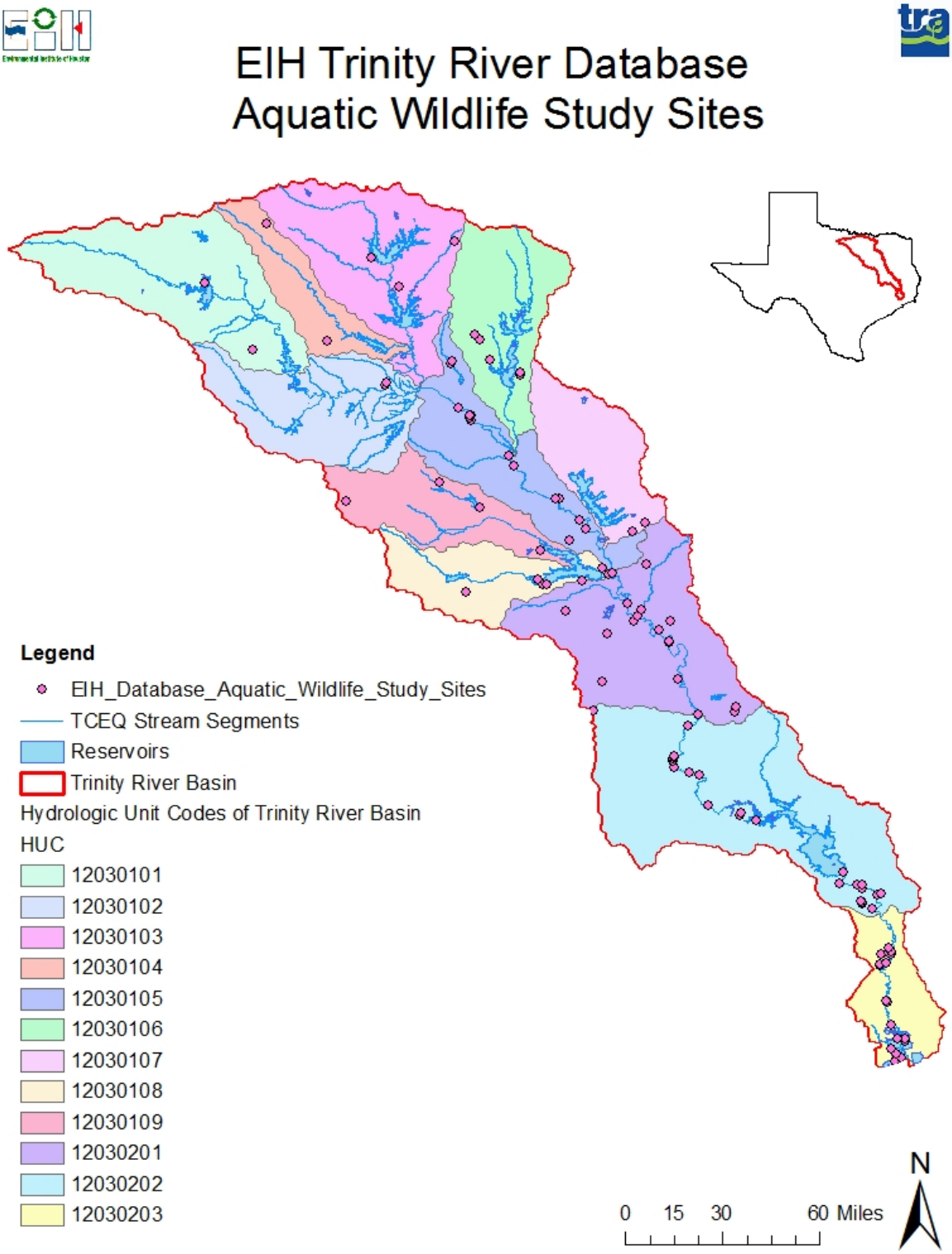


Figure 5. Location of historical aquatic non-fish vertebrate collection and study sites within the Trinity River Basin.

Table 5. Candidate focal invertebrate species in the Trinity River. TWAP SC listings highlighted in yellow.

Species	Trinity	Status	Known Hosts	Spawning Season	Stressors: Notes
Lilliput (Toxolasma parvus)	X		Warmouth sunfish, green sunfish, bluegill sunfish, orangespotted sunfish, white crappie	April-August	Found in quiet waters of lakes, mud and silt, 0.25-1.07 m.
Texas Lilliput (Toxolasma texasiensis)	X		Warmouth sunfish, longear sunfish	October to June	Found in oxbows, tributaries in mud, absent in flow rivers
Fawnsfoot (Truncilla donaciformis)	X	(TWAP-SC)		May-August at minimum	Found in still to swift water, small to large rivers, sand and gravel, 2.5 to 152 cm in depth
Texas Fawnsfoot (Truncilla macrodon)	?	3 (TWAP-SC)		unknown	unknown
Tapered Pondhorn (Uniomerus declivis)	X			May-June at minimum	clay bottom lakes, intermittent streams; drought tolerant
Pondhorn (Uniomerus tetralasmus)	X		Golden shiner	April-August at minimum	mud bottom lakes, rivers and streams; drought tolerant
Little Spectaclecase (Villosa lienosa)	X			unknown	creeks, rivers and reservoirs
Giant Floater (Pyganodon grandis = Anodonta grandis)	X		Alligator gar, longnose gar, skipjack herring, gizzard shad, common carp, redfin shiner, golden shiner, creek chub, yellow bullhead, brook silverside, green sunfish, longear sunfish, bluegill sunfish, largemouth bass, black crappie, white crappie, freshwater drum	August to May	Mud bottom, 0.3-1.5 m deep, current 0-57.9 cm/s, often common in no flow
Paper Pondshell (Utterbackia imbecillis = Anodonta imbecillis)	X		Green sunfish, creek chub, western mosquitofish, largemouth bass, warmouth sunfish, bluegill sunfish, dollar sunfish	Year round	Variety of substrate, most common in silt, common in impounded water
White Heelsplitter (Lasmigona complanata)	X		Common carp, green sunfish, largemouth bass, white crappie	Sept-May	large rivers and streams, mud, mud gravel; pollution tolerant
Fragile Papershell (Leptodea fragilis)	X		Freshwater drum	Year round	Wide range of sediment, depths and flows, pollution tolerant
Texas Heelsplitter (Potamilus amphichaenus)	X	1 (TWAP-SC)		July at minimum	Sand and mud, slow water and reservoir
Pink Papershell (Potamilus ohiensis)	X		Freshwater drum, white crappie	April-September	Found mostly in flowing waters, various substrate, 2.5 to 14.2 cm depth, maybe tolerant to environmental stress
Texas Pigtoe (Fusconaia askewi)	X	1,2 (TWAP-SC)		July at minimum	Rivers with mixed mud, sand and gravel
Wabash Pigtoe (Fusconaia flava)	X		Bluegill sunfish, white crappie, black crappie	May-August	especially intolerant of changing stream environments,
Triangle Pigtoe (Fusconaia lananensis)		1		July at minimum	Mixed mud and gravel
Sothern Hickorynut (Obovaria jacksoniana)	X	3 (TWAP-SC)		October at minimum	gravel, creeks and rivers with moderate flow

Table 5. Continued.

Species	Trinity	Status	Known Hosts		Stressors: Notes
Threehorn Wartyback (Obliquaria reflexa)	X			June-August	Various substrate, medium to large rivers, depths 2.5 cm to 1.2 m in standing water, can tolerate impoundment
Louisiana Pigtoe (Pleurobema riddellii)	X	1 (TWAP-SC)		unknown	Streams
Southern Mapleleaf (Quadrula apiculata)	X			May-August	Wide range of sediment, depths,and waterbodies, very shallow to 4.6 meters
Western Pimpleback (Quadrula mortoni)	X			July-August minimum	rivers, streams and reservoirs, 1 to 3 m deep
Gulf Mapleleaf (Quadrula nobilis)	X			no data collected	no data collected
Deertoe (Truncilla truncate)	X		Freshwater drum	May-July	swift water, various substrate, 2.5 to 152 cm deep, flows of 457 cm/s, small to large rivers
Threeridge (Amblema plicata)	X		White bass, green sunfish, bluegill sunfish, warmouth sunfish, white crappie, black crappie, largemouth bass, channel catfish, flathead catfish	June-August	various substrates; drought tolerant, water quality tolerant, depth 2.5 cm to 1.5 m; velocities from 0 to 45.7 cm/s
Rock Pocketbook (Arcidens confragosus)	X	(TWAP-SC)	American eel, gizzard shad, white crappie, freshwater drum, channel catfish	Sept-June	Various substrates, flows 6 cm/s to swift, depths 10 to 107 cm; medium to large rivers
Washboard (Megalonaias nervosa)	X		Bowfin, gizzard shad, skipjack herring, American eel, black bullhead, channel catfish, flathead catfish, tadpole madtom, white bass, bluegill sunfish, largemouth bass, white crappie, black crappie, freshwater drum	Sept-Feb and April-May	large, low velocity rivers, mud or gravel, 0.3 to 22.4 meters deep
Bankclimber (Plectomerus dombevanus)	X			July	ditches, lowland rivers, various substrates, moderate to sluggish currents
Pistolgrip (Tritogonia verrucosa)	X				typical of oxygen rich riffles and runs
Round Pearlyshell (Glebula rotundata)	X			March-October	slow moving bayous, can occur In estuaries at low salinities,
Sandbank Pocketbook (Lampsilis satura)	X	1 (TWAP-SC)		unknown	small to large rivers, gravel and sand bottoms, swift currents 6.1 to 6.5 m depths
Bleufer (Potamilus purpuratus)	X		Freshwater drum	Potentially year round	Deep water streams or quiet pools with mud bottoms, large and small reservoirs or streams and rives with slow to moderate current, mud or gravel 0.5 to 3.0 m.
Louisiana Fatmucket (Lampsilis hydiana)	X		Longear sunfish (possible)	May to August at minimum	Various substrate, low flow or backwater areas; rivers, streams and reservoirs
Yellow Sandshell (Lampsilis teres)	X		Longnose gar, alligator gar, green sunfish, orangespotted sunfish, largemouth bass, black crappie, white crappie, warmouth sunfish	April-November	dewatering; actively follow flood flow onto land, then retreat back as flows return to channel; various substrates, warm water and
Pond Mussel (Ligumia subrostrata)	X			June-August at minimum	various substrates and flows; 5.1 to 106.7 cm deep, shallow ponds, oxbox, sloughs and streams
Crustacean: Macrobrachium ohione (Ohio shrimp)	X			March to August	inhabits main stem rivers; migratory species

Sources: Pers. Comm. Clint Robertson TPWD; Marsha May TPWD Texas Mussel Watch; (Bender et al. 2005; Howells 2009; Howells et al. 1996) X = Recent Occurrences (within last 30 years); Status: TWAP-SC = Species of Concern, TPWD Texas Wildlife Action Plan 2005 1 = State Rank (S1) – Critically imperiled, extremely rare, very vulnerable to extirpation, 5 or fewer occurrences 2 = State Rank (S2) – Imperiled in state, vulnerable to extirpation, 6 to 20 occurrences 3 = Proposed for Federal Listing

A sanctuary has been designated on the Trinity River along Houston, Leon, Madison, and Trinity, Walker counties at its upper boundary at the intersection with State Highway and at the lower boundary with the State Highway 19 (Figure 4). TPWD also suggested including *Macrobrachium ohione*, river prawn, which undergoes spawning migrations to estuaries and may be effected by instream flow conditions (Bauer and Delahoussaye 2008). Aquatic invertebrates are considered excellent sentinel organisms due to their limited mobility and in some cases sensitivity to variations in flow regimes and water quality (Barbour et al. 1999; Rosenberg and Resh 1993). However, with the exception of freshwater mussels, information on the distribution and long-term trends in these populations are very limited (Howells 2009; Howells et al. 1996).

Although not mentioned by the TPWD biologists who were consulted, there are several other invertebrate and vertebrate species of concern listed in their Texas Wildlife Action Plan that may occur within the Trinity River basin (Bender et al. 2005). These additional species are listed in Table 6. With the exception of Blue sucker *Cycleptus elongates* and Creek chubsucker *Erimyzon oblongus* all the listed species were designated species of concern. Blue sucker and Creek chubsucker are on the state threatened species list.

The State of Texas has in recent years moved to protect some species of turtles due to concerns with excessive commercial harvesting. (TPWD (Texas Parks and Wildlife) 2008). River turtles are currently potentially sensitive to changes in river hydrology. Most river turtles live in higher order systems often characterized by high flows (Moll and Moll 2004). Many species nest on sand banks and are therefore potentially sensitive to unexpected flood flows. Alligator snapping turtle is the only state threatened species of reptiles or amphibians in the piney woods ecosystem that is likely to be found in the Trinity River basin (Bender et al. 2005).

Table 6. List of aquatic species identified in the Texas Comprehensive Wildlife Conservation Strategy that are found in the Trinity River basin but not originally nominated by TPWD biologists.

Species	Status	Known Host	Spawning Season	Stressor Notes
MacNeeses crayfish *Fallicamberus macneesei*	SC	NA	Spawning usually in September (early fall), egg release normally in April (spring)	Defined as vulnerable by AFS due to narrow range and sensitivity to pollution, habitat change and modified flow regimes, only found close to coastal areas within 50 miles
Steigmans Crayfish *Procambarus steigmani*	SC	NA	Spawning usually in September (early fall), egg release normally in April (spring)	According to AFS this species is in imminent danger of extinction or extirpation throughout large portion of range. Found in the extreme northern portion of the Trinity Basin, lives in higher elevation riparian prairie
Bigclaw River Shrimp *Macrobrachium carcinus*	SC	NA	Probably carry eggs in March to September.	Dams limit upstream migration of juveniles. Adults migrate to freshwater and release hatched larvae.
Creeper Mussel *Stophitus undulatus*	SC	Largemouth bass, creek chub, green sunfish	July to April and May; may not need fish host	Found many sites, but rare not seen in state of Texas since 1992, rated stable by AFS.
Texas emerald dragonfly *Somatochlora margarita*	SC	NA	Very little known about biology or larval habitat.	Limited in Texas to a few counties adjacent to the Trinity River and E. Texas. Endemic to two states in the United States (Louisiana and Texas). The species currently is known from six counties in these two states. This species has a restricted range (currently only seven locations are known).
Fishes				
American eel *Anguilla rostrata*	SC	NA	Jan to August in mid-Atlantic - Catadromous	Dams impede upstream movement of juveniles
Blue sucker *Cycleptus elongatus*	ST	NA	Late April to May	Abundance of *Cycleptus elongatus* has been decreased by impoundment, pollution, and reduced water flows in those systems in which it occurs.
Creek chubsucker *Erimyzon oblongus*	ST	NA	March to May	Not listed by AFS.
Sabine shiner *Notropis sabinae*	SC	NA	May to December	*N. sabinae* was designated a species of conservation concern in Texas and Louisiana by U.S. Forest Service Region 8 and U.S. Fish and Wildlife Service Region 2, and as a species of special concern in Mississippi

Sources: (Abbott 2006; Bender et al. 2005; Bonner 2009; Hobbs III 2001; Howells 2009; Howells et al. 1996; Jelks et al. 2008; Johnson and Johnson 2008; Kondratieff 2000; Taylor et al. 2007) X = Recent Occurrences (within last 30 years); Status: TWAP-SC = Species of Concern, TPWD Texas Wildlife Action Plan 2005 1 = State Rank (S1) – Critically imperiled, extremely rare, very vulnerable to extirpation, 5 or fewer occurrences 2 = State Rank (S2) – Imperiled in state, vulnerable to extirpation, 6 to 20 occurrences 3 = Proposed for Federal Listing

Results

Hydrology Summary

Graphical summaries of the hydrology at each priority USGS gage site were used to illustrate seasonal and annual trends. One very obvious trend that was observed is the decline in average daily flows at the USGS Elm Fork gage after 1951 (Figure 6). The initial decline occurred during the drought of record, but flows never did substantially increase after this period (Estaville and Earl 2008). This is probably due to the construction and filling of Lake Grapevine Lake and Lake Lewisville reservoirs which are located less than 5 miles upstream of this gage and were first impounded in 1952 and 1954 respectively (Richard Browning TRA – personal communication)(Farquhar and McDonald 1991; Gandara and Jones 1995)(Table 7). Seasonally the lowest average stream discharge occurs during the months of August through October with little variation (Figures 7-9). Largest daily fluctuations and overall variability of flows occurs during the months of January through June (Figures 8 and 9). Highest average daily flows also generally occur during these months (Figure 7).

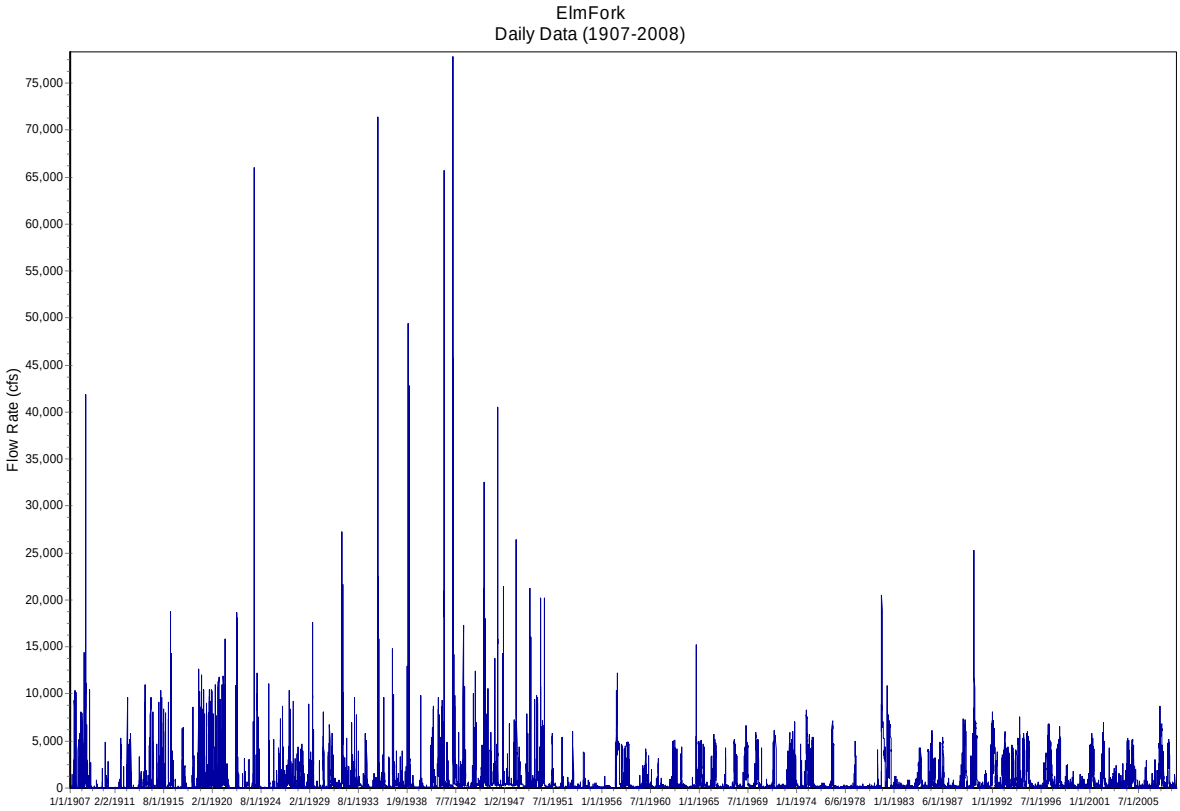


Figure 6. Average daily flows recorded at the USGS Elm Fork Trinity River near Carrollton (08055500) gage from 1907 to 2008.

Table 7. List of reservoirs and associated characteristics within the Trinity River Basin.

Name	1st impndmnt (yr)	mi^2 total watershed	mi^2 uncontr watershed	Elev normal pool	Acres normal pool	Ac-Ft normal pool	Depth mean (ft) normal pool	Elev. strmbd @ dam	Evap net 40-65 ave in/y	Evap net 50-56 ave in/y	Own/Oper	Yield,mgd	Flood Control, AF
JACKSBORO	1950	25.7	25.7	1015.4	142.5	2129	14.9	975	43	56	Jacksboro	0.4665	
LOST CREEK	1990	29.2	3.5	1009.5	367	11961	32.6	925	43	56	Jacksboro	1.03588	
BRIDGEPORT	1932	1111	1082	836	12900	374836	29.1	750	42	55	TRWD		
AMON G. CARTER	1956	106	106	920	1848	28589	15.5	865	41	53	Bowie	2.32	
EAGLE MOUNTAIN	1934	1970	753	649	6480	177520	27.4	589	42	53	TRWD	69.5	
WORTH	1914	2064	94	594.3	3560	37775	10.6	555	42	52	Fort Worth		
WEATHERFORD	1957	109	109	896	1158	18714	16.2	850	44	55	Weatherford	1.96	
BENBROOK	1952	429	320	694	3635	85648	23.6	617	43	53	COE	6.07	170350
CLEAR FORK	1882	518	89	533	43	259	6	524	41	52	Fort Worth	2	
NUTT DAM	1910	2615	33	520	96	673	7	510	41	52	TU	1	
ARLINGTON	1957	143	143	550	1939	38785	20	489	40	50	Arlington	5.35	
JOE POOL	1986	232	232	522	7470	176900	23.7	456	38	48	COE	14.2	127100
MOUNTAIN CREEK	1937	295	63	457	2710	22840	8.4	420	38	47	TU	13.4	
KIOWA	1968	16.4	16.4	700	560	7000	12.5	670	33	46	L Kiowa Inc		
RAY ROBERTS	1986	692	676	632.5	29350	799600	27.2	524	35	46	COE		265000
LEWISVILLE	1954	1660	968	522	29170	571926	19.6	435	36	47	COE	165	314806
GRAPEVINE	1952	695	695	535	7380	181100	24.5	451	38	49	COE	20.6	244400
CARROLLTON	1912	2459	104	433.71	89	666	7.5	418	37	48	Dallas		
NORTH	1957	3	3	510	800	17000	21.2	448	37	48	TU	0.4	
CALIFORNIA CROSSING	1912	2530	68	418	180	990	5.5	410	36	47	Dallas		
FRAZIER	1928	2580	50	408	72	434	6	397	36	46	Dallas	18.1	
WHITE ROCK	1910	100	100	458	1088	9004	8.3	458	35	43	Dallas		
LAVON	1953	770	770	492	21400	456500	21.3	433	31	40	COE	92.9	291700
RAY HUBBARD	1968	1074	304	435.5	21683	413526	19.1	387	32	40	Dallas	50.4	
NEW TERRELL	1955	14	14	504	849	8594	10.1	480	28	35	Terrell	0.7	
FOREST GROVE	1980	53	53	359	1502	20038	13.3	325	24	31	TU	1.6	
CEDAR CREEK	1965	1007	940	322	32623	637180	19.5	248	26	34	TRWD	156	
TRINIDAD	1925	1.2	1.2	284.5	740	7450	10.1	265	23	31	TU	2.1	
NAVARRO MILLS	1963	320	320	424.5	5070	56960	11.2	375.3	32	43	COE	14.7	149240
ALVARADO	1965	15.3	15.3	691.8	503	4757	9.5	668	39	49	Alvarado	0.7	
WAXAHACHIE	1956	30	30	531.5	690	10779	19.6	479	35	47	ECWCID	2.4	
BARDWELL	1965	178	148	421	3138	46472	14.8	377.6	33	43	COE	9.8	79600
HALBERT	1921	12	12	368	603	6033	10	330	29	39	Corsicana	0.5	
RICHLAND-CHAMBERS	1987	1957	1432	315	41356	1136600	27.5	235	27	35	TRWD	187	
WORTHAM	1952	1.5	1.5	416	42	252	6	400	28	39	Wortham		
FAIRFIELD	1969	34	34	310	2159	44169	20.5	248	25	32	TU	6.9	
HOUSTON COUNTY	1966	44	44	260	1330	17665	13.3	215	15	27	HCWCID	10	
LIVINGSTON	1969	16616	6764	131	83277	1741867	20.9	59.6	12	22	TRA	1120	
WALLISVILLE	1998	17584	968	1	0	0	0	-18	11	19	COE	80	
ANAHUAC	1914	199	199	5	5300	35300	6.7	-2	11	19	CLCND	21.7	

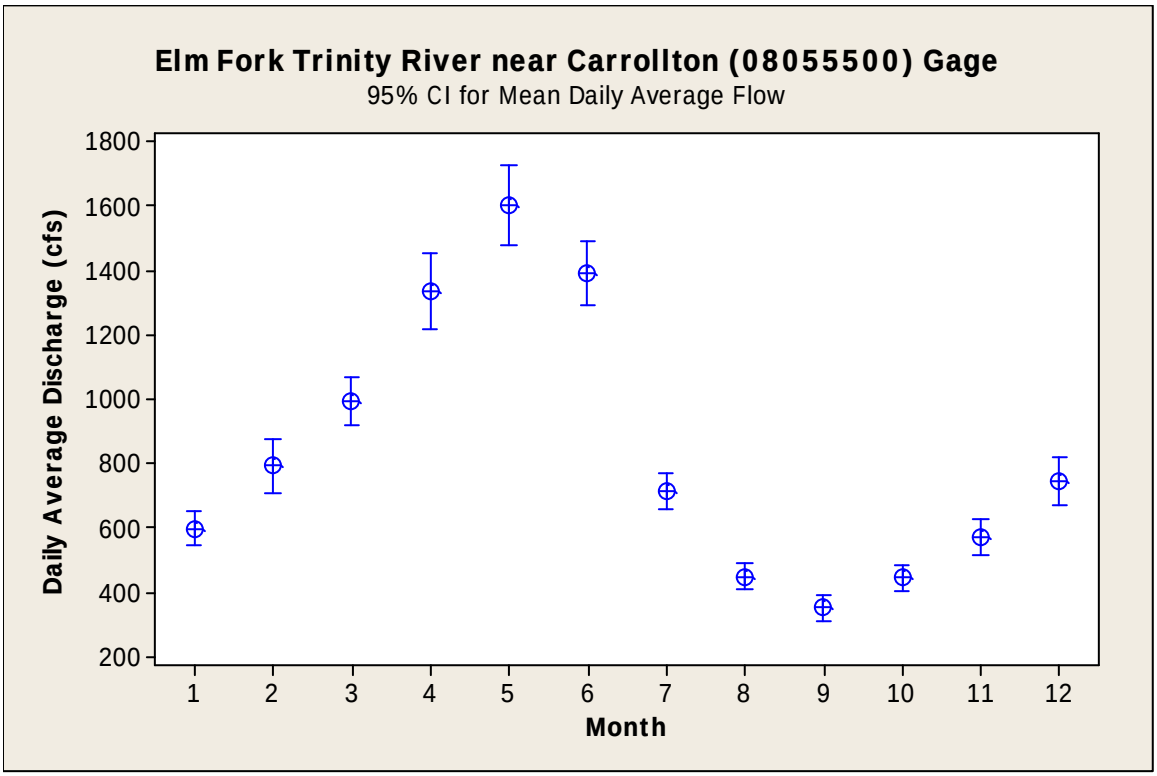


Figure 7. Monthly mean and 95% confidence intervals for daily average flows recorded at the USGS Elm Fork Trinity near Carrollton, (08055500) gage from 1907 through 2008.

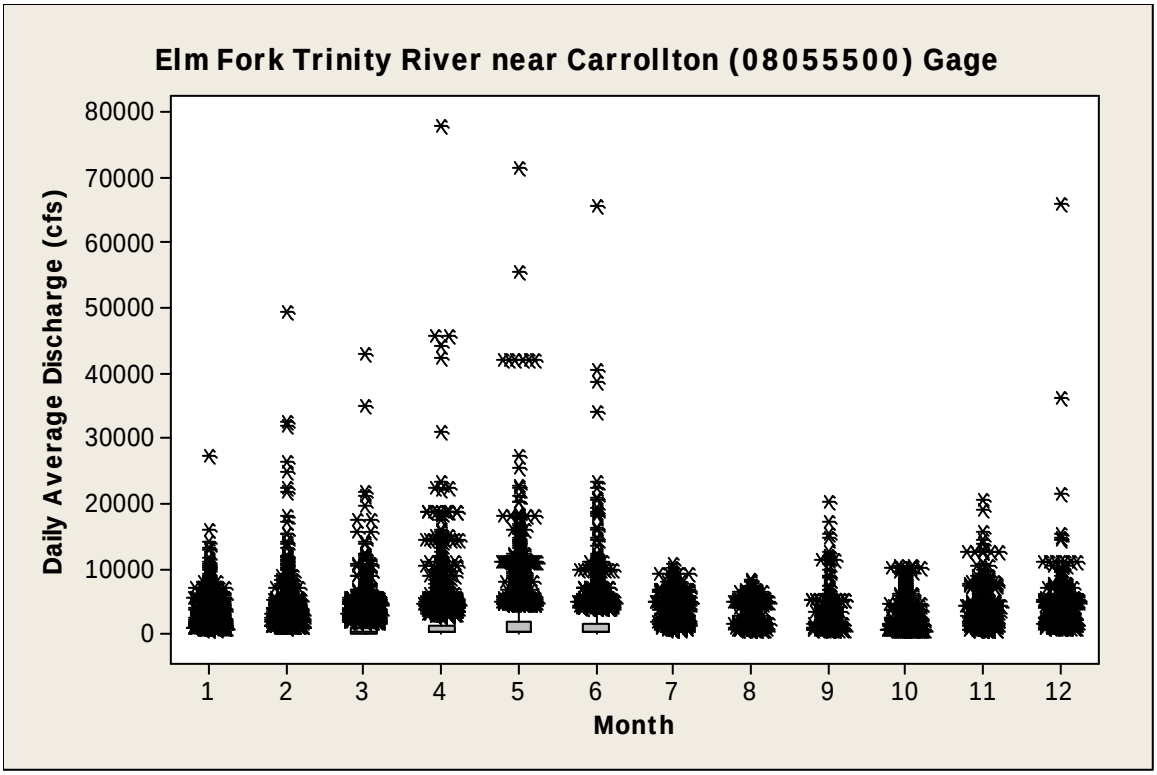


Figure 8. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average flows recorded at the USGS Elm Fork Trinity near Carrollton, (08055500) gage from 1907 through 2008.

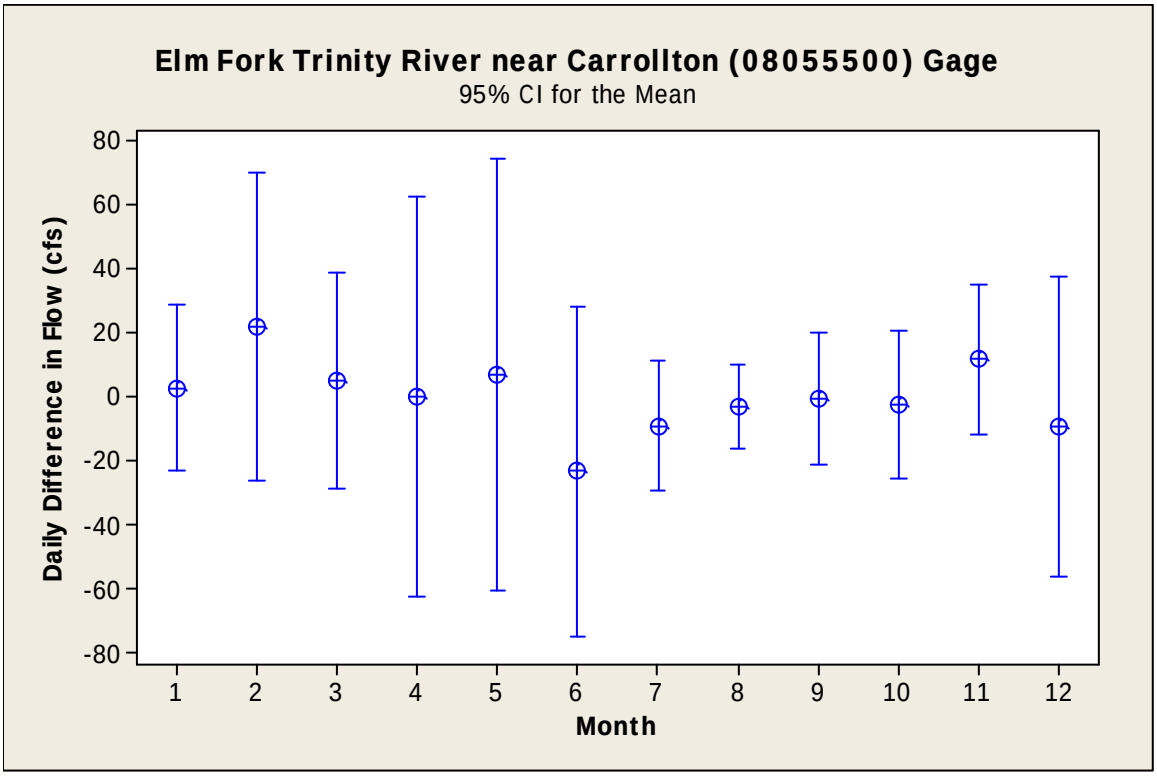


Figure 9. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the Elm Fork Trinity River near Carrollton (08055500) gage from 1907 through 2008.

The remaining priority gages, although exhibiting different absolute levels in flow and differences in flow variation, generally followed the same seasonal patterns exhibited by the Elm Fork gage. As expected, stream flow generally increased as you move downstream. Throughout the basin seasonally the lowest average stream discharges occur during the months of July through October with associated reductions in daily and short-term flow variability (Figures 10-37). In contrast, average daily flow rates are elevated and exhibit the largest daily and short-term fluctuations during the months of March through May or June (Figures 10-37). During these periods stream velocities would generally increase and the probability of overbank (flood) flows would increase. In addition, sediment transport capacity would also increase. These patterns in average daily flow and flow variability can effect instream habitat components (e.g. depth, cover, and velocity), larval drift, nesting behavior, and availability of riparian habitat (e.g. overbank flooding, and connectivity to oxbow lakes and associated wetlands. In addition, increased river flows in the spring months have a higher capacity for downstream sediment and nutrient transport including deposition in estuaries. This has major implications for fluvial processes including bank erosion, channel stability and pollutant transport. Preliminary estimates of draft 7Q2 values for selected gages in each major segment of the Trinity River are provided in Table 7. These were obtained from TCEQ water quality standards staff in September 2009 and are subject to change.

Trinity River hydrology has to varying degrees been influenced by the construction of dams and reservoirs. In addition, these structures and associated reservoirs generally trap sediments and increase residence times which can effect nutrient processing in addition to attenuating flood pulses depending on dam operations (Collier et al. 2000; Yeager 1993). Although the magnitude and frequency of some components of the river's hydrology have likely changed due to dam construction, water diversions, and increased urban and wastewater loading, many of the remaining local fauna have most likely evolved or retained life history traits that allow them to persist under these conditions. Later when we discuss the important biological resources we will try to identify key life history traits that may be important for dealing with these seasonal patterns in flow and flow variability and related water quality and geomorphological processes. Based on our limited analysis we did not see any large shift in hydrology post dam construction at the other gage sites in comparison to the Elm Fork site. However, we did not conduct a detailed hydrological analysis but rather provide broad spatial and temporal patterns in hydrology that may affect water quality, sediment transport and instream habitat.

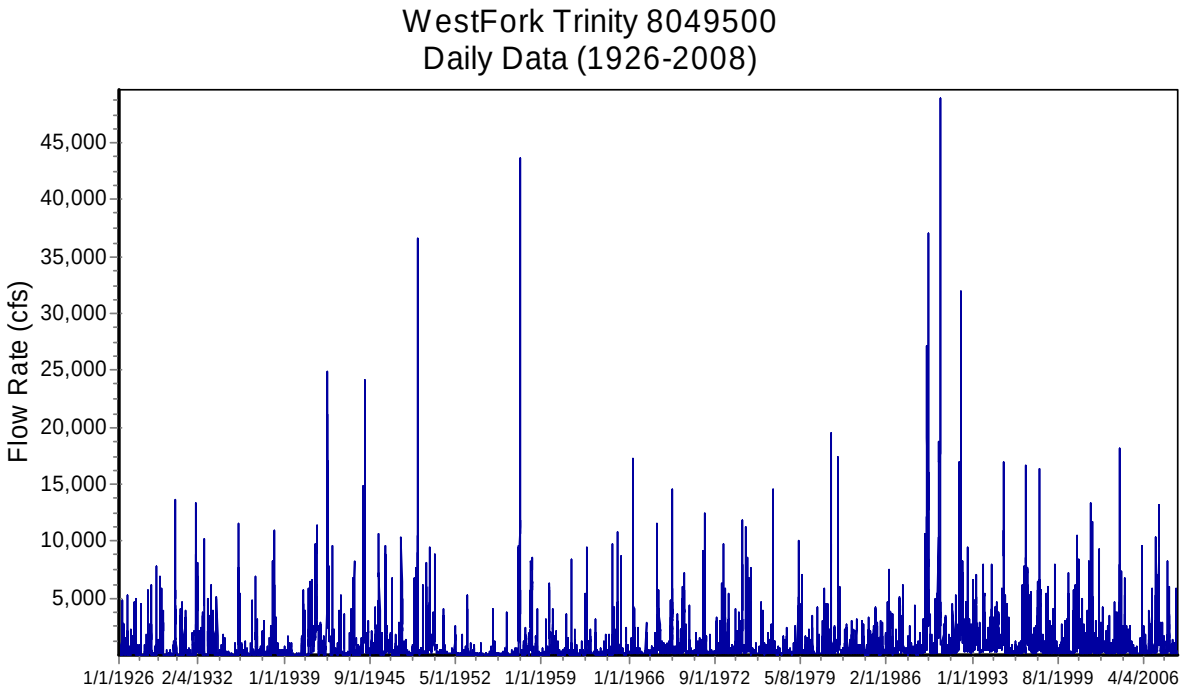


Figure 10. Average daily flows recorded at the USGS West Fork Trinity River (08049500) gage from 1926 through 2008).

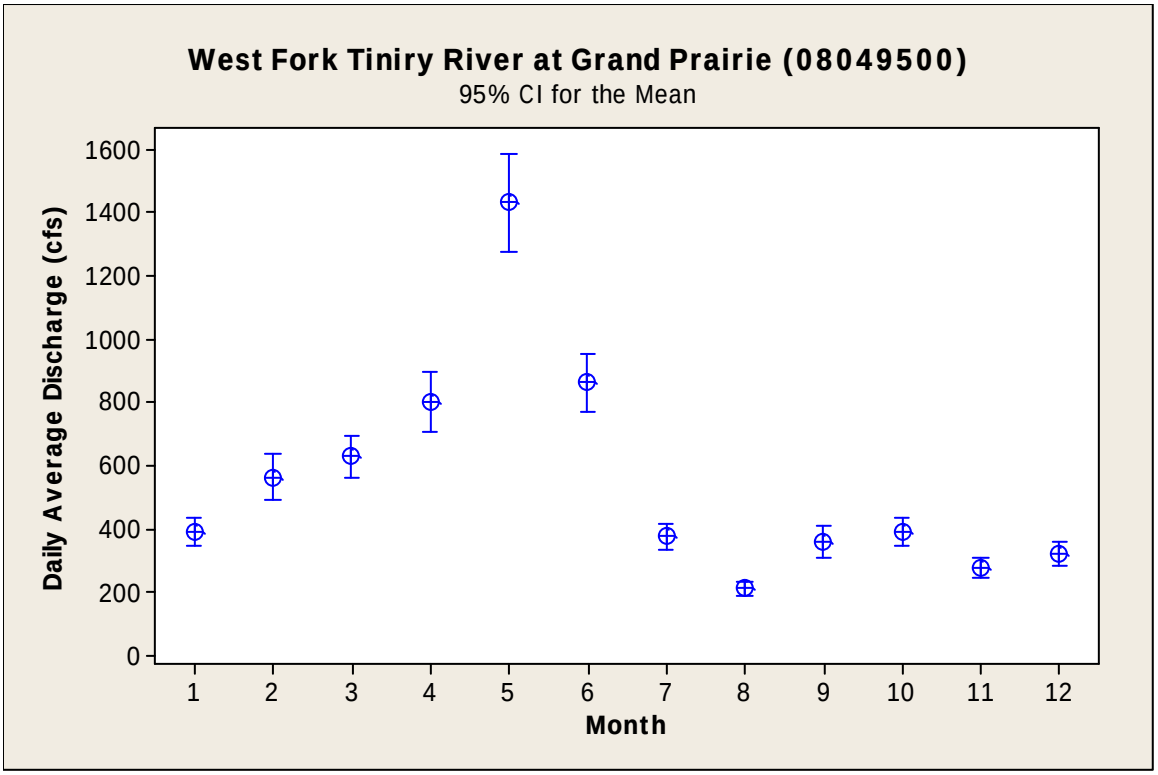


Figure 11. Monthly mean and 95% confidence intervals for daily average flow recorded at the USGS West Fork Trinity River at Grand Prairie (08049500) gage from 1926 through 2008.

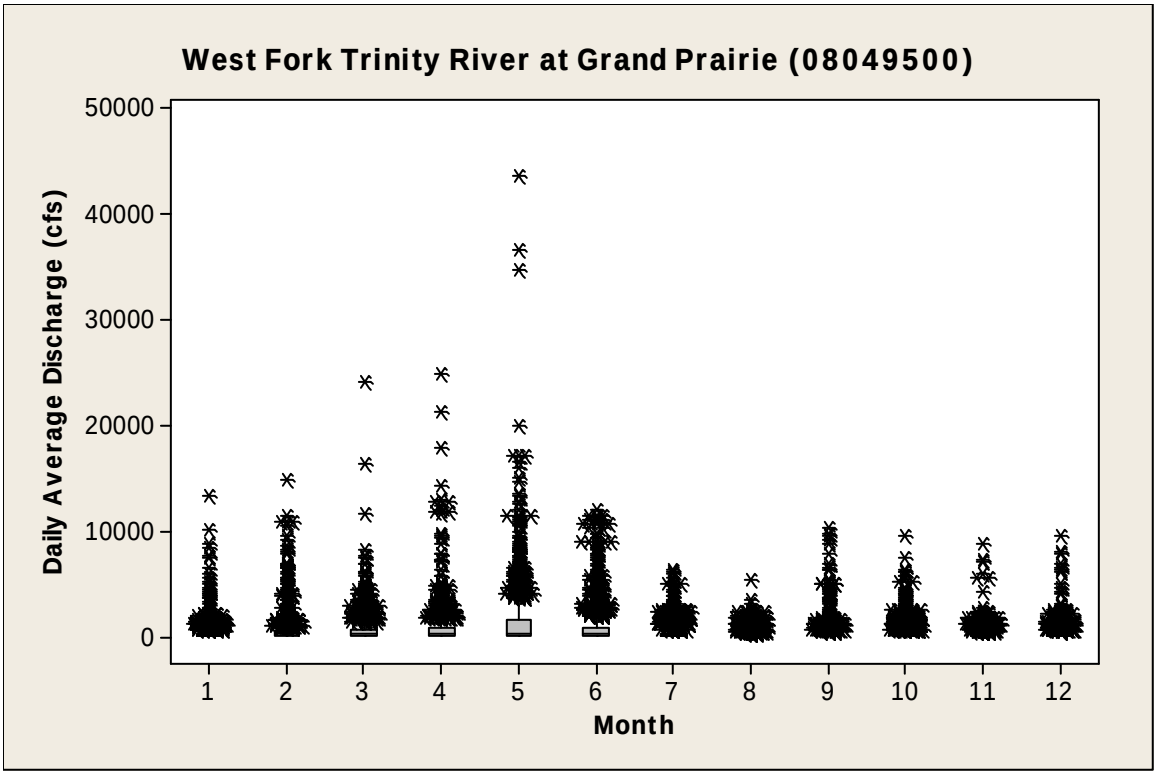


Figure 12. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average flows recorded at the USGS Elm Fork Trinity near Carrollton (08055500) gage from 1907 through 2008.

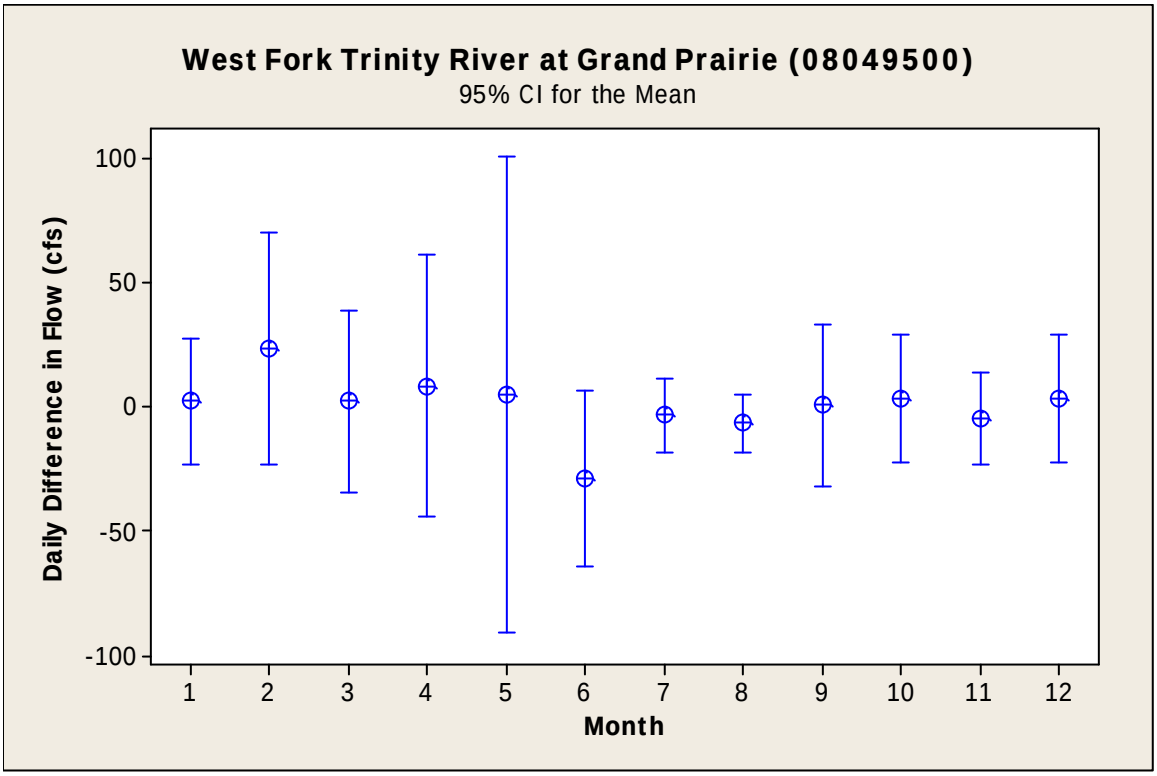


Figure 13. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the West Fork Trinity River at Grand Prairie (08049500) gage from 1926 through 2008.

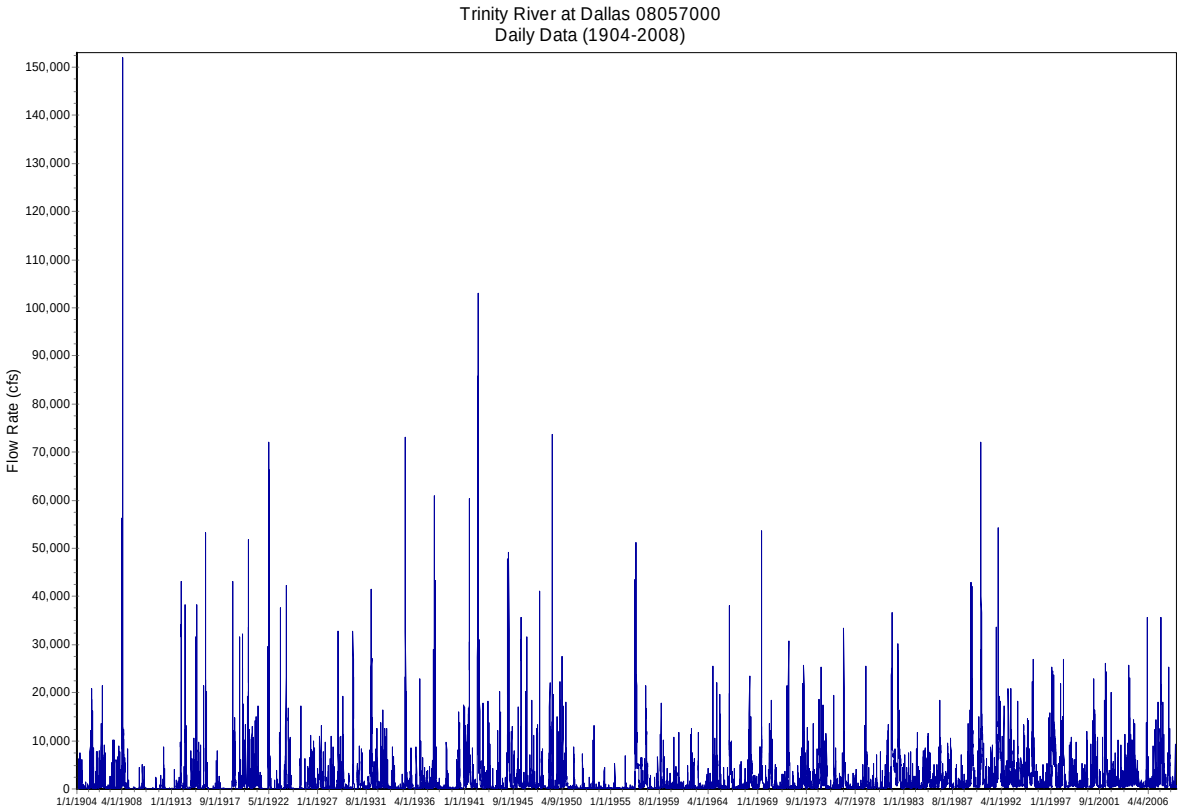


Figure 14. Average daily flows recorded at the USGS Trinity River at Dallas (08057000) gage from 1904 through 2008.

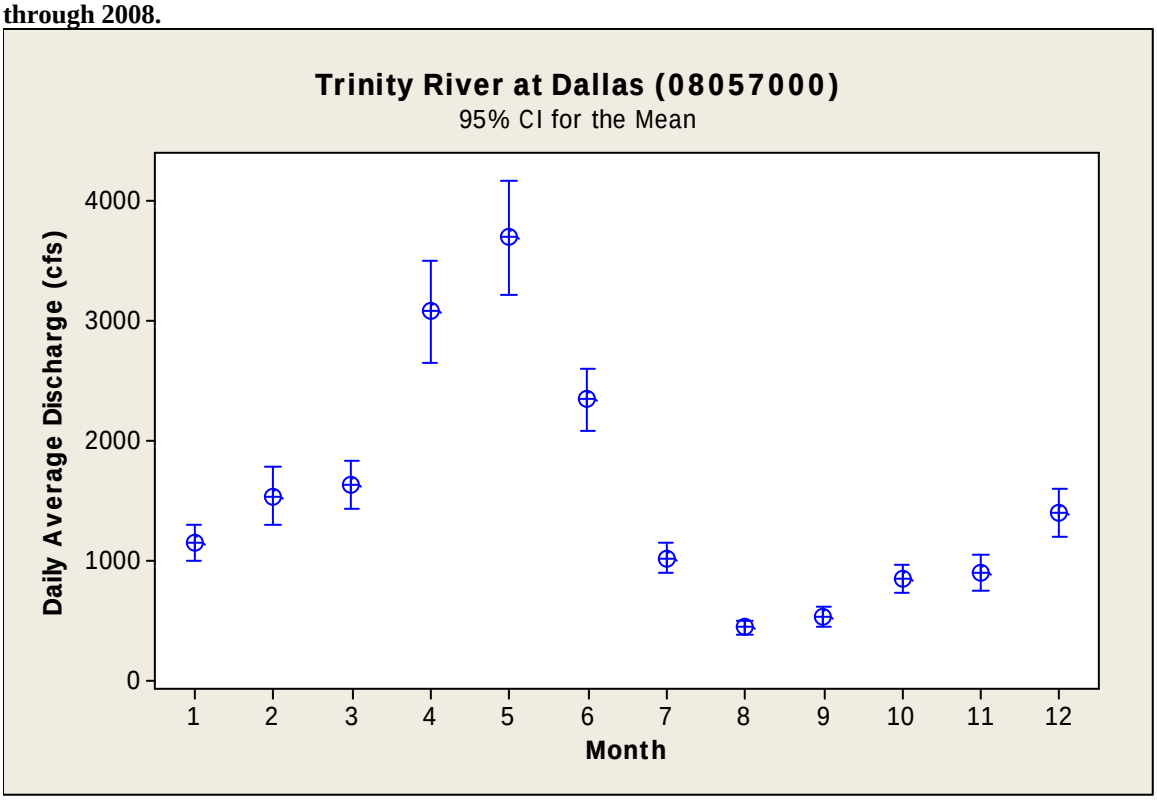


Figure 15. Monthly mean and 95% confidence intervals for daily average flow recorded at the USGS Trinity River at Dallas (08057000) gage from 1904 through 2008.

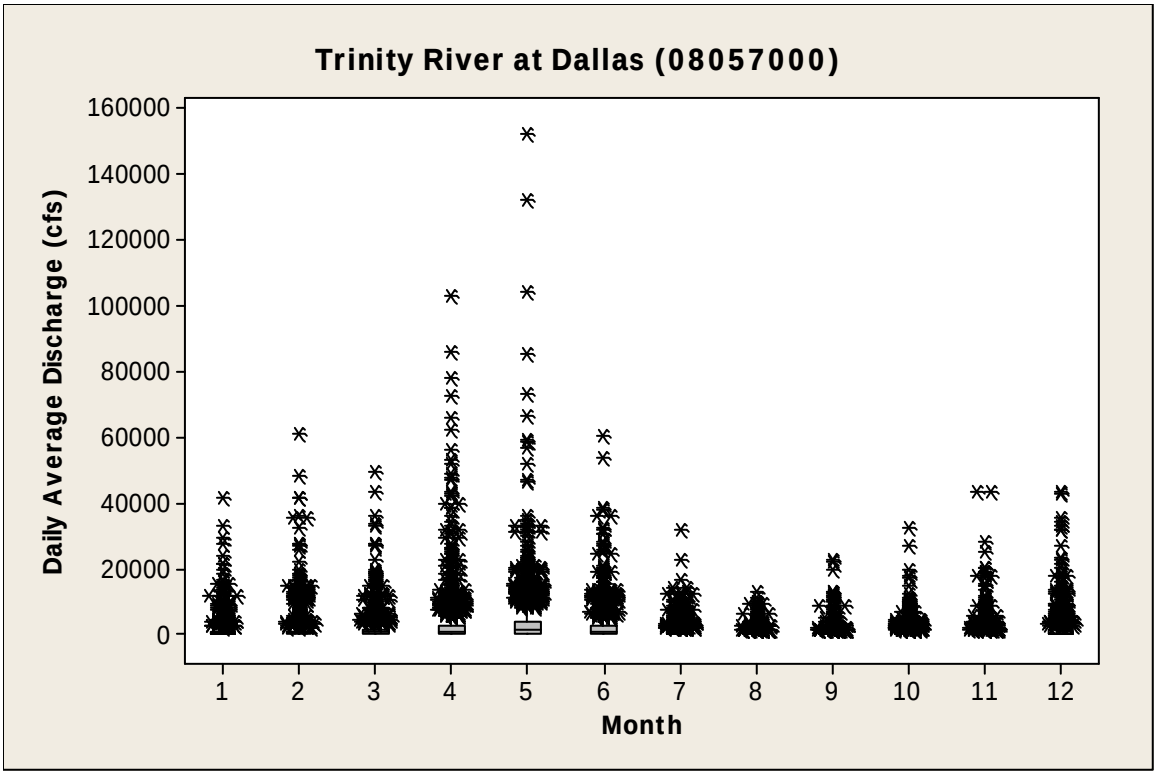


Figure 16. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average flows recorded at the USGS Elm Fork Trinity near Carrollton (08055500) gage from 1907 through 2008.

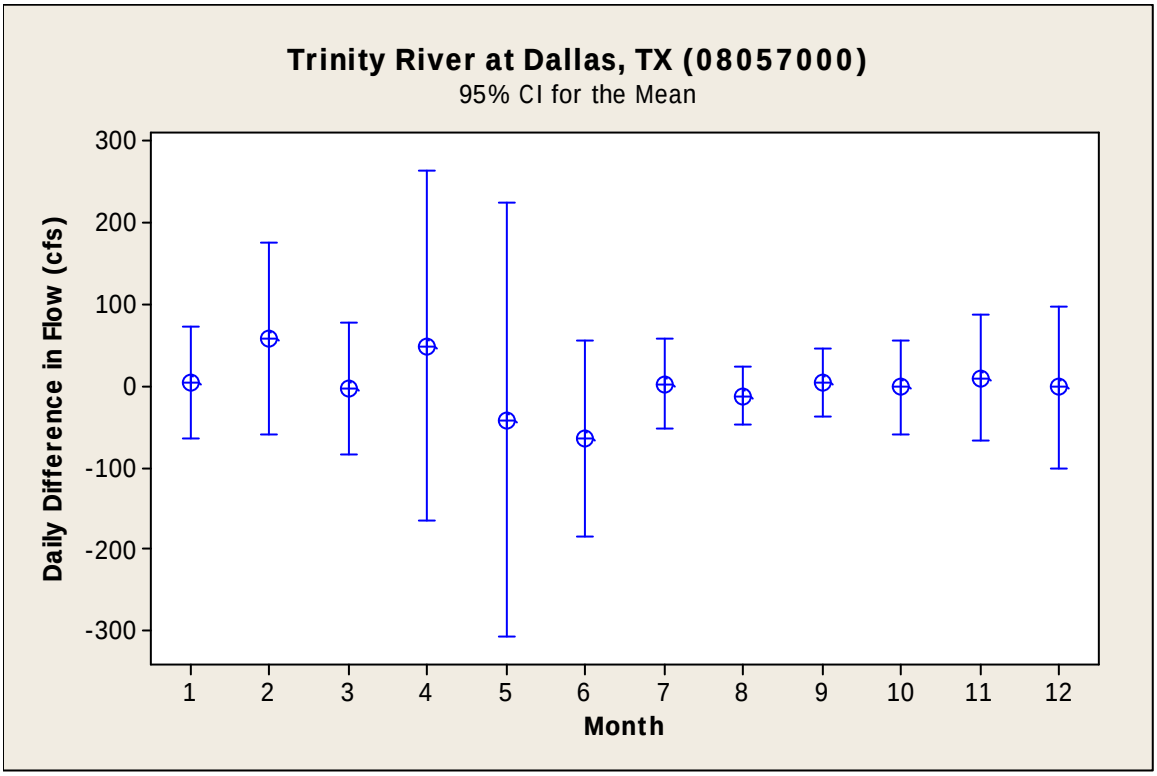


Figure 17. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the USGS Trinity River at Dallas (08057000) gage from 1904 through 2008.

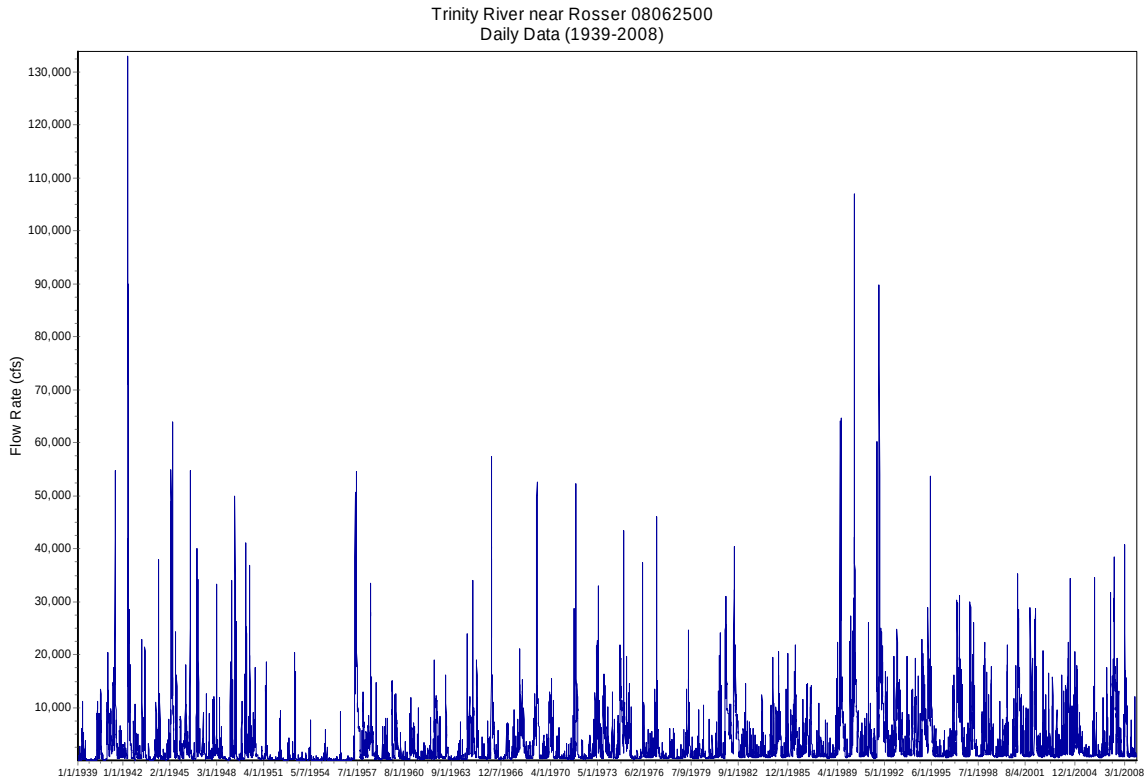


Figure 18. Average daily flows recorded at the USGS Trinity River at Rosser (08062500) gage from 1939 through 2008.

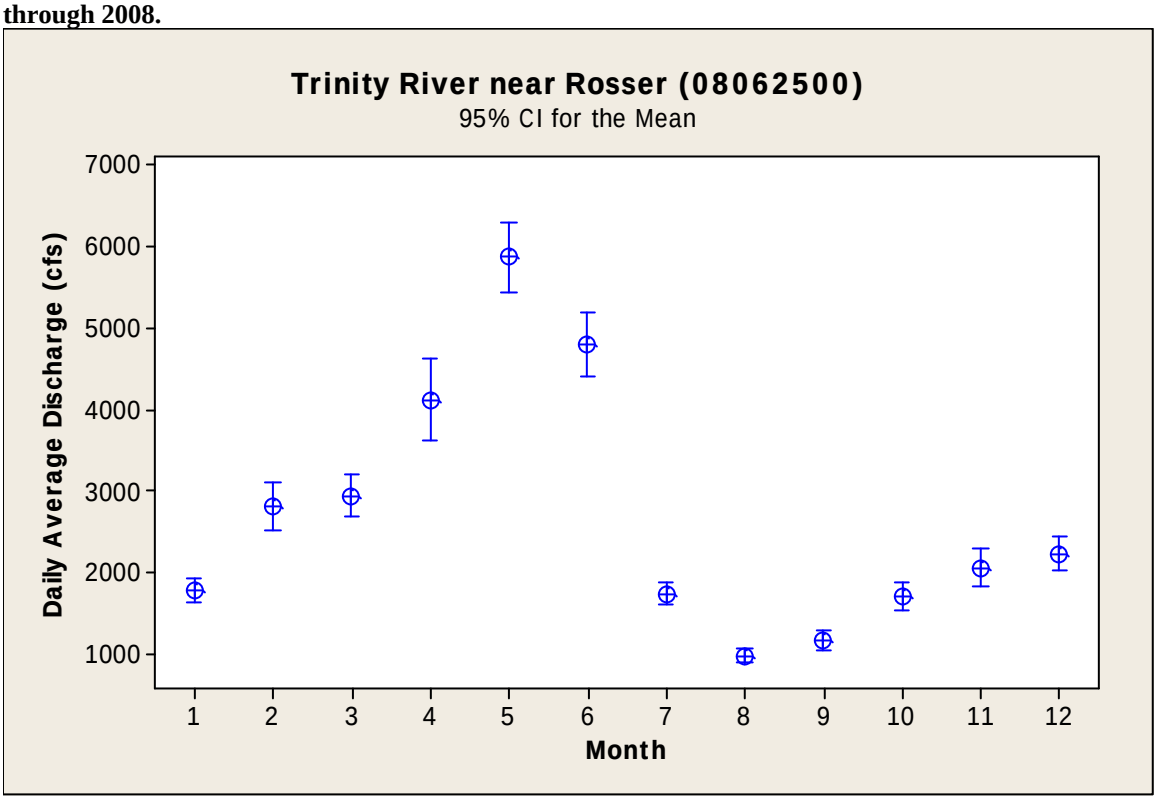


Figure 19. Monthly mean and 95% confidence intervals for daily average flow recorded at the USGS Trinity River at Rosser (08062500) gage from 1939 through 2008.

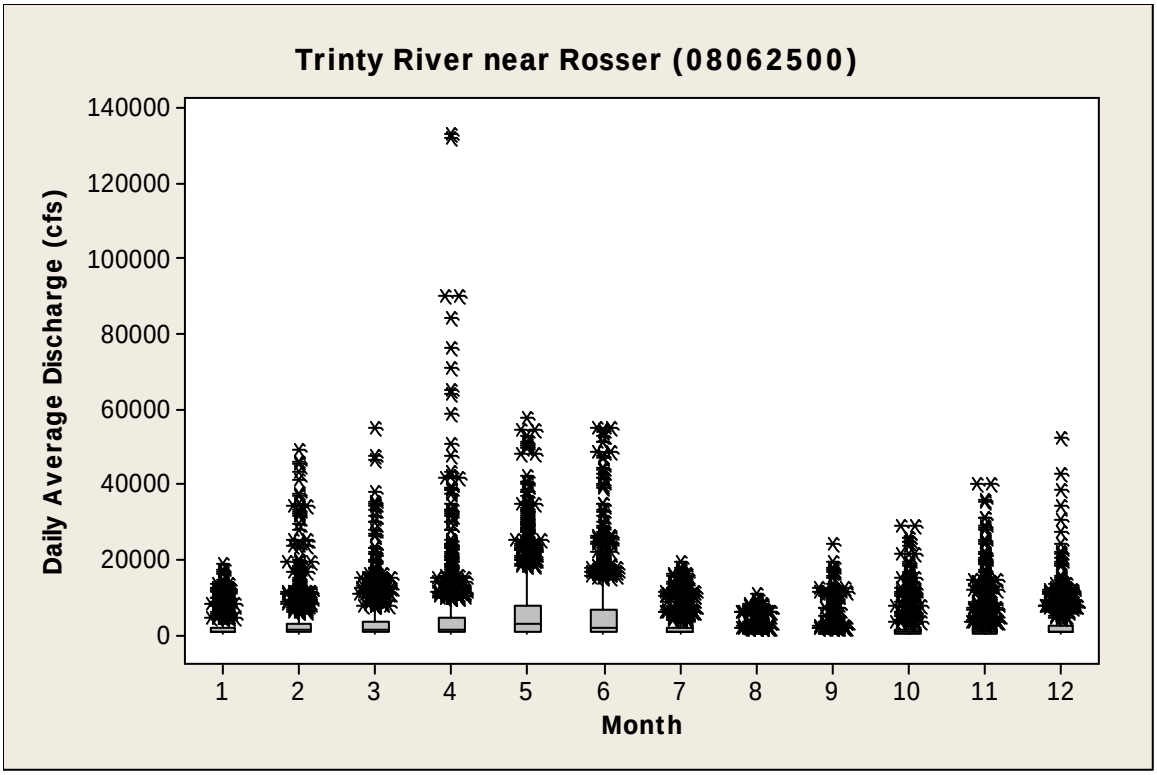


Figure 20. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average flows recorded at the USGS Trinity near Rosser (08062500) gage from 1939 through 2008.

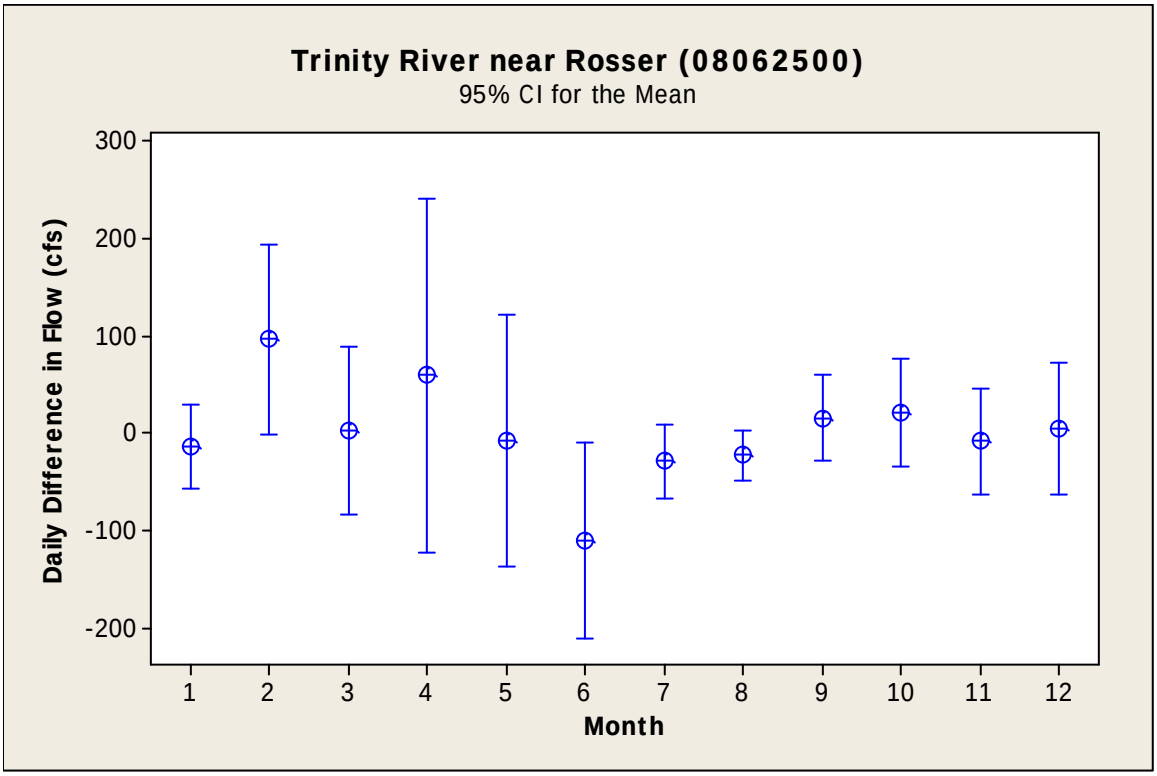


Figure 21. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the USGS Trinity River near Rosser (08062500) gage from 1939 through 2008.

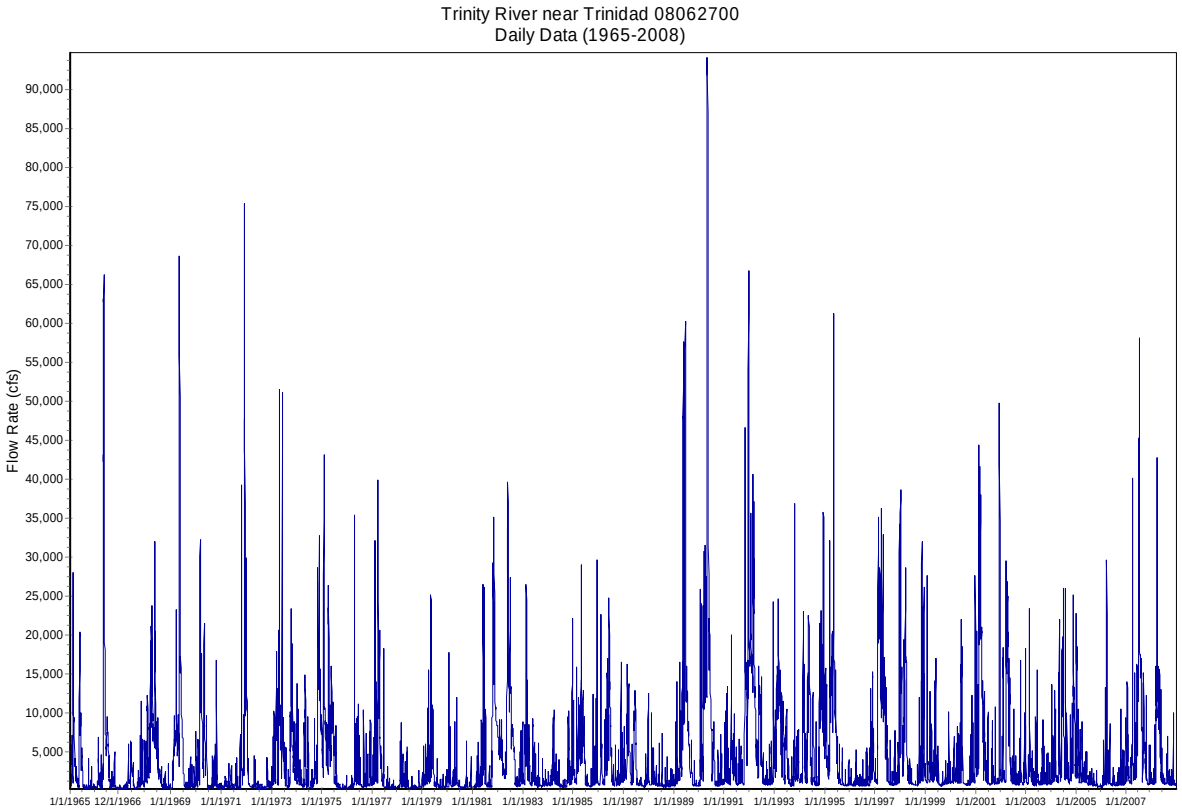


Figure 22. Average daily flows recorded at the USGS Trinity River near Trinidad (08062700) gage from 1965 through 2008.

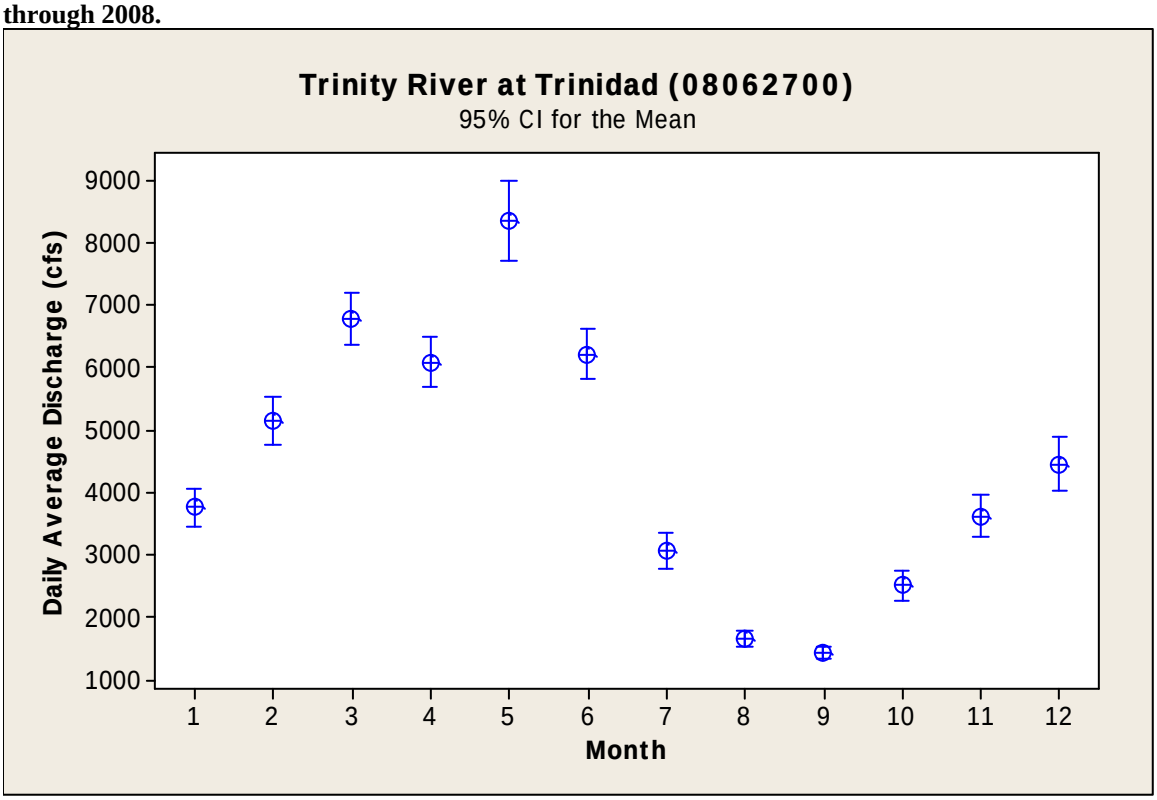


Figure 23. Monthly mean and 95% confidence intervals for daily average flow recorded at the USGS Trinity River at Trinidad (08062700) gage from 1965 through 2008.

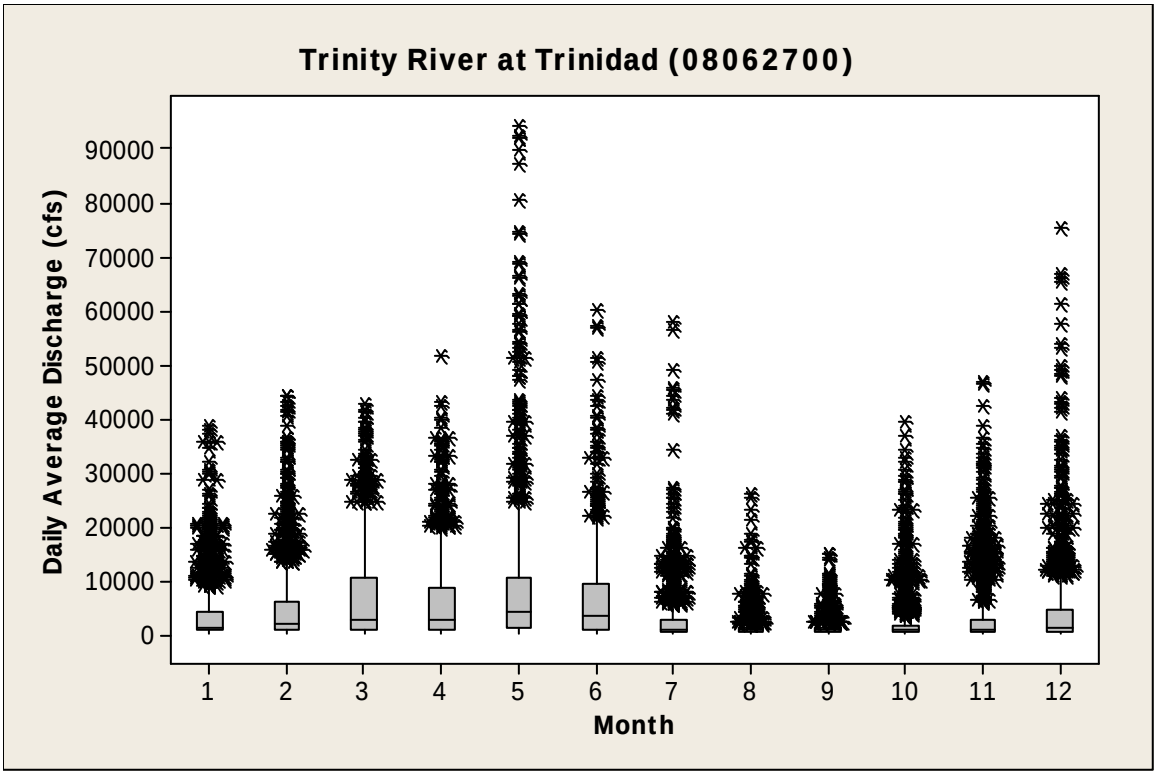


Figure 24. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average flows recorded at the USGS Trinity near Rosser (08062500) gage from 1939 through 2008.

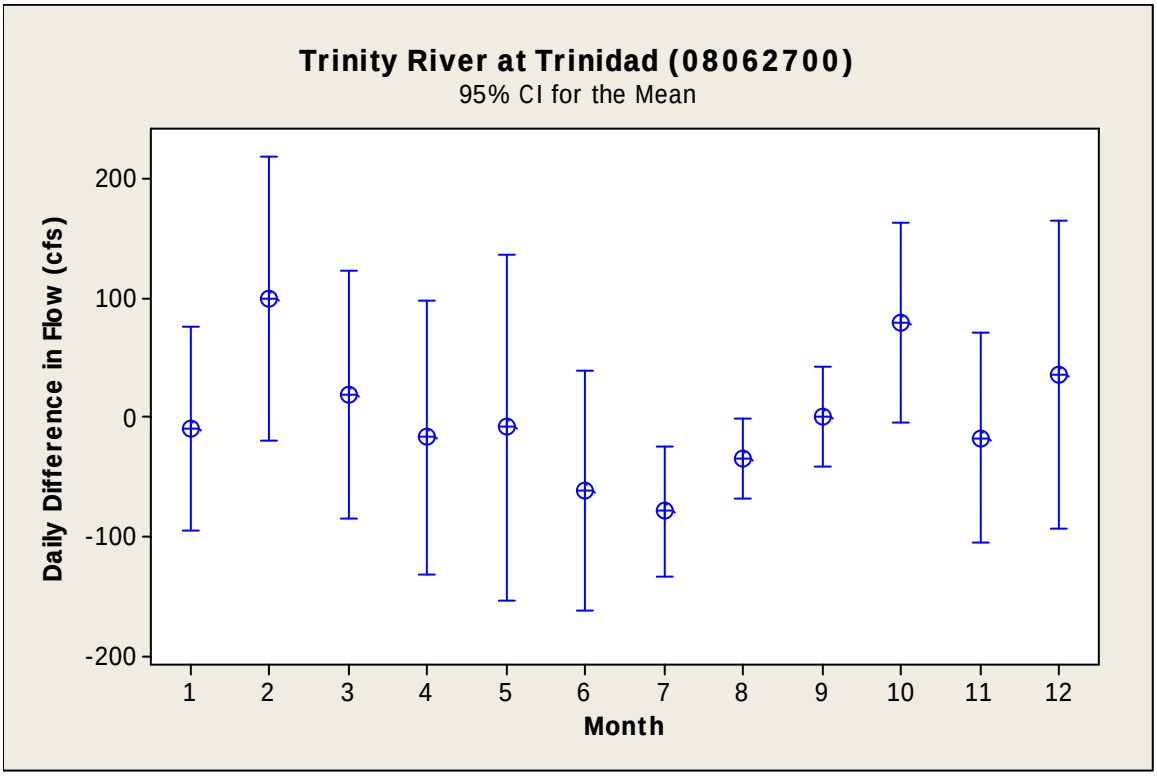


Figure 25. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the USGS Trinity River at Trinidad (08062700) gage from 1965 through 2008.

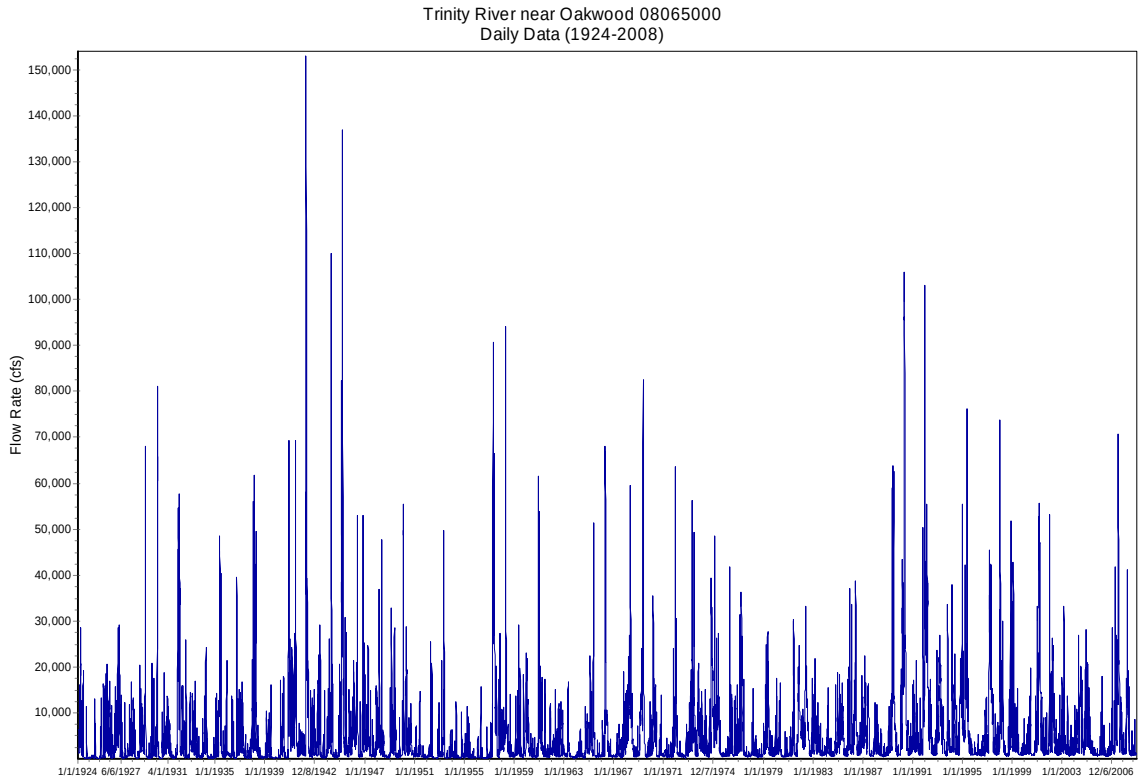


Figure 26. Average daily flows recorded at the USGS Trinity River near Oakwood (08065000) gage from 1924 through 2008.

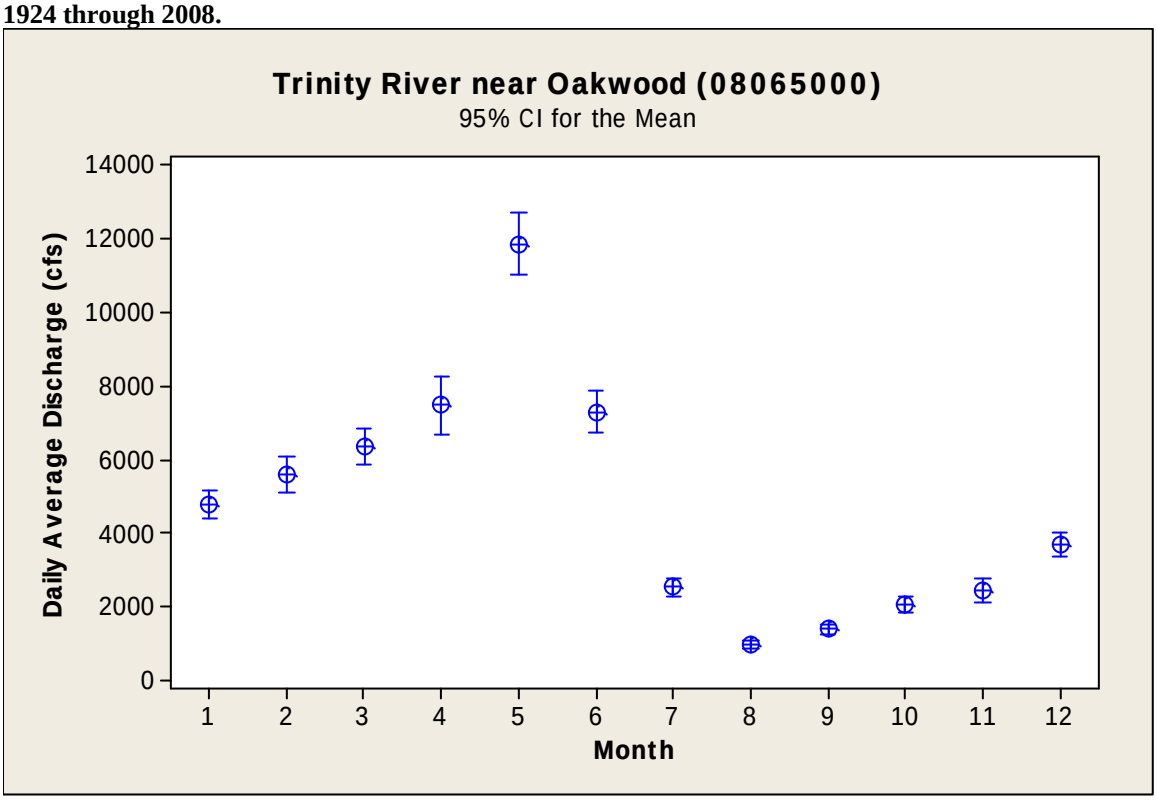


Figure 27. Monthly mean and 95% confidence intervals for daily average flow recorded at the USGS Trinity River near Oakwood (08065000) gage from 1924 through 2008.

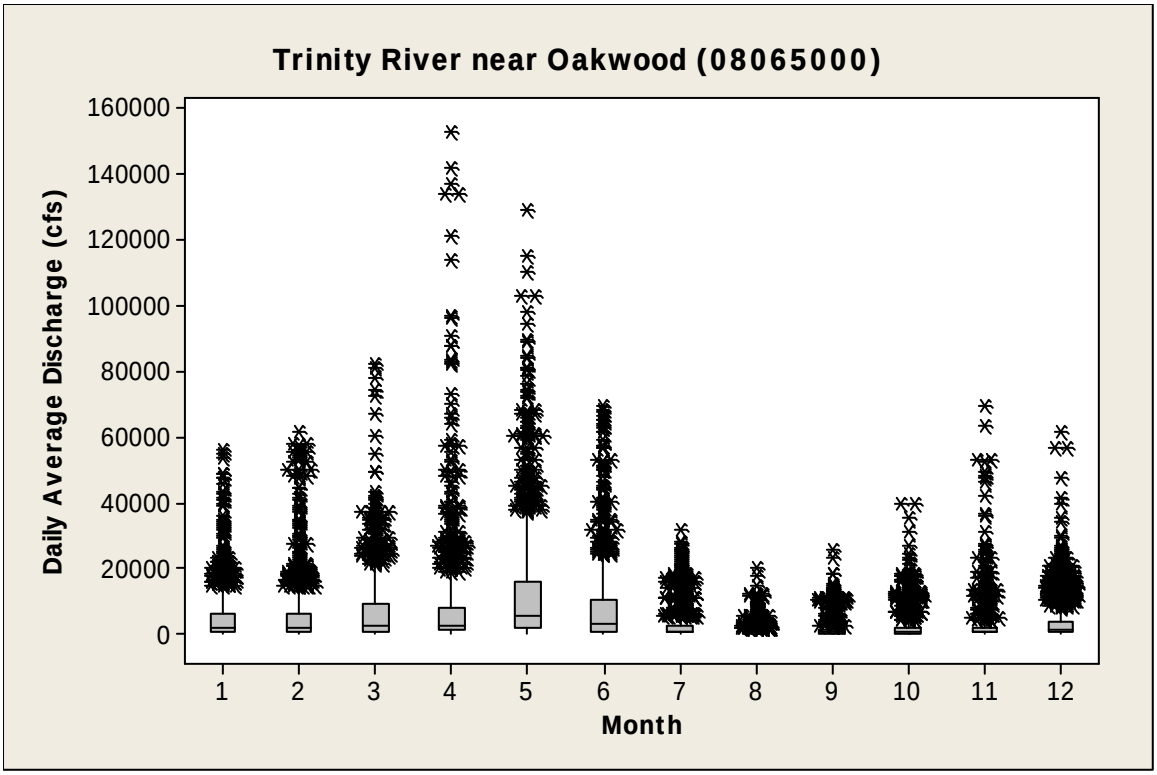


Figure 28. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average flows recorded at the USGS Trinity near Oakwood (08065000) gage from 1924 through 2008.

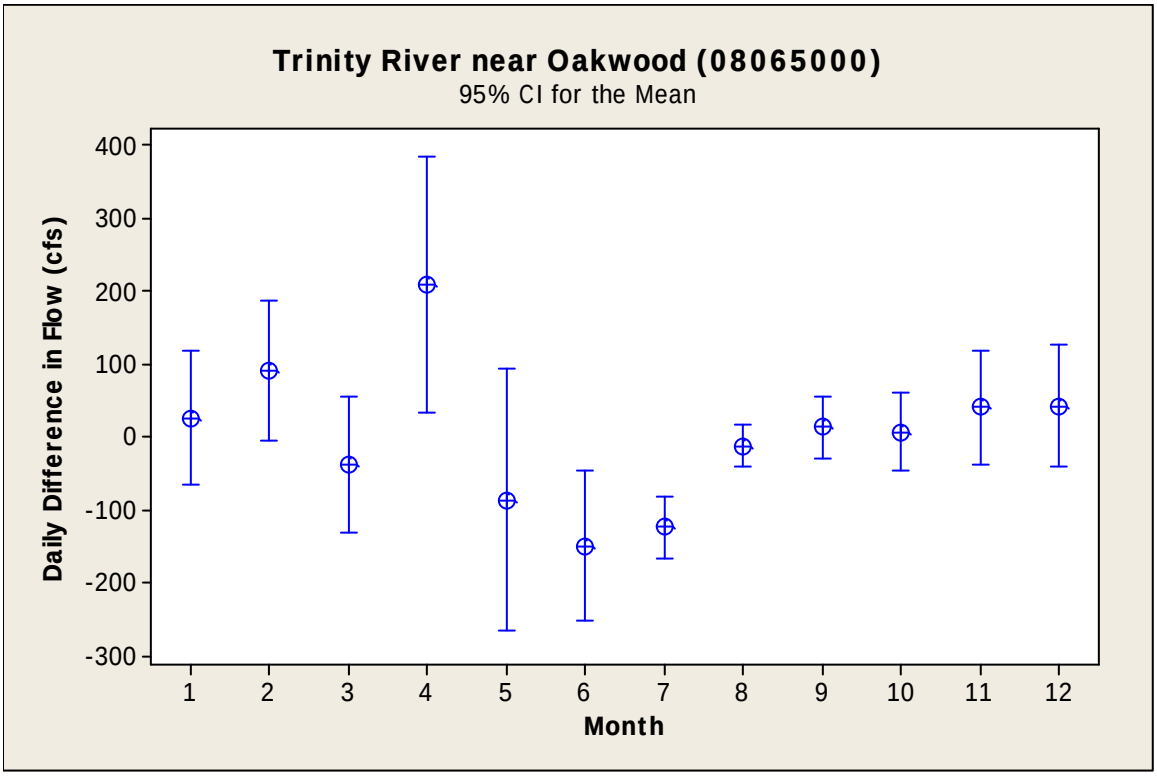


Figure 29. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the USGS Trinity River at Oakwood (08065000) gage from 1924 through 2008.

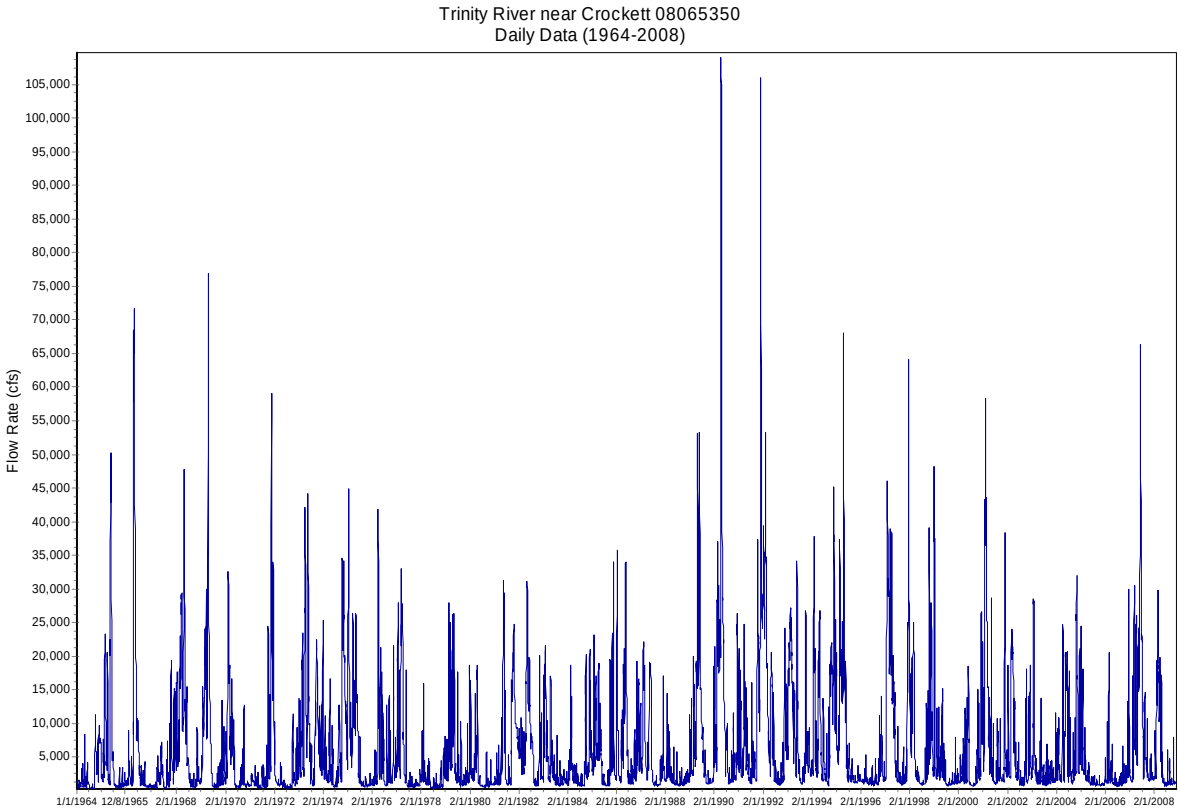


Figure 30. Average daily flows recorded at the USGS Trinity River near Crockett (08065350) gage from 1964 through 2008.

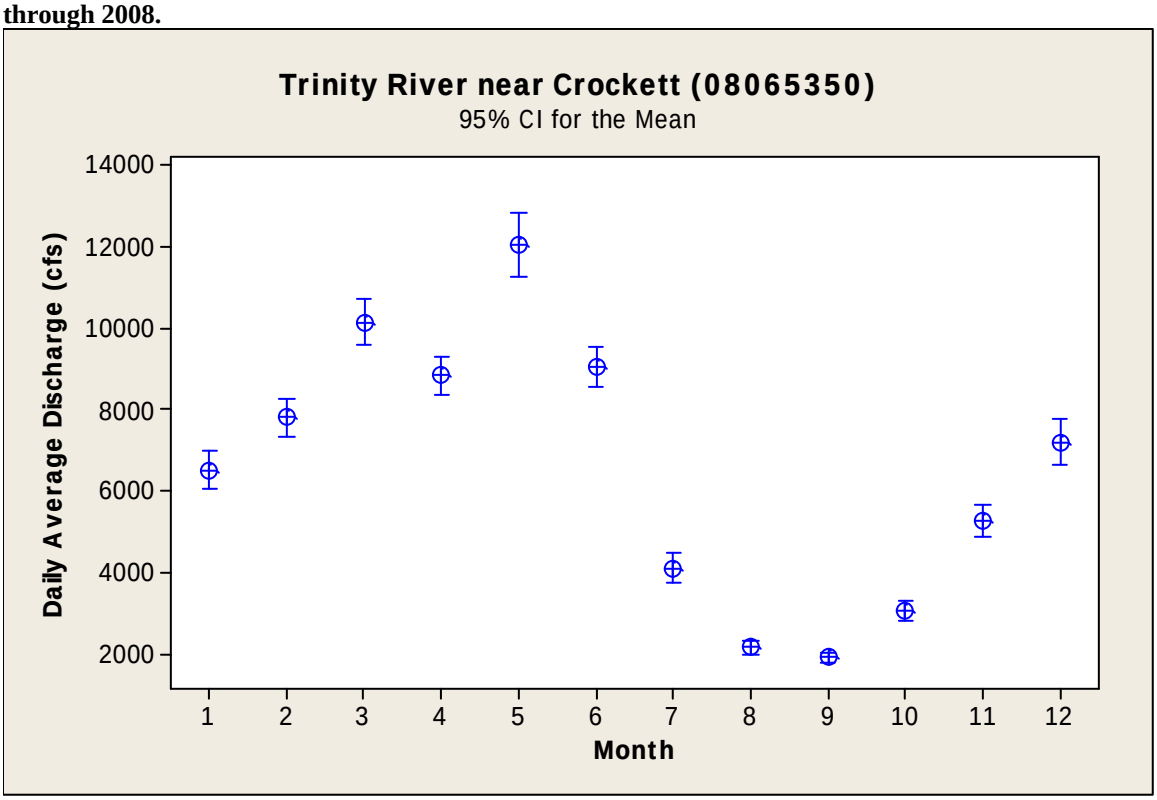


Figure 31. Monthly mean and 95% confidence intervals for daily average flow recorded at the USGS Trinity River near Crockett (08065350) gage from 1964 through 2008.

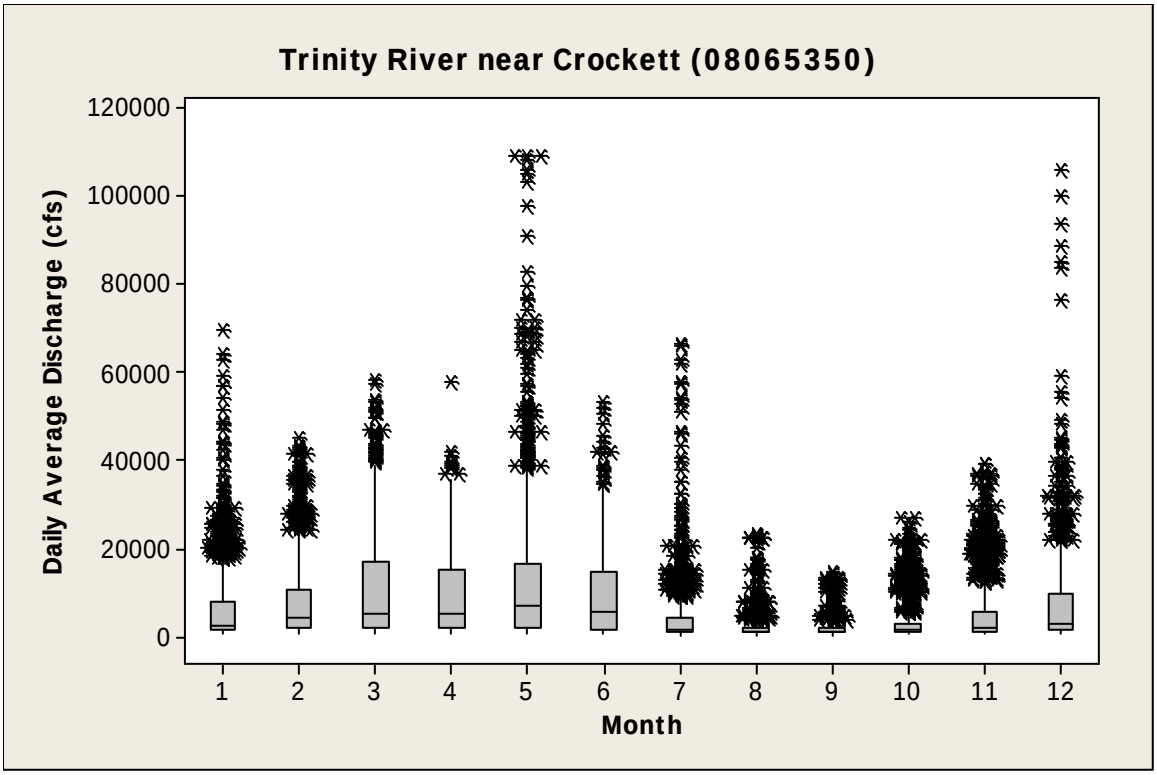


Figure 32. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average.

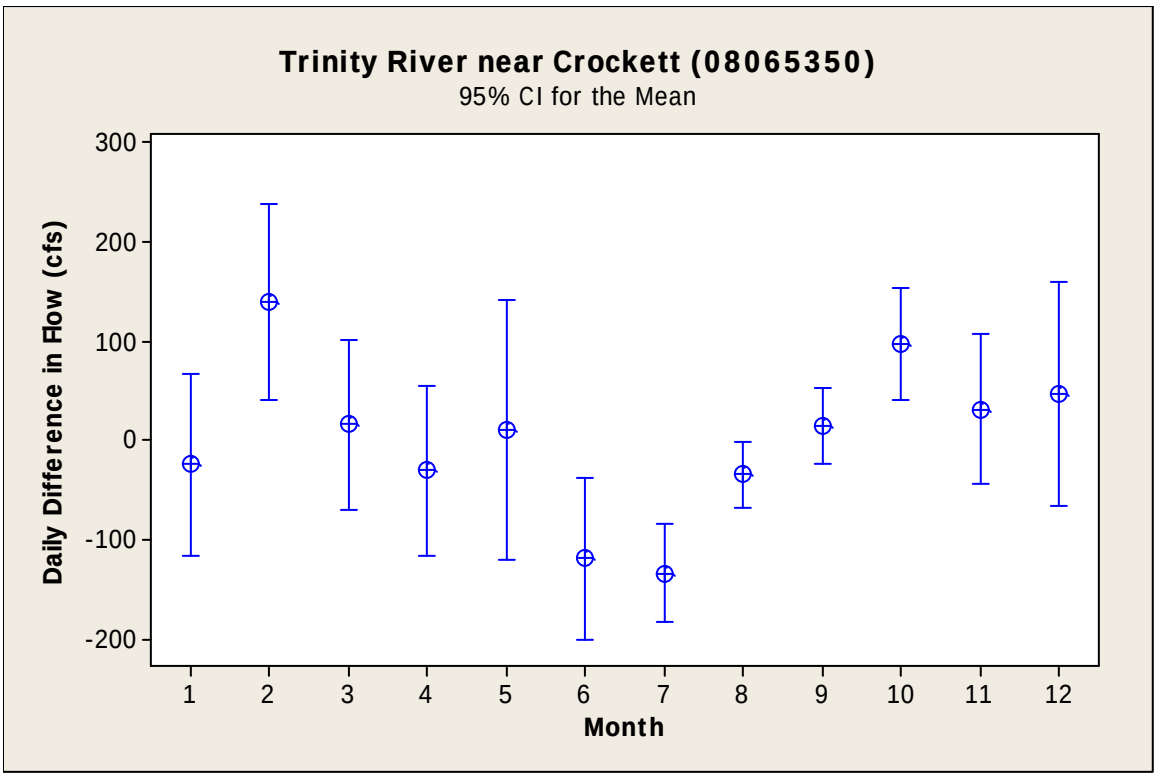


Figure 33. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the USGS Trinity River near Crockett (08065350) gage from 1964 through 2008.

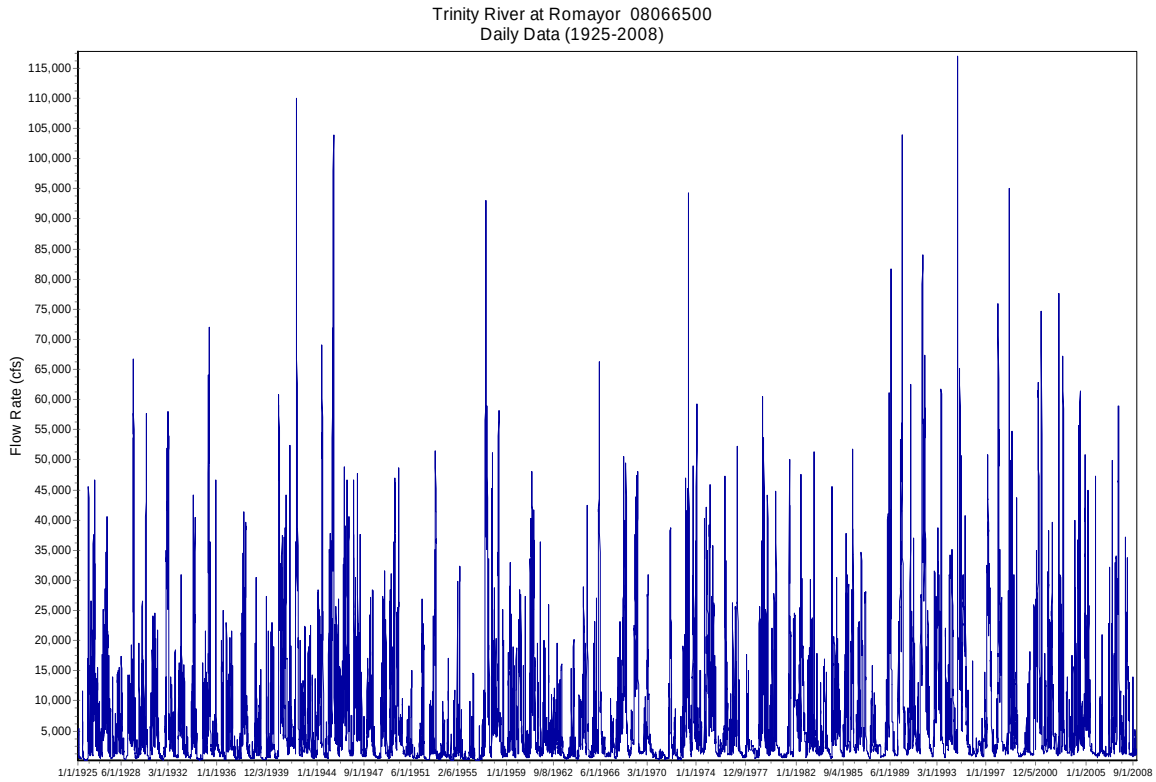


Figure 34. Average daily flows recorded at the USGS Trinity River at Romayor (08066500) gage from 1925 through 2008.

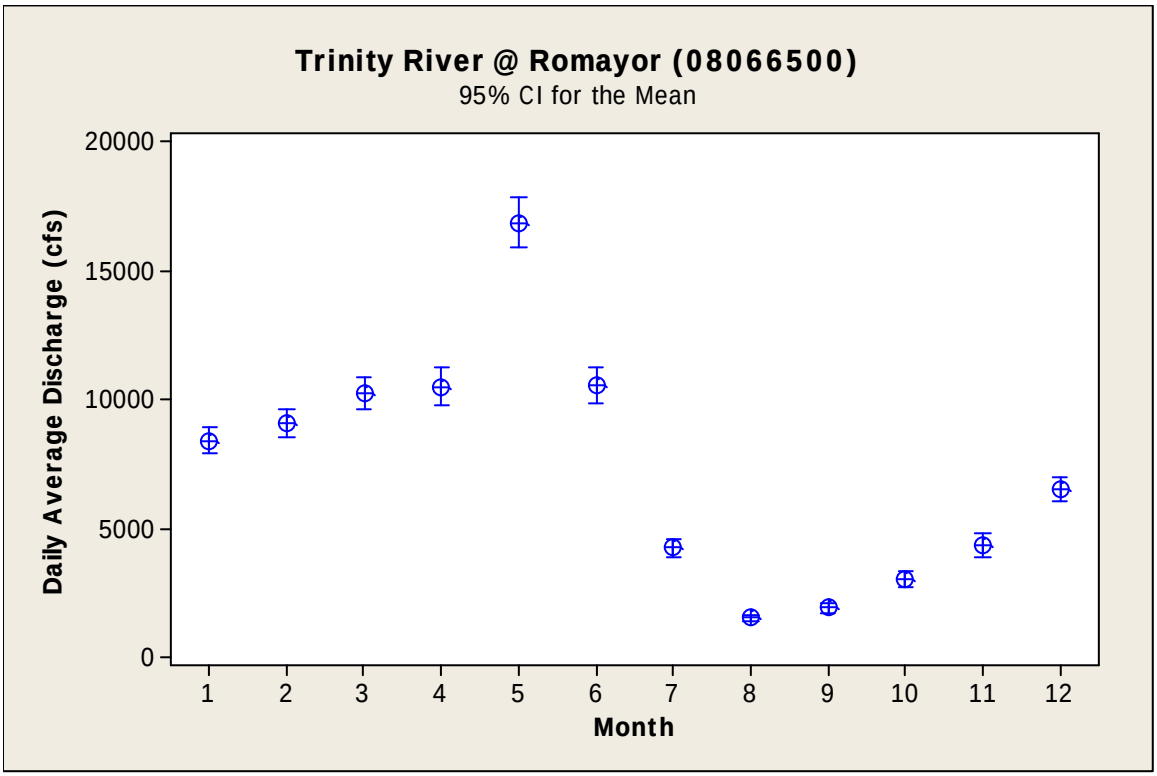


Figure 35. Monthly mean and 95% confidence intervals for daily average flow recorded at the USGS Trinity River at Romayor (08066500) gage from 1925 through 2008.

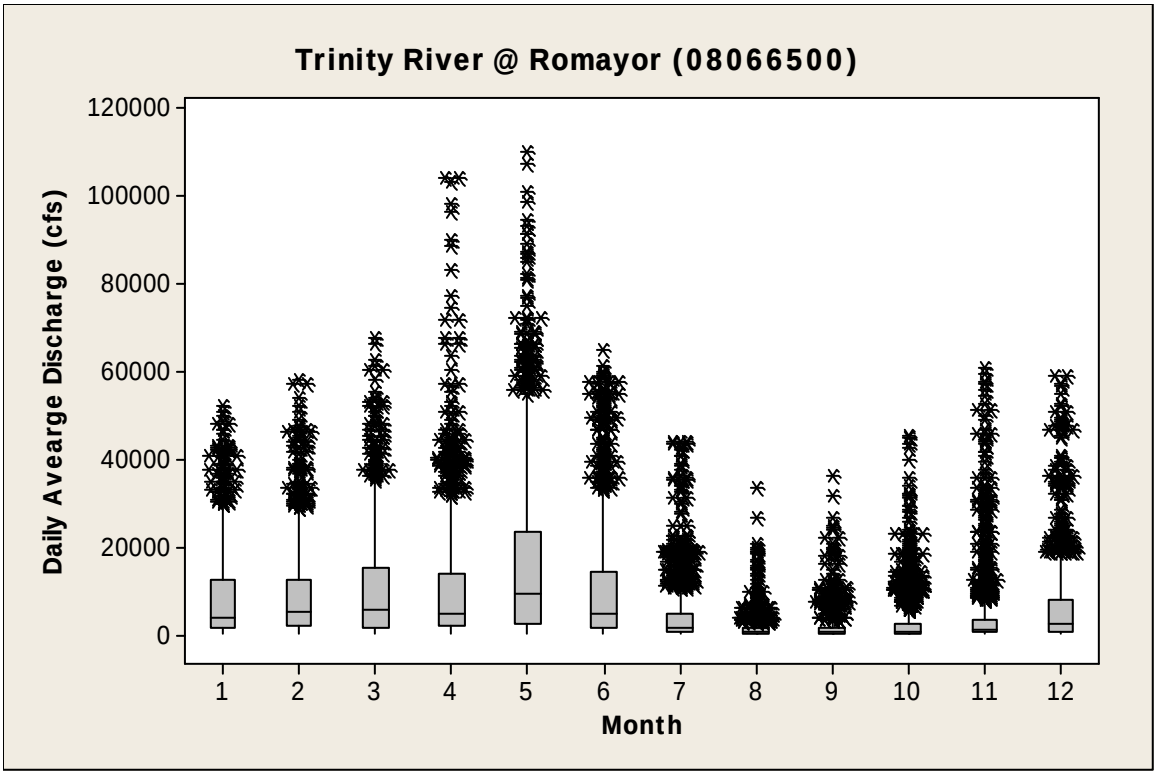


Figure 36. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average.

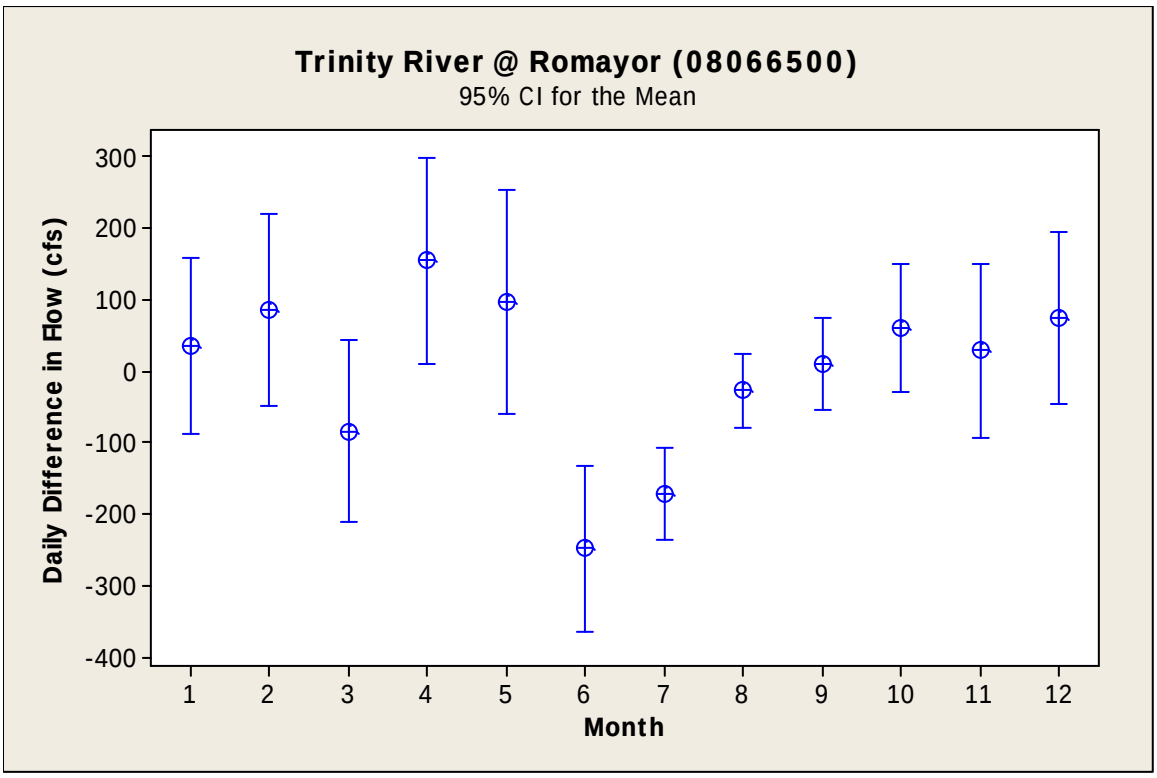


Figure 37. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the USGS Trinity River at Romayor (08066500) gage from 1925 through 2008.

Table 8. Preliminary list of 7Q2 estimates for various gage sites in the Trinity River Basin obtained form TCEQ in September 2009. Cell in yellow highlight are priority gage sites.

Gage	GageID	Start_Year	End_Year	7Q2	County_1	County_2	Stream_Name	Discontin	Gaps	Below_res	Dist_res	Res_ name	Res_date	Segment#
08066250	254	1979	2007	728	POLK	SAN JACINTO	TRINITY R			Y	11.9	LIVINGSTON RESERVOIR	6/26/69	0802
08066500	257	1979	2007	775	LIBERTY		TRINITY R			Y	34.9	LIVINGSTON RESERVOIR	6/26/69	0802
08065500	244	1960	1970	510	MADISON	HOUSTON	TRINITY R	Y		Y	147.8	RICHLAND CHAMBERS RESERVOIR	12/88	0803
08062700	224	1982	2007	722	HENDERSON	NAVARRO	TRINITY R			Y	101.4	LAKE RAY HUBBARD	3/22/78	0804
08065000	241	1982	2007	759	ANDERSON	FREESTONE	TRINITY R			Y	64.8	RICHLAND CHAMBERS RESERVOIR	12/88	0804
08065350	243	1981	2007	833	LEON	HOUSTON	TRINITY R			Y	112.8	RICHLAND CHAMBERS RESERVOIR	12/88	0804
08057000	197	1989	2007	396	DALLAS		TRINITY R			Y	39.3	LAKE ARLINGTON	3/31/57	0805
08057410	202	1975	2007	503	DALLAS		TRINITY R		Y	Y	47.8	LAKE ARLINGTON	3/31/57	0805
08057448	204	1998	2002	662	DALLAS		TRINITY R	Y		Y	60.4	LAKE ARLINGTON	3/31/57	0805
08062500	222	1982	2007	678	KAUFMAN	ELLIS	TRINITY R			Y	41.2	LAKE RAY HUBBARD	3/22/78	0805
08048000	159	1979	2007	12	TARRANT		TRINITY R, W FK			Y	12	BENBROOK LAKE	9/29/52	0806
08048543	163	1979	2007	13	TARRANT		TRINITY R, W FK			Y	19.2	BENBROOK LAKE	9/29/52	0806
08043100	148	1985	1989	1.6	WISE		TRINITY R, W FK	Y		Y	2.9	BRIDGEPORT RESERVOIR	1972	0810
08044500	150	1979	2007	7	WISE		TRINITY R, W FK			Y	25	BRIDGEPORT RESERVOIR	1972	0810
08042800	147	1979	2007	0	JACK		TRINITY R, W FK			N				0812
08064100	238	1984	2007	0.04	NAVARRO		CHAMBERS CR			Y	10.6	BARDWELL LAKE	3/27/66	0814
08061750	216	2003	2007	25	KAUFMAN		TRINITY R, E FK			Y	1.9	LAKE RAY HUBBARD	3/22/78	0819
08061970	218	1989	1992	33	DALLAS		TRINITY R, E FK	Y		Y	10	LAKE RAY HUBBARD	3/22/78	0819
08061980	219	1989	1996	63	DALLAS		TRINITY R, E FK	Y	Y	Y	13	LAKE RAY HUBBARD	3/22/78	0819

Table 8. Continued.

Gage	GageID	Start_Year	End_Year	7Q2	County_1	County_2	Stream_Name	Discontin	Gaps	Below_res	Dist_res	Res_ name	Res_date	Segment#
08062000	221	1993	2007	64	KAUFMAN		TRINITY R, E FK			Y	21.7	LAKE RAY HUBBARD	3/22/78	0819
08061000	213	1960	1989	0	COLLIN		TRINITY R, E FK	Y		Y	0.7	LAVON LAKE	10/53	0820
08053000	189	1979	2007	61	DENTON		TRINITY R, ELM FK			Y	1.9	LAKE LEWISVILLE	8/55	0822
08055500	194	1979	2007	15	DALLAS		TRINITY R, ELM FK			Y	11.9	LAKE LEWISVILLE	8/55	0822
08050300	177	1960	1973	0.01	COOKE		TRINITY R, ELM FK	Y		N				0824
08050400	178	1998	2007	0.03	COOKE		TRINITY R, ELM FK			N				0824
08050410	179	1988	1998	4.3	COOKE		TRINITY R, ELM FK	Y		N				0824
08055000	193	1966	2007	11	DENTON		DENTON CR		Y	Y	5.6	GRAPEVINE LAKE	7/3/52	0825
08047000	156	1979	2007	1.6	TARRANT		TRINITY R, CLEAR FK			Y	1.5	BENBROOK LAKE	9/29/52	0829
08047500	158	1979	2007	4.4	TARRANT		TRINITY R, CLEAR FK			Y	10	BENBROOK LAKE	9/29/52	0829
08045850	152	1980	2005	0.2	PARKER		TRINITY R, CLEAR FK	Y	Y	Y	2.8	LAKE WEATHERFORD	1957	0831
08046000	153	1960	1975	0	PARKER		TRINITY R, CLEAR FK	Y		Y	15	LAKE WEATHERFORD	1957	0831
08046020	154	1989	1996	9.8	TARRANT		TRINITY R, CLEAR FK	Y		Y	19	LAKE WEATHERFORD	1957	0831
08064550	779	1994	2008	5	FREESTONE		RICHLAND CR			Y	0	RICHLAND CHAMBERS RESERVOIR	12/88	0835
08063500	232	1960	1988	0	NAVARRO		RICHLAND CR	Y		Y	30	NAVARRO MILLS LAKE	9/19/63	0836
08063100	230	1979	2007	0.01	NAVARRO		RICHLAND CR			Y	1.7	NAVARRO MILLS LAKE	9/19/63	0837
08051100	778	1988	2008	2	DENTON		TRINITY R, ELM FK			Y	0	LAKE RAY ROBERTS	6/30/87	0839
08051130	183	1986	1992	0.04	DENTON		TRINITY R, ELM FK	Y		Y	0.1	LAKE RAY ROBERTS	6/30/87	0839
08049500	170	1979	2007	140	DALLAS		TRINITY R, W FK			Y	25	LAKE ARLINGTON	3/31/57	0841

Water Quality and Geomorphological Factors

Historical Data

Based on their most recent assessment the TCEQ identified 37 impaired waterbody segments within the Trinity watershed (Texas Commission on Environmental Quality (TCEQ) 2009). The majority (29) of these segments were listed exclusively for not meeting contact recreational use criteria that is exceeding numerical indicator bacteria criteria (Table 9). Only five segments were listed as not supporting aquatic life uses, primarily due to not meeting dissolved oxygen criteria. These segments located in the upper watershed include Cotton Bayou, Catfish Creek, West Fork Trinity River and Clear Fork Trinity River (Table 9). Four stream segments were also listed for not meeting general use criteria (e.g. chlorides, sulfate, TDS and pH). These data suggest that the majority of majority of the Trinity River basin is meeting aquatic life use numerical water quality criteria and aquatic life uses. Prior to 1990's water quality was severely impaired in the upper portions of the Trinity River basin, downstream of Dallas and Fort Worth, due to inadequate wastewater treatment (Arnold 1989; Dickson et al. 1991; Lamb 1961; Leifeste and Hughes 1967). The resulting anoxia or hypoxia created areas devoid of life and/or later caused periodic fish kills following storm events, commonly referred to as the "black rise"(Davis 1987; Davis and Bastian 1988). Since the early 1990's dissolved oxygen levels have improved and seldom drop below 4.0 mg/l based on data collected during routine monitoring conducted by TCEQ and partner agencies (Figures 38 and 39). Dissolved oxygen concentrations in most portions of the Trinity River now appear to be meeting aquatic life use criteria (Figure 40 and 41). Median values within the basin during 1968 through 2008 appear to fluctuate between 5 and 10 mg/l, although there are occasional periods when levels have dropped below 2.0 mg/l.

Table 9. Current 303d listed impaired water bodies within the Trinity River Basin and concerns.

Segment	Description	Extent	Status	Year Listed	Concern	Human Health	Aquatic Life	General
0801C	Cotton Bayou	portions	unclassified	2006	low oxygen		X	
0803	Lake Livingston	portions	classified	2006-2008	sulfate, pH			X
0804G	Catfish Creek	entire	unclassified	2006	low oxgyen, imparied benthos		X	
0805	Upper Trinity River	portions	classified	1996-2002	bacteria, PCB in tissue	X		
0806	W. Fork Trinity River Below Lake Worth	portions	classified	1996	PCB in tissue	X		
0806D	Marine Creek	portions	unclassified	2006	bactera	X		
0806E	Sycamore Creek	portions	unclassified	2006	bacteria	X		
0810	West Fork Trinity R. below Bridgeport Reservoir	portions	classified	1998	bacteria	X		
0810A	Big Sandy Creek	portions	unclassified	2006	bacteria	X		
0810B	Garrett Creek	portions	unclassified	2006	bacteria	X		
0810C	Martin Branch	portions	unclassified	2006	bacteria	X		
0810D	Salt Creek	portions	unclassified	2006	bacteria	X		
0812	West Fork Trinity R. above Bridgeport Res.	portions	classified	1998	chloride, low oxygen, TDS,	X	X	X
0818	Cedar Creek Reservoir	portions	classified	2002	pH			X
0819	E. Fork Trinity River	entire	classified	2008	sulfate, TDS, chloride			X
0820C	Muddy Creek	entire	unclassified	2002	bacteria	X		
0822	Elm Fork T. River below Lewisville	portions	classified	2006	bacteria	X		
0822A	Cottonwood Branch	portions	unclassified	2006	bacteria	X		
0822B	Grapevine Creek	portions	unclassified	2006	bacteria	X		
0829	Clear Fork Trinity River below Benbrook L.	portions	classified	1996	PCBs in tissue	X		

Table 9. Continued.

0831	Clear Fork Trinity River below Lake Weatherford	portions	classified	1996	low oxygen		X	
0833	Clear Fork Trinity River above Lake Weatherford	portions	classified	1996	low oxygen		X	
0838C	Walnut Creek	portions	unclassified	2006	bacteria	X		
0841	Lower West Fork Trinity River	portions	classified	1996	bacteria, PCB in tissue	X		
0841B	Bear Creek	entire	unclassified	2006	bacteria	X		
0841C	Arbor Creek	entire	unclassified	2006	bacteria	X		
0841D	Big Bear Creek	entire	unclassified	2006	bacteria	X		
0841E	Copart Branch Mountain Creek	entire	unclassified	2006	bacteria	X		
0841F	Cottonwood Creek	entire	unclassified	2006	bacteria	X		
0814G	Dalworth Creek	entire	unclassified	2006	bacteria	X		
0814H	Delaware Creek	entire	unclassified	2006	bacteria	X		
0814J	Estelle Creek	entire	unclassified	2006	bacteria	X		
0841K	Fish Creek	entire	unclassified	2006	bacteria	X		
0841M	Kee Branch	entire	unclassified	2006	bacteria	X		
0841N	Kirby Creek	entire	unclassified	2006	bacteria	X		
0814S	Vilbig Lakes	portions	unclassified	2006	bacteria	X		
0814U	West Irving Creek	portions	unclassified	2006	bacteria	X		
Total						**30**	**5**	**4**

Source: (Texas Commission on Environmental Quality (TCEQ) 2009)

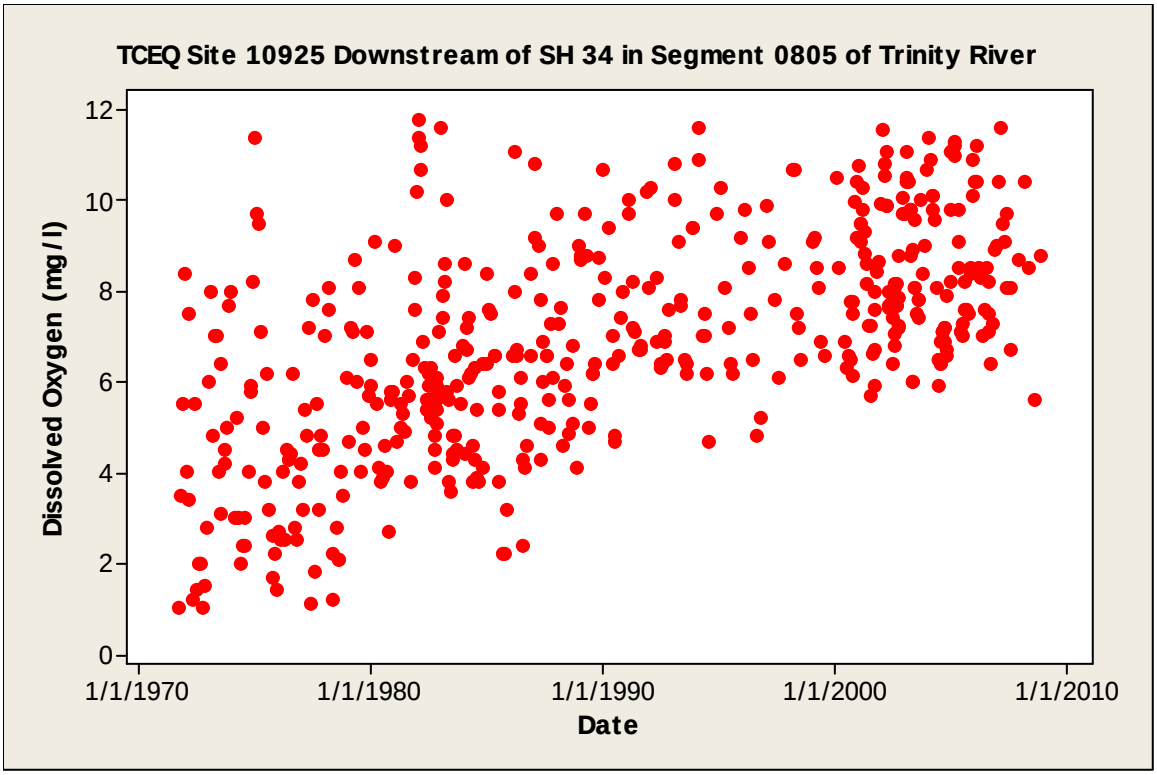


Figure 38. Trends in dissolved oxygen measured at the TCEQ monitoring site 10925 located downstream of SH 34 in segment 0805 of the Trinity River from 1971 through 2008.

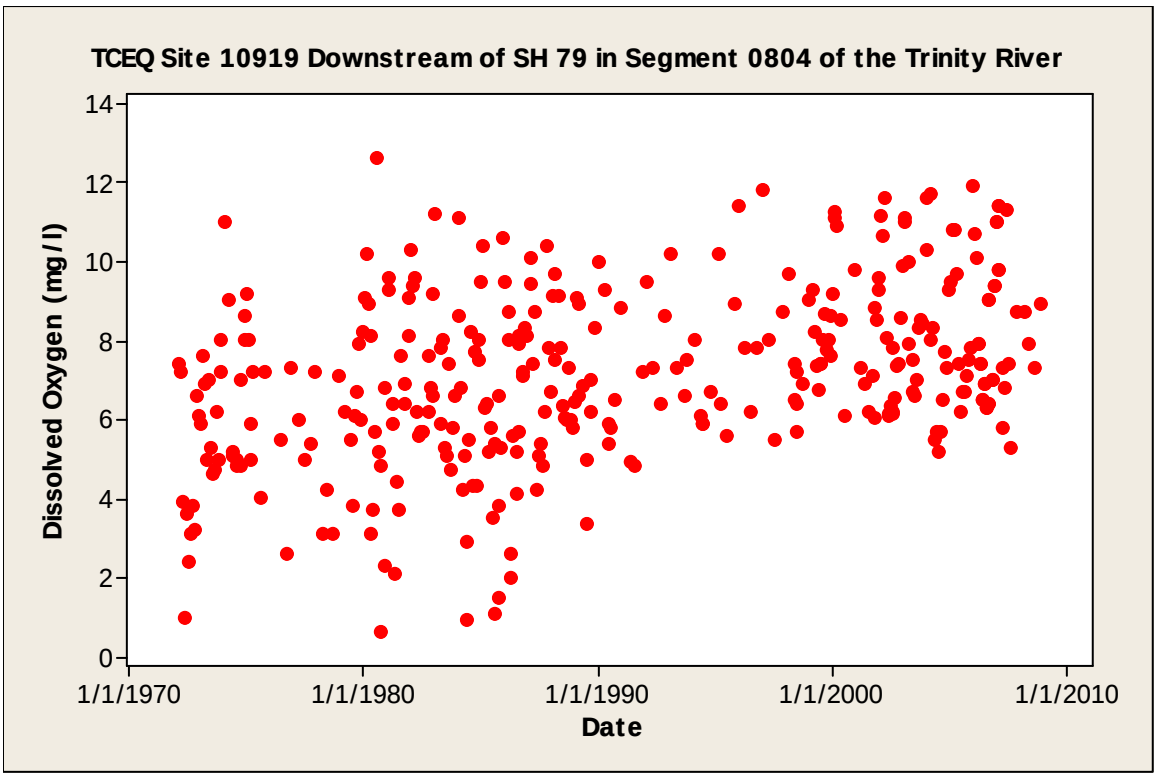


Figure 39. Trends in dissolved oxygen measured at the TCEQ monitoring site 10925 downstream of SH 79 in segment 0804 of the Trinity River from 1972 through 2008.

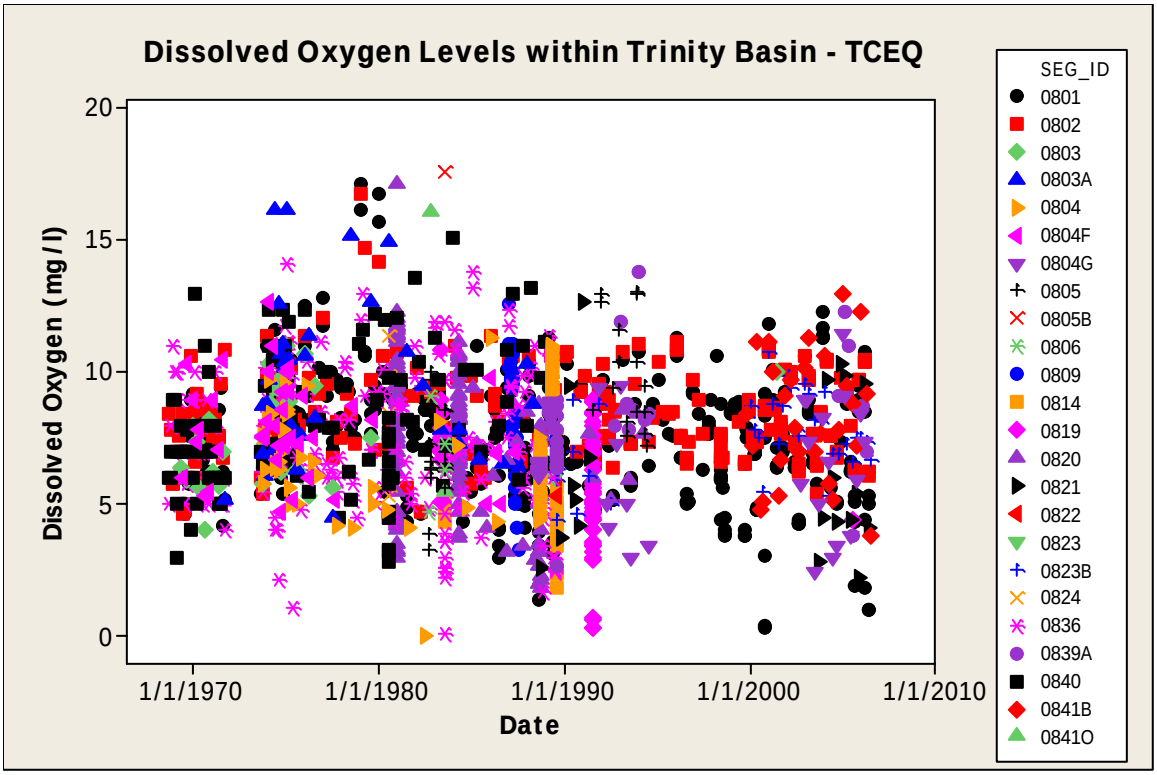


Figure 40. Long terms trends in dissolved oxygen measured at various sites in the all segments of the Trinity River basin based on historical data extracted TCEQ SWQM database from 1968 through 2006, n= 1894.

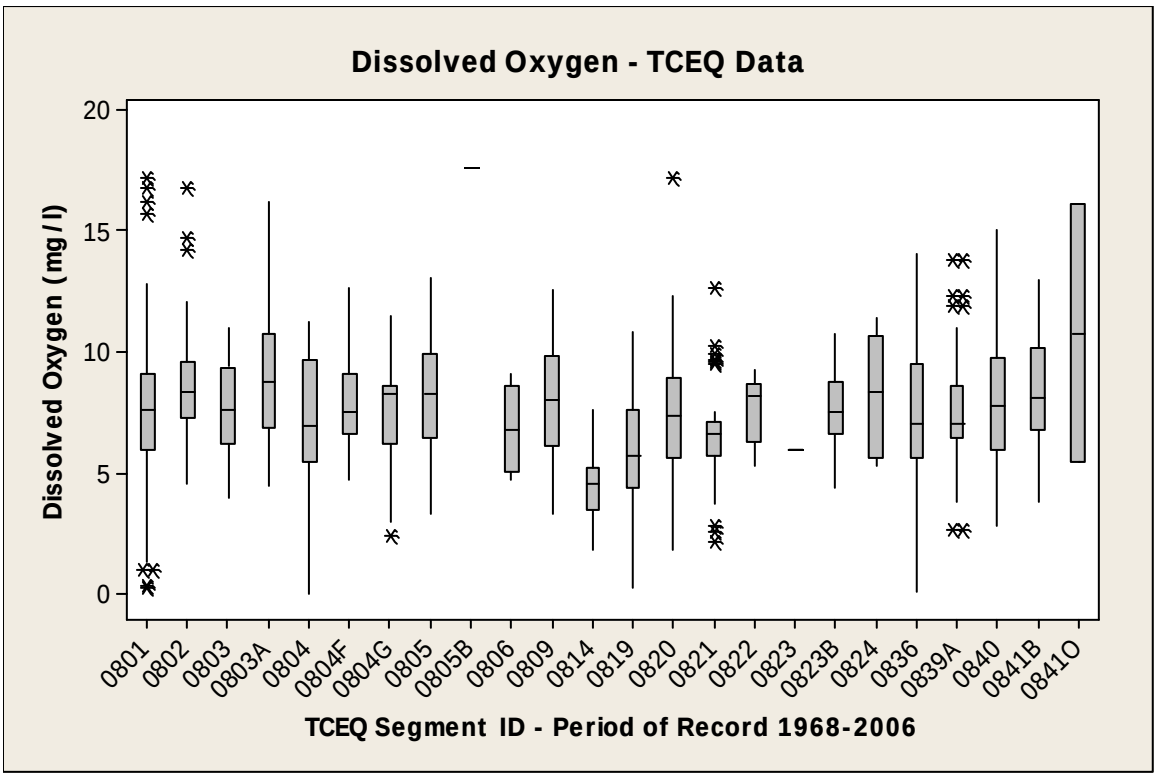


Figure 41. Long term spatial trends in dissolved oxygen measured at various sites within each segment of the Trinity River basin based on historical data extracted TCEQ SWQM database from 1968 through 2006, n= 1894.

Using historical USGS data we prepared a series of graphs depicting possible relationships between instantaneous flow and selected variables including water temperature, specific conductance (uS), total suspended sediments (TSS), total nitrogen (N) and total phosphorus (P) data at priority gage sites (Figures 42- 124). In many cases one or more variables were not collected at the site during the same time. In addition, we also utilized data compiled at the Romayor (08066500) site to estimate loading of selected constituents including TSS, N and P to Galveston Bay. The variables investigated included total nitrogen and phosphorus (Figure 122-123). Finally we utilized historical TCEQ data to evaluate long-term spatial trends in total suspended solids (Figures 127-128). Suspended solids loading was also estimated at the Trinity River near Oakwood gage (08065000) since it was one of the few gages that contained sufficient long-term data to estimate sediment loading at various flows. At some gage sites little data was available for the parameters of interests. In some cases there was insufficient data for selected parameters for a subset of the priority gages. In these cases graphical depictions between discharge and that parameter is not depicted. Again, for flow versus water quality relationships we only utilized data where paired instantaneous and water quality data were present. In some cases paired daily average daily flow and grab samples results for a particular chemical or physical trait were available. However, we did not utilize these for development of predictive relationships due to different time scales that the data parameters integrate.

Specific conductance was the only water quality parameter collected at a sufficient frequency at the at the Elm Fork Trinity gage (080555500) (Figure 42). Specific conductance did not exhibit a strong relationship with flow. In contrast several water quality parameters including water temperature, dissolved oxygen, specific conductance, total nitrogen, ammonia, nitrate and nitrite nitrogen, phosphates, orthophosphate, and phosphorous were measured at a sufficient intensity at the West Fork Trinity to evaluate effects of stream flow on their concentration (Figures 42-57). Water temperature during all seasons was depressed at higher flows (Figures 42-45). The strongest response occurred during the summer months (Figure 42). Flows above 3000 cfs generally resulted in water temperatures below 26 C, whereas at low flows temperatures ranged between 33 and 27 C. Over the period of record dissolved oxygen also increased slightly at higher flows (Figures 47 to 50). During the spring through fall dissolved oxygen levels were seldom below 6.0 mg/l at flows above 2000 cfs. During the winter dissolved oxygen seldom dropped below 8.0 mg/l whenever flows were above 1000 cfs. Highest variability and highest frequency of hypoxia and anoxia usually occurred at flows below 500 cfs. Specific conductance declined as flows decreased and was generally depressed below 400 uS above 2000 cfs (Figure 48). Nutrient concentrations generally peaked at 200 to 1000 cfs and then declined with increasing flows (Figures 52-58). This pattern is likely due to increased loading occurring during the ascending limb of flood events with subsequent dilution at higher flows.

Winter water temperature varied little flow, however higher flows during other months generally resulted in declining water temperatures at the Rosser gage (08062500)(Figures 60-62). This relationship was strongest during the summer months (Figure 62). Dissolved oxygen exhibited similar seasonal responses to increasing flows with greatest increases occurring in the summer months (Figures 63 to 65). Dissolved oxygen levels at the Rosser gage were seldom below 4.0 mg/l when flows were above 5000 to 6000 cfs. Specific conductance was depressed at higher flows and was seldom above 400 uS at flows greater than 5000 cfs. Nutrient levels at Rosser varied considerably at lower flows (<2500 cfs) but generally declined above 5000 cfs (Figures 68-74). Elevated levels of nutrients below 2000 cfs are likely due to storm events causing temporary increases in their levels as they are washed out into the watershed.

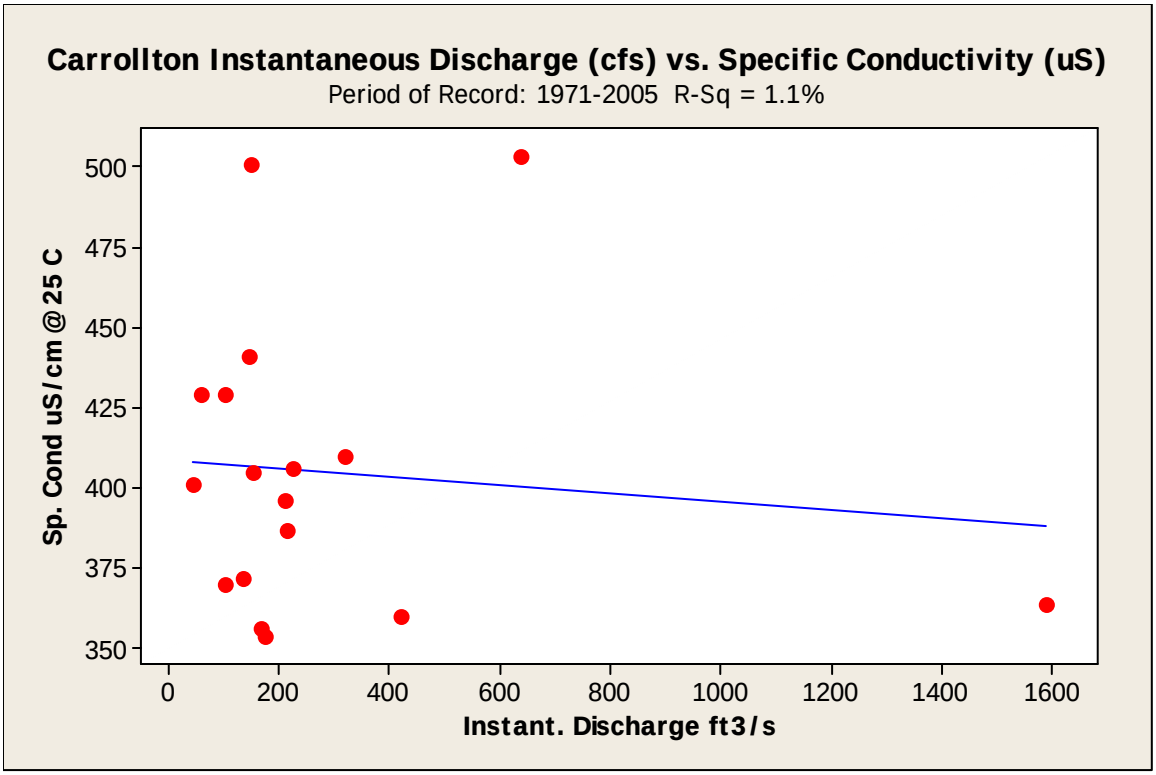


Figure 42. Flow versus specific conductance at the Elm Fork Trinity River gage near Carrollton (08055500) during 1971 through 2005.

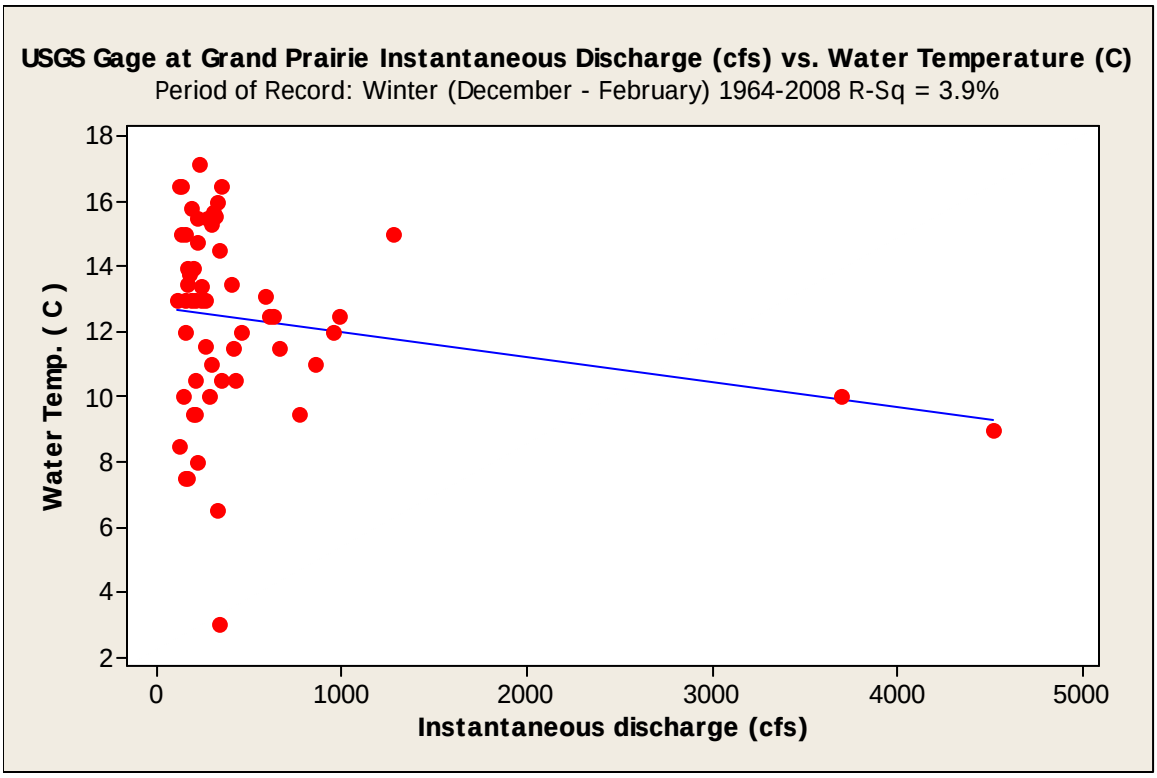


Figure 43. Flow versus winter water temperature at the West Fork Trinity River at Grand Prairie 08049500 gage during 1964 through 2008.

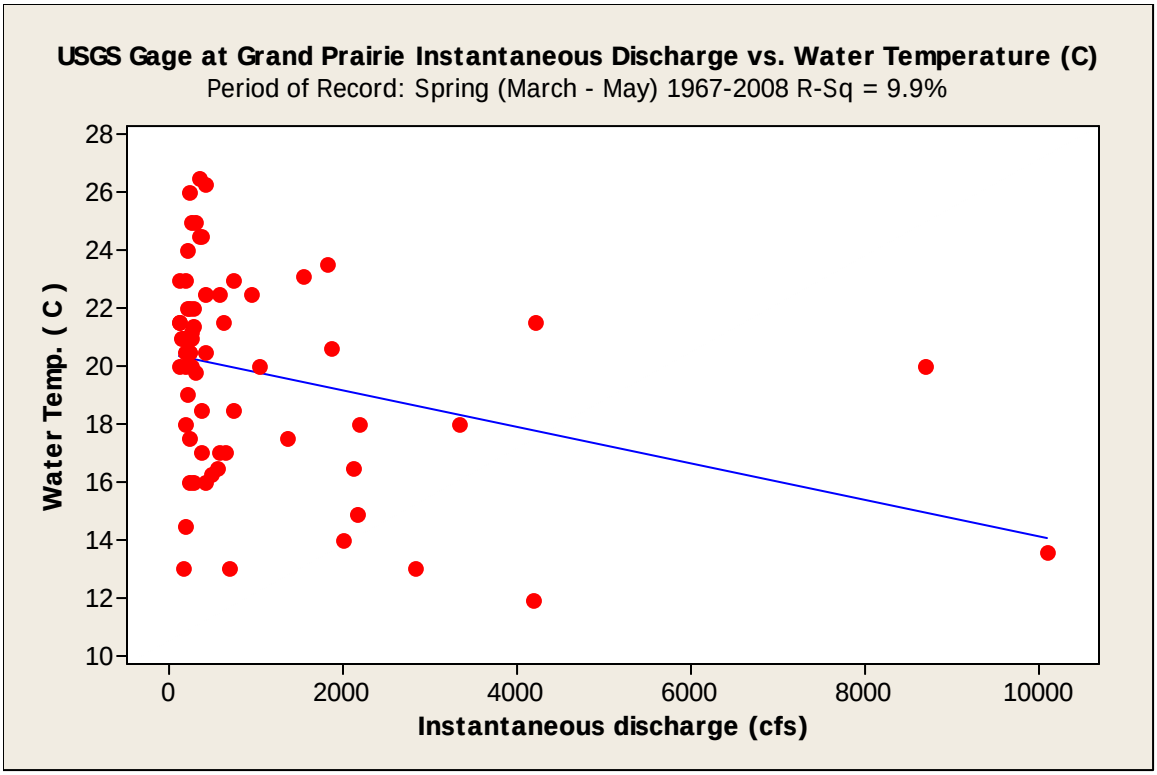


Figure 44. Flow versus spring water temperature at the West Fork Trinity River at Grand Prairie 08049500 gage during 1967 through 2008.

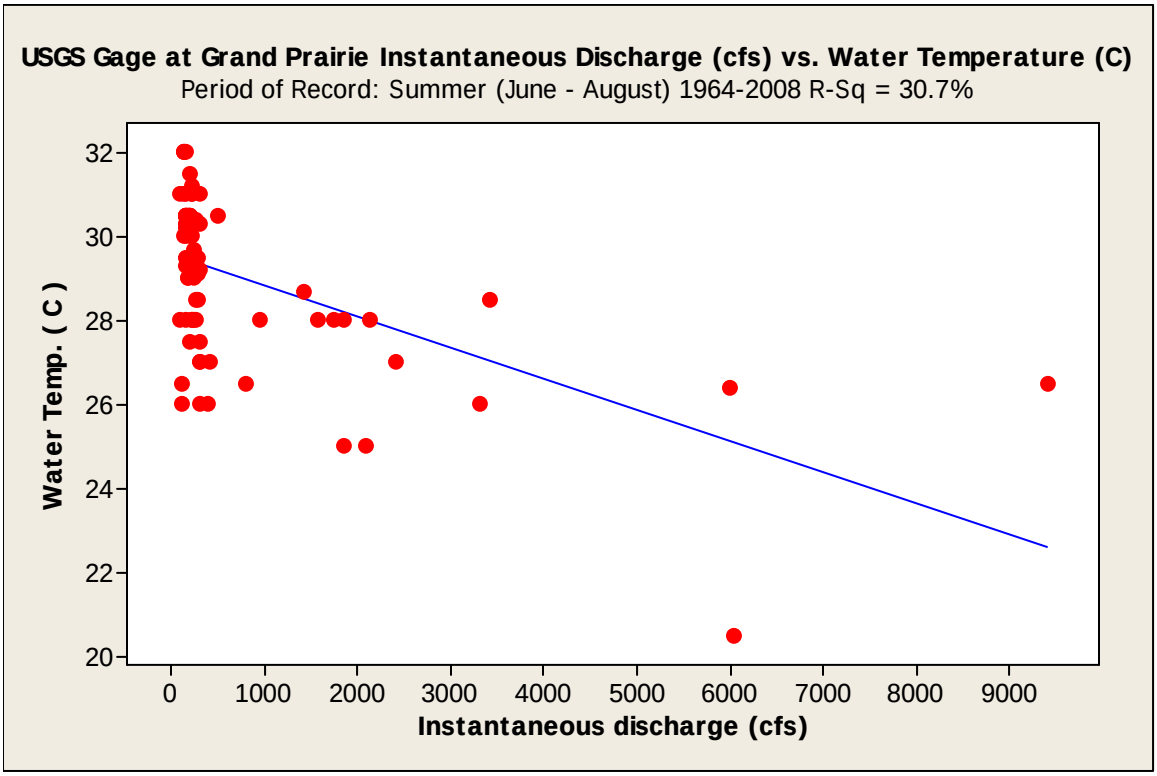


Figure 45. Flow versus summer water temperature at the West Fork Trinity River at Grand Prairie 08049500 gage during 1964 through 2008.

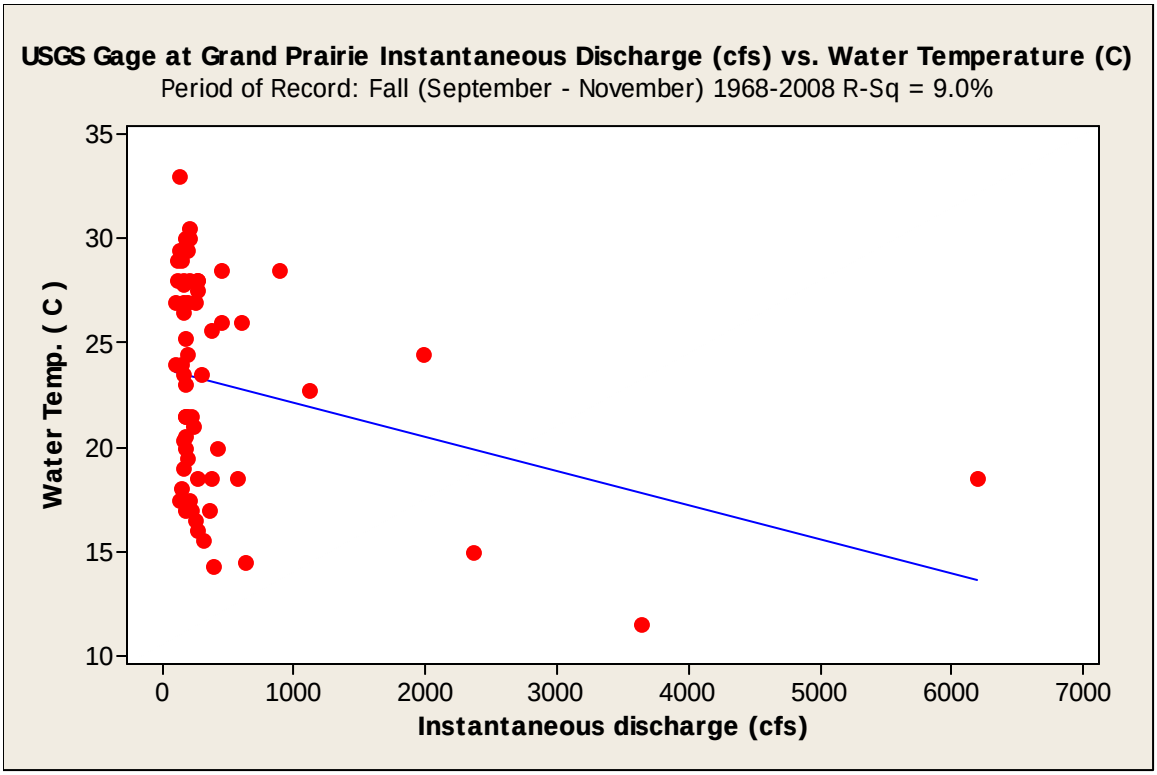


Figure 46. Flow versus fall water temperature at the West Fork Trinity River at Grand Prairie 08049500 gage during 1968 through 2008.

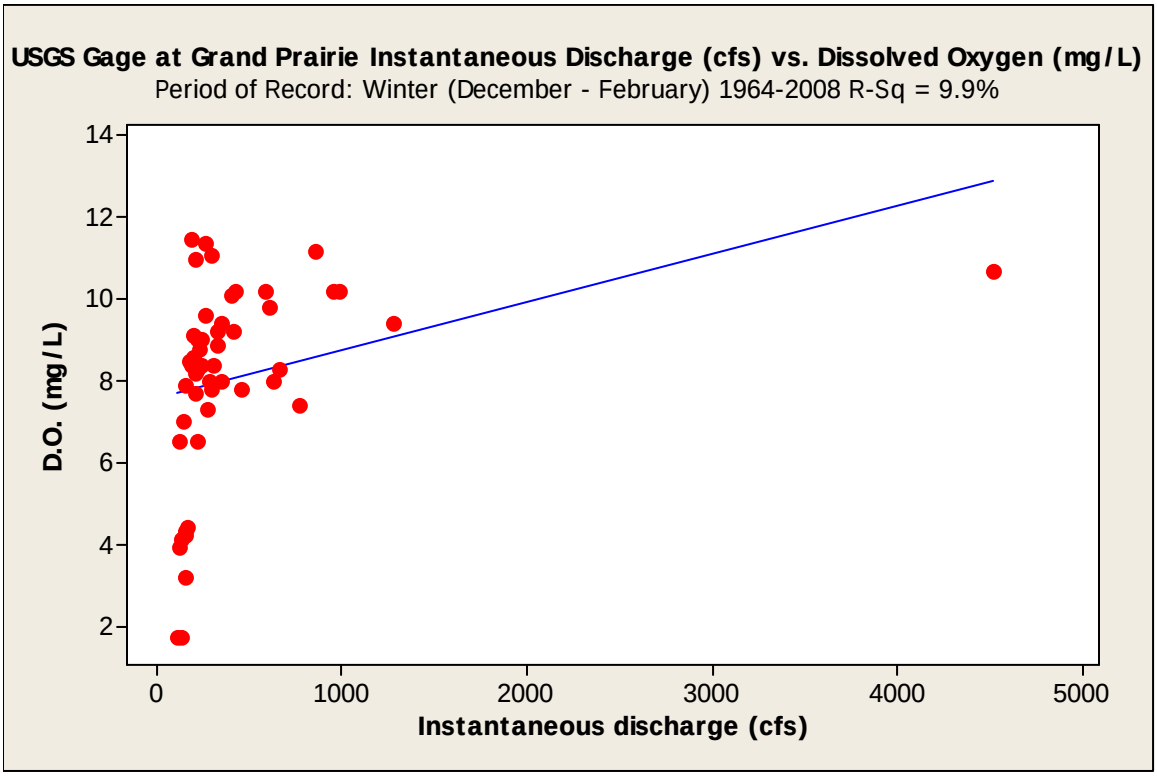


Figure 47. Flow versus winter dissolved oxygen at the West Fork Trinity River at Grand Prairie 08049500 gage during 1964 through 2008.

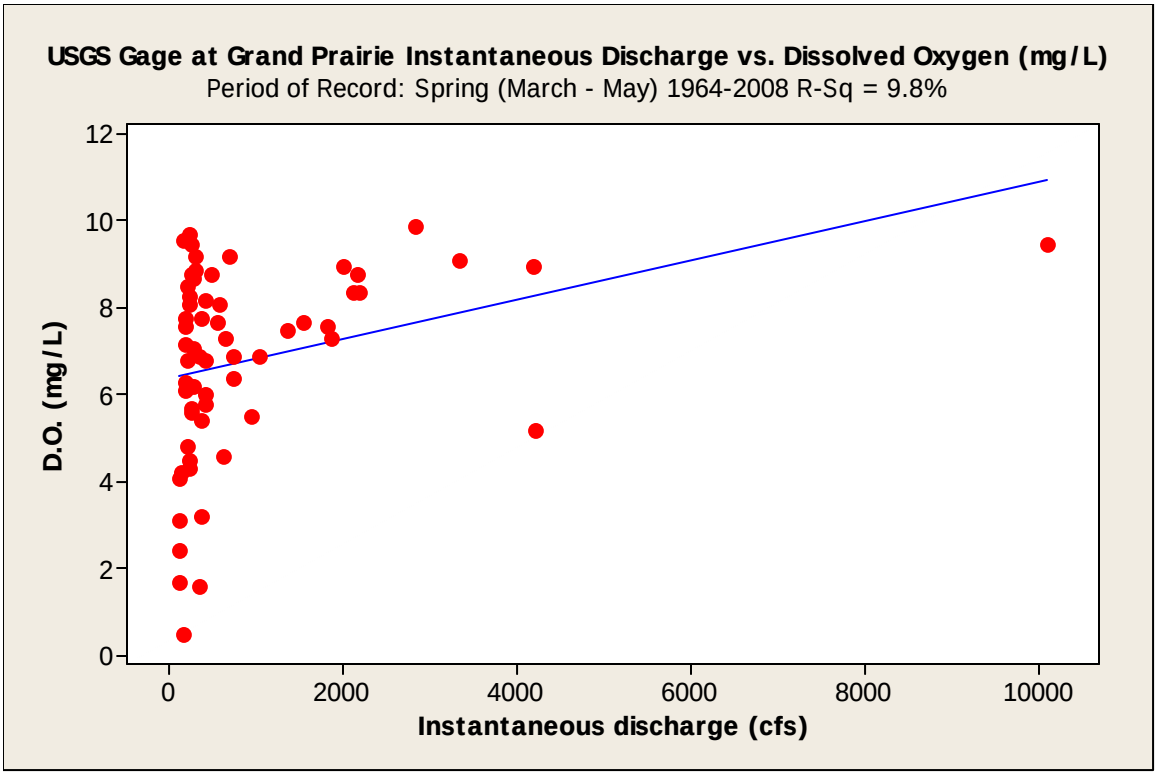


Figure 48. Flow versus spring dissolved oxygen at the West Fork Trinity River at Grand Prairie 08049500 gage during 1964 through 2008.

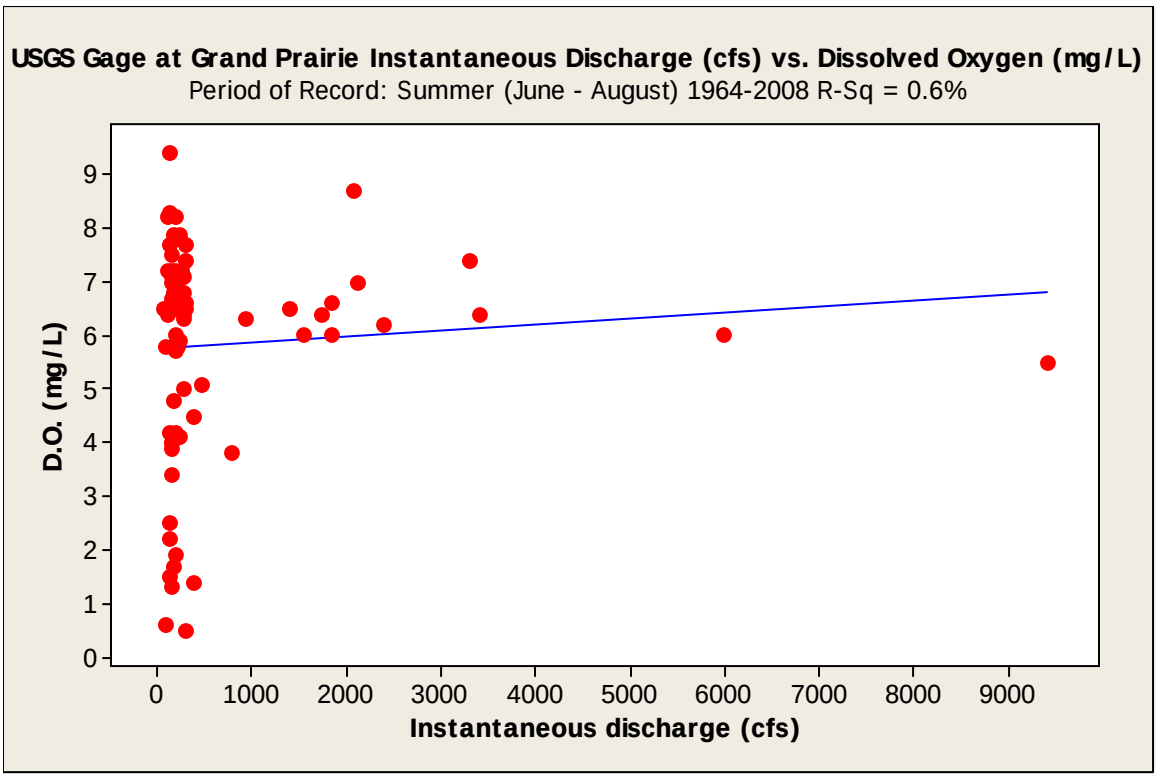


Figure 49. Flow versus summer dissolved oxygen at the West Fork Trinity River at Grand Prairie 08049500 gage during 1964 through 2008.

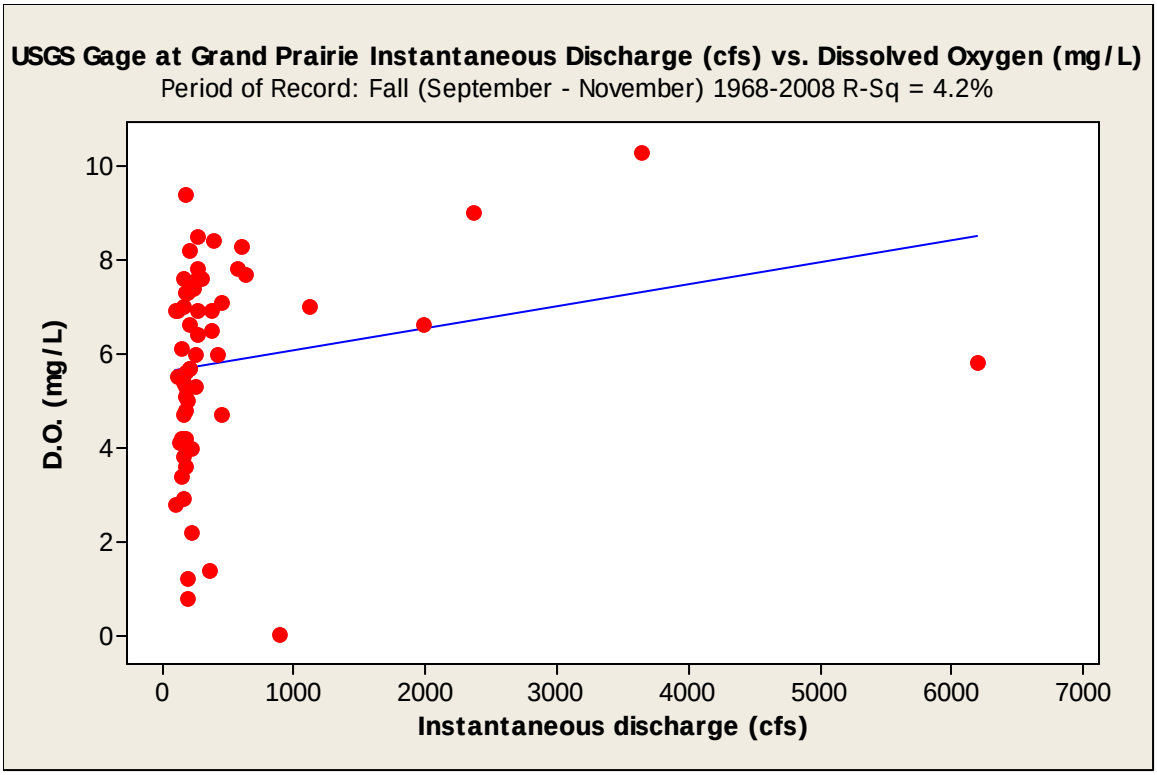


Figure 50. Flow versus fall dissolved oxygen at the West Fork Trinity River at Grand Prairie 08049500 gage during 1964 through 2008.

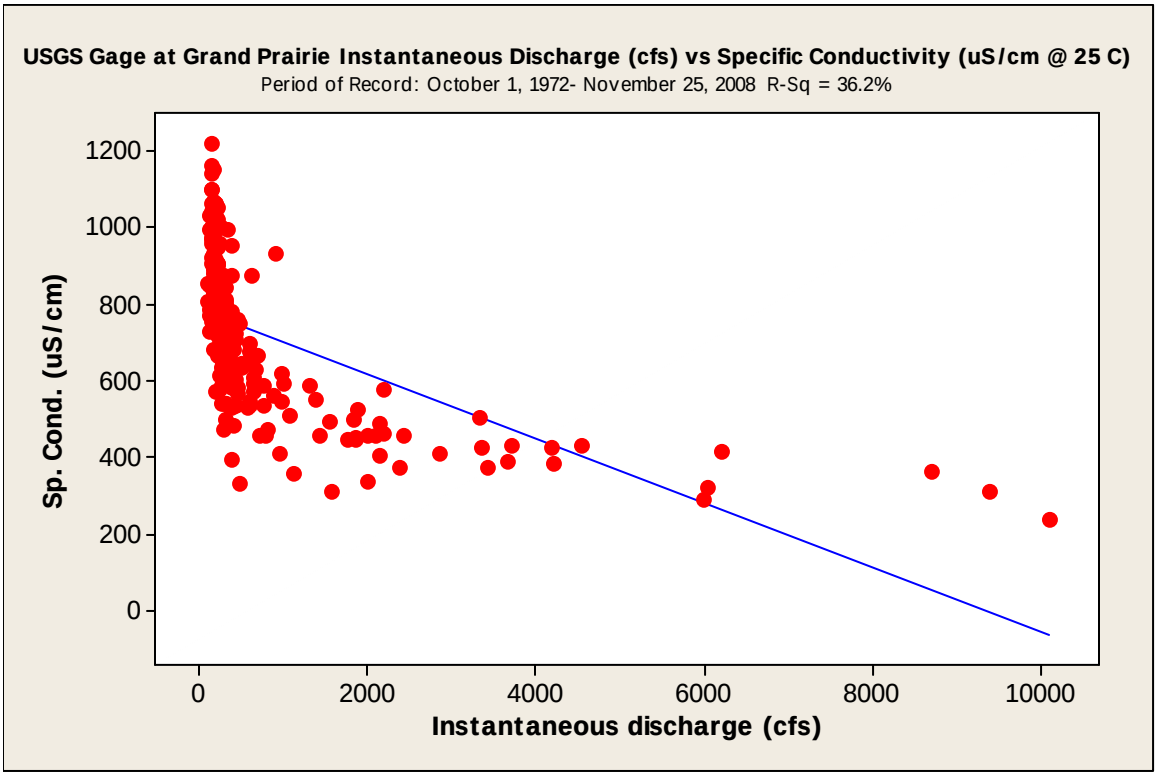


Figure 51. Flow versus specific conductance at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008.

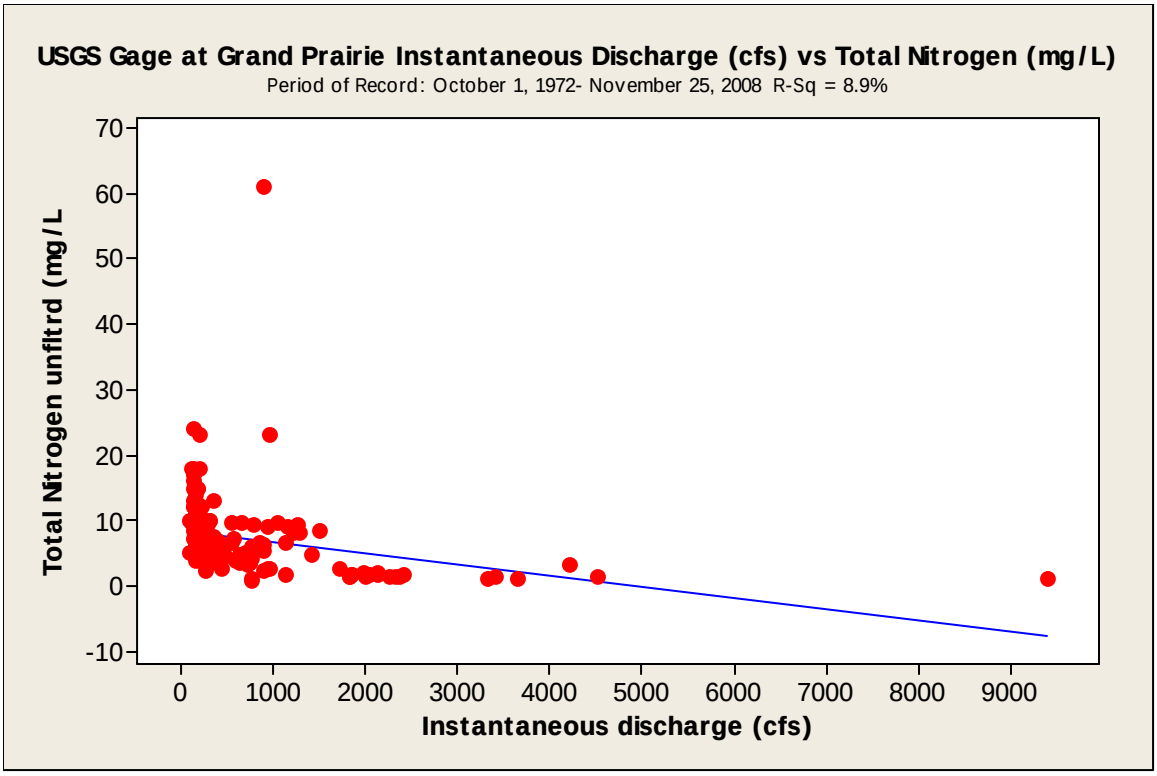


Figure 52. Flow versus total nitrogen at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008.

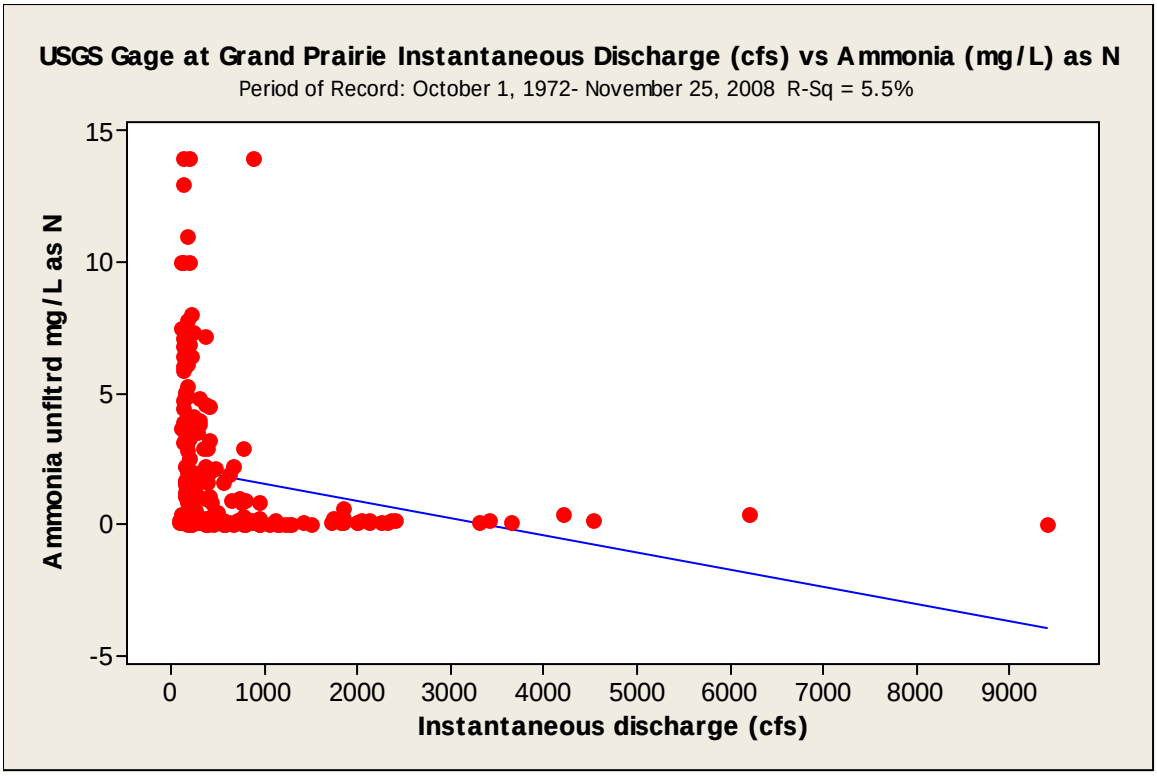


Figure 53. Flow versus ammonia nitrogen at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008.

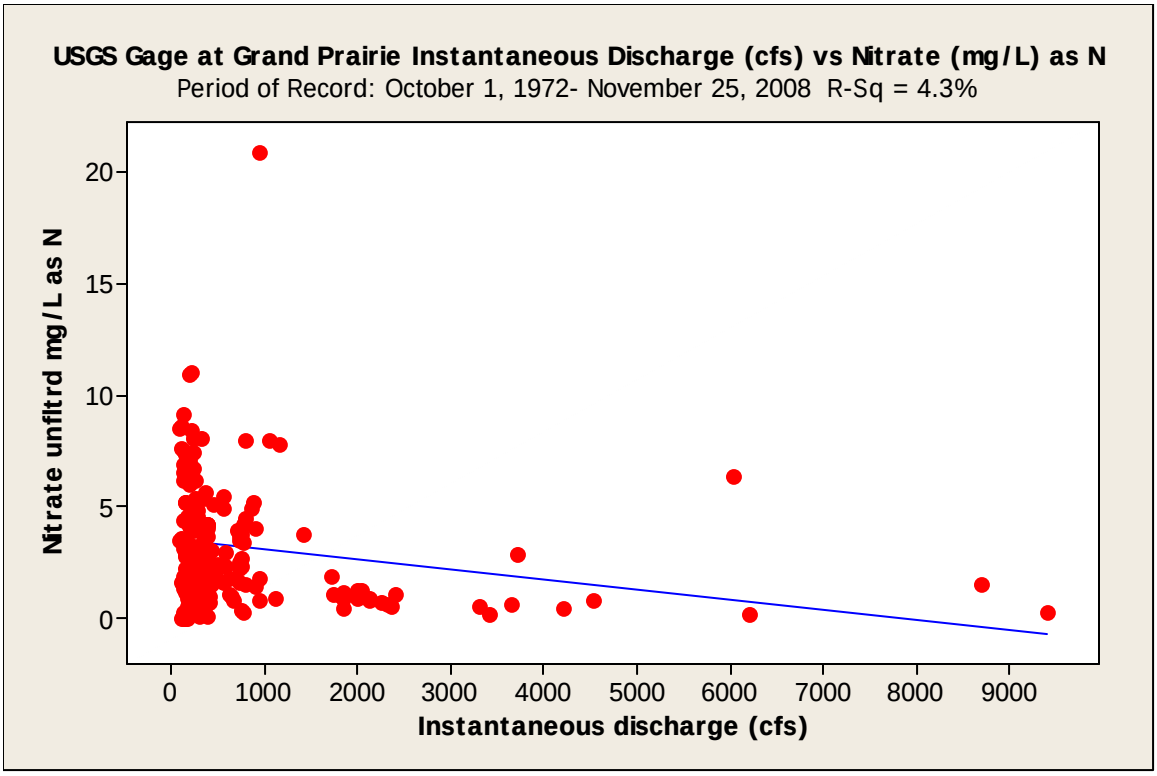


Figure 54. Flow versus nitrate at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008

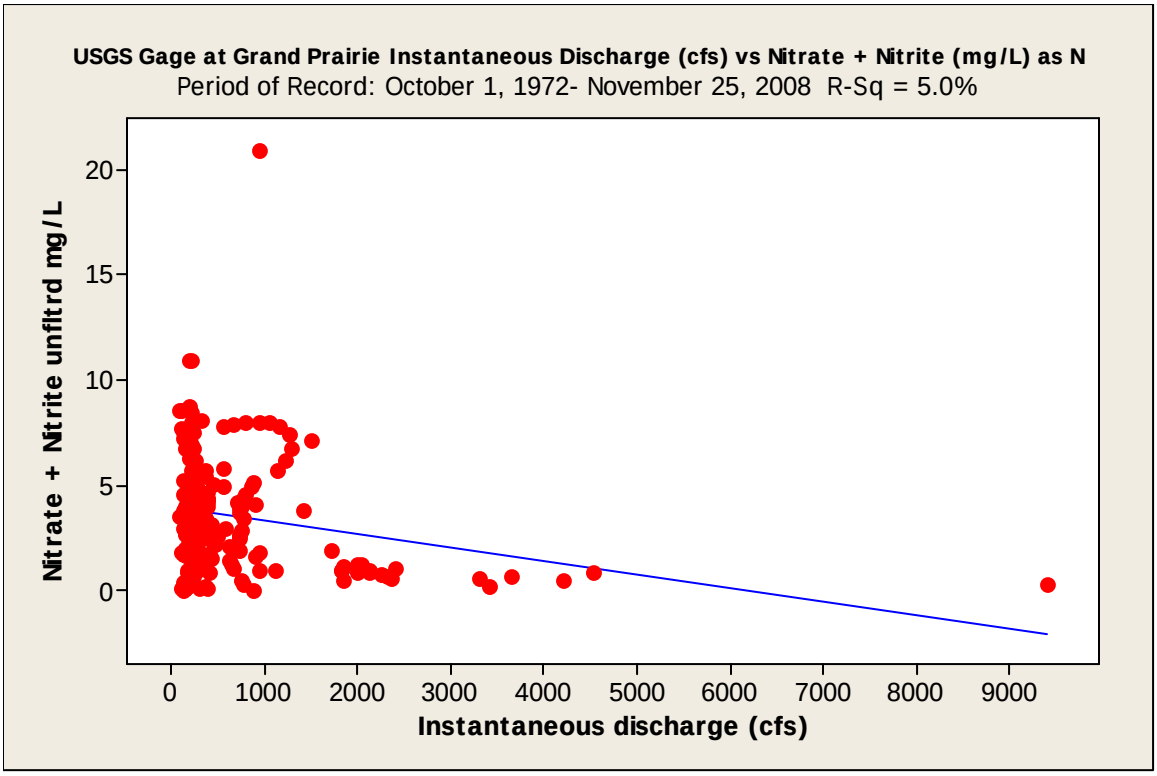


Figure 55. Flow versus nitrate+nitrite at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008

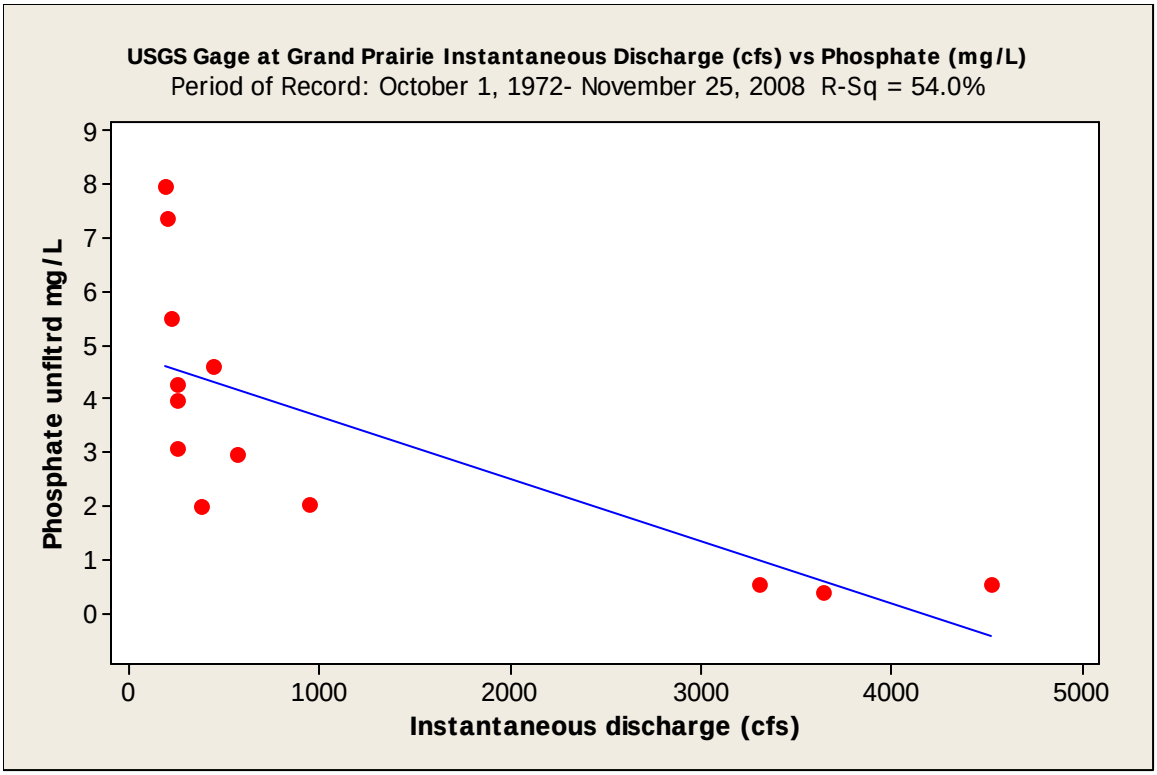


Figure 56. Flow versus phosphate at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008

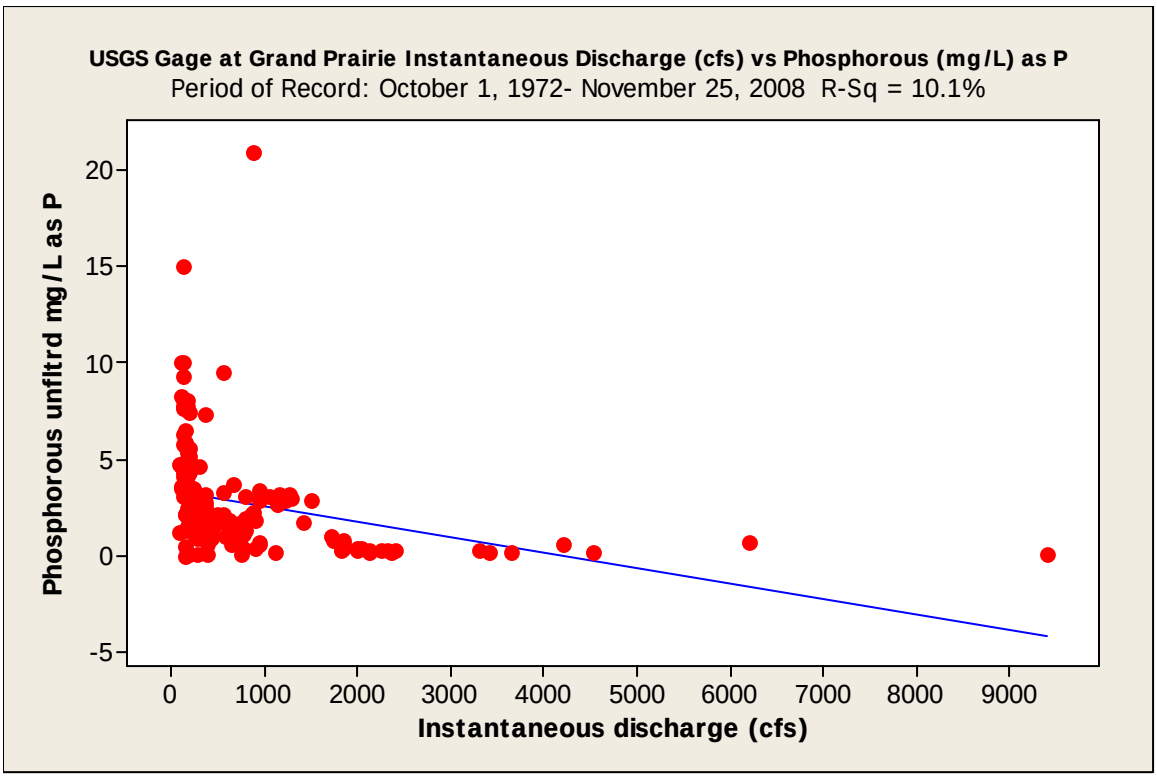


Figure 57. Flow versus phosphorus at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008.

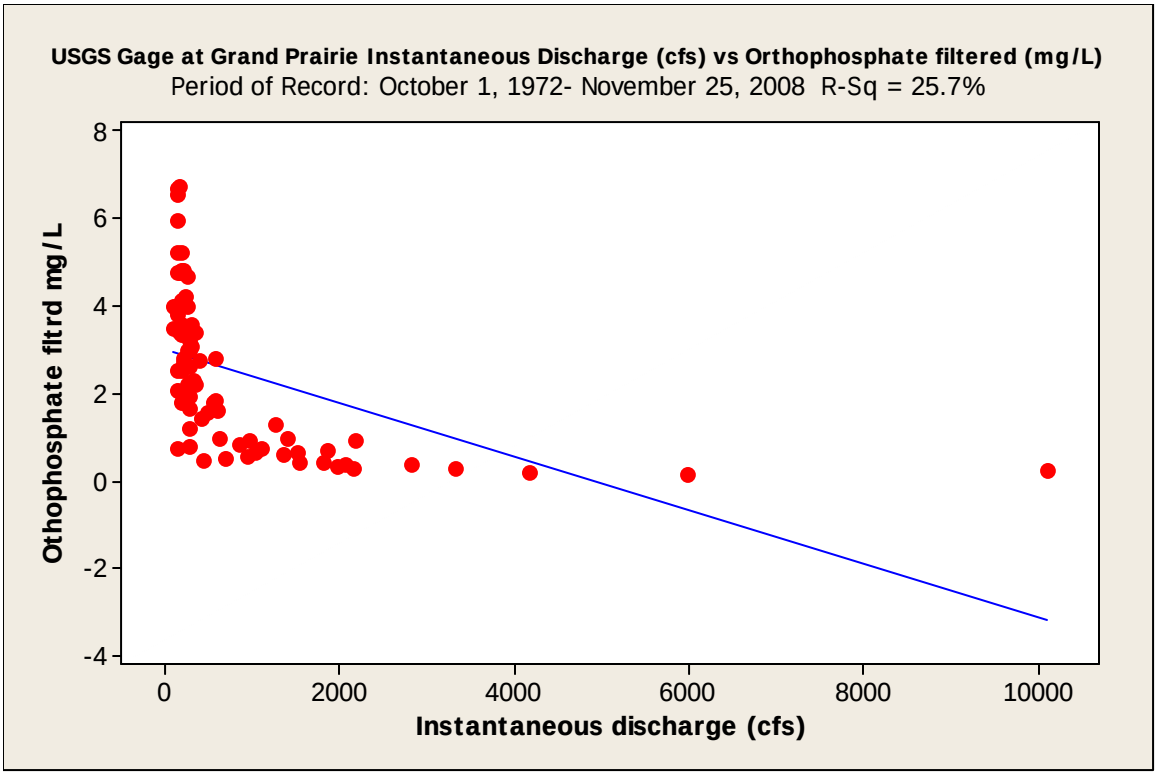


Figure 58. Flow versus orthophosphate at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008.

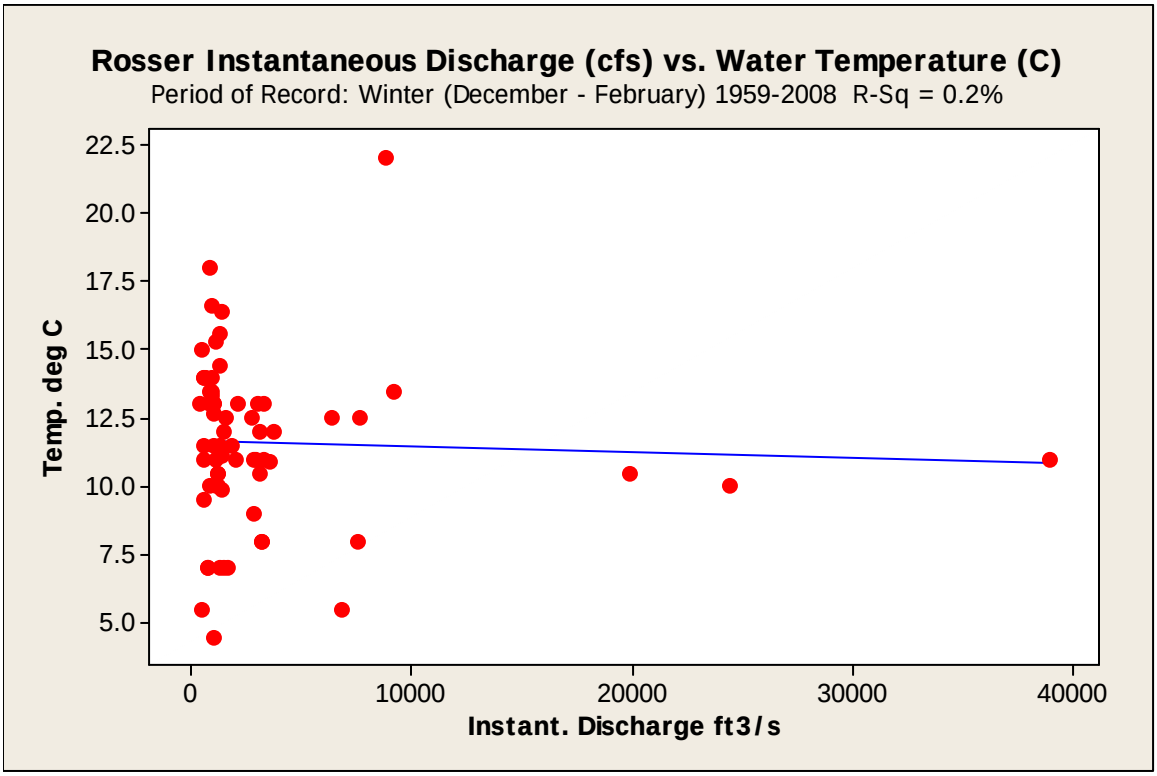


Figure 59. Flow versus winter temperature at the Trinity River at Rosser 08062500 gage during 1959 through 2008.

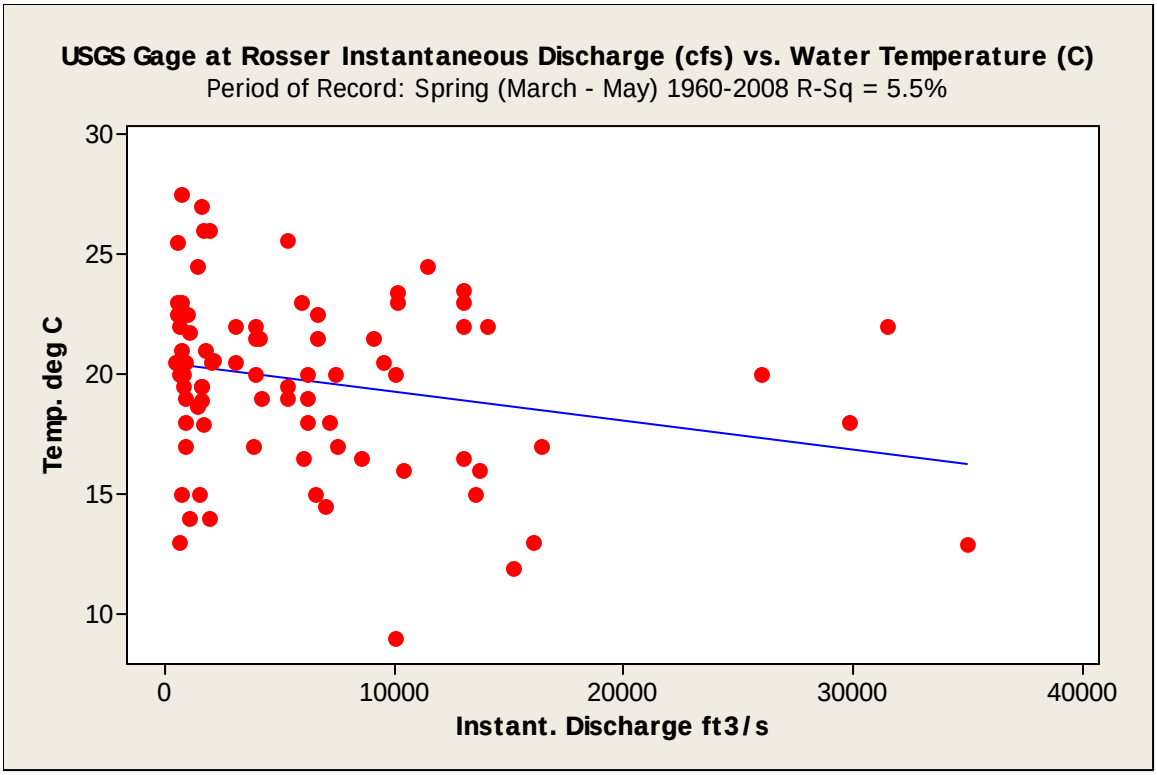


Figure 60. Flow versus spring water temperature at the Trinity River at Rosser 08062500 gage during 1959 through 2008.

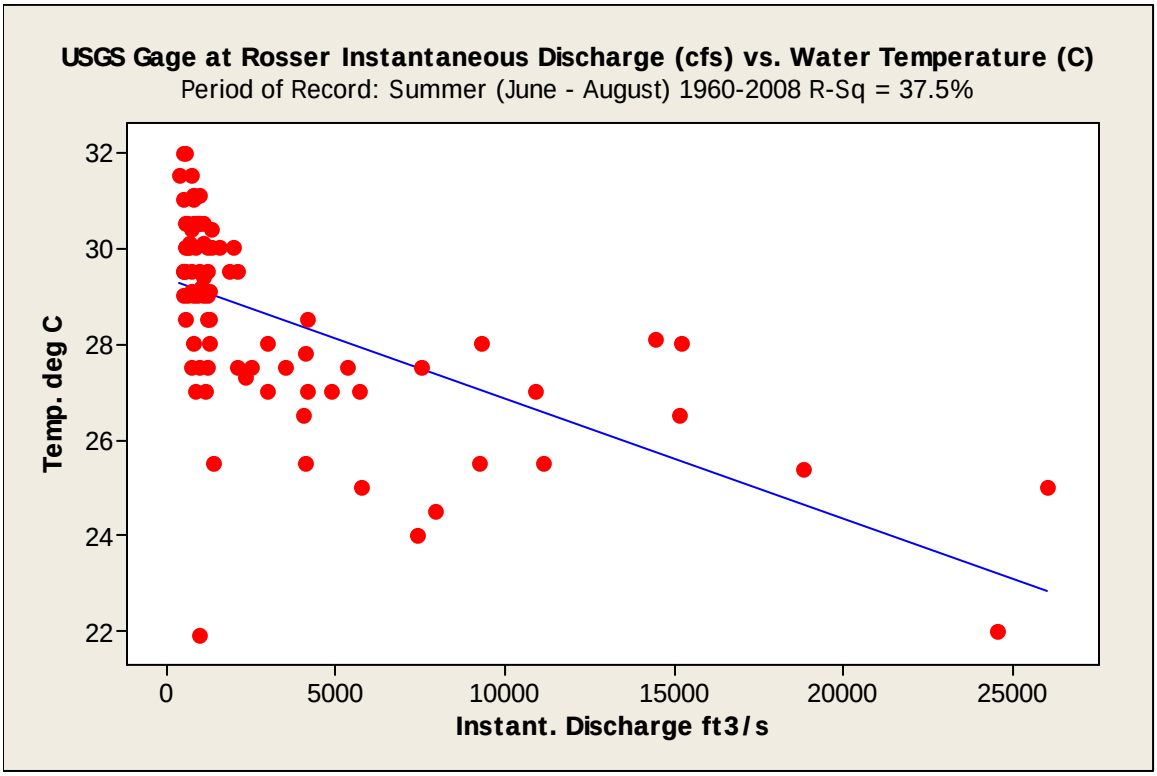


Figure 61. Flow versus summer water temperature at the Trinity River at Rosser 08062500 gage during 1959 through 2008.

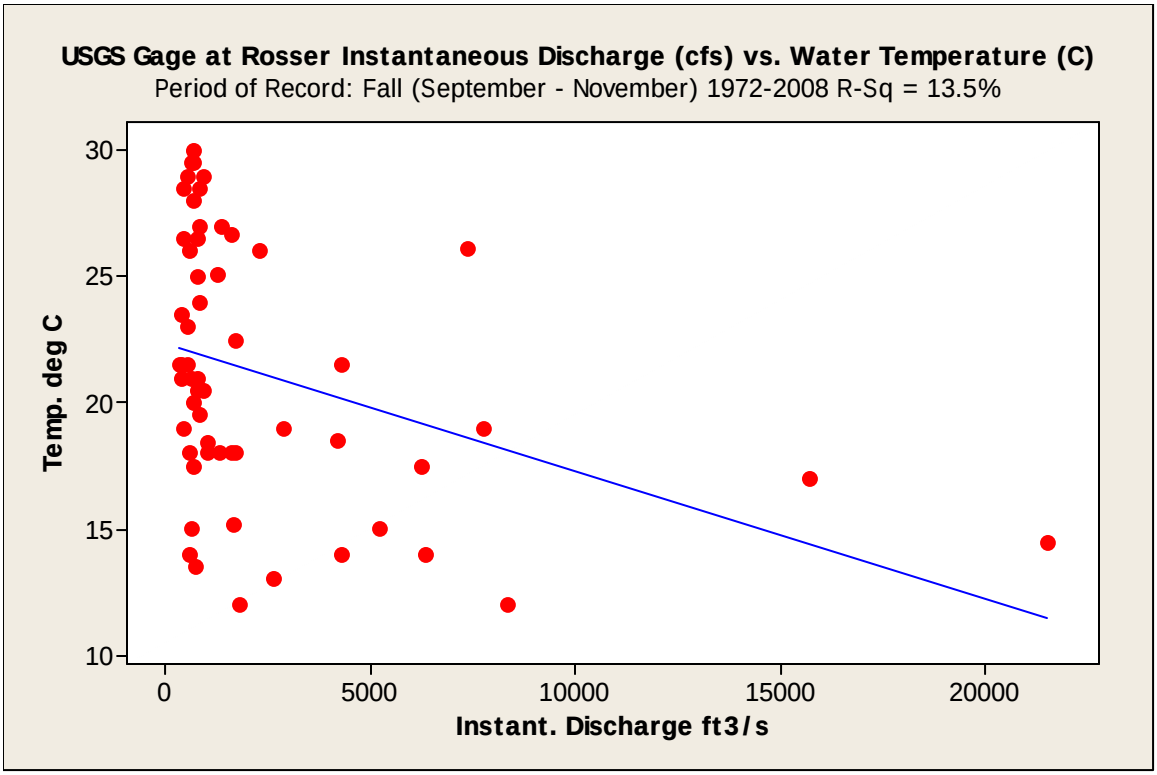


Figure 62. Flow versus fall water temperature at the Trinity River at Rosser 08062500 gage during 1959 through 2008.

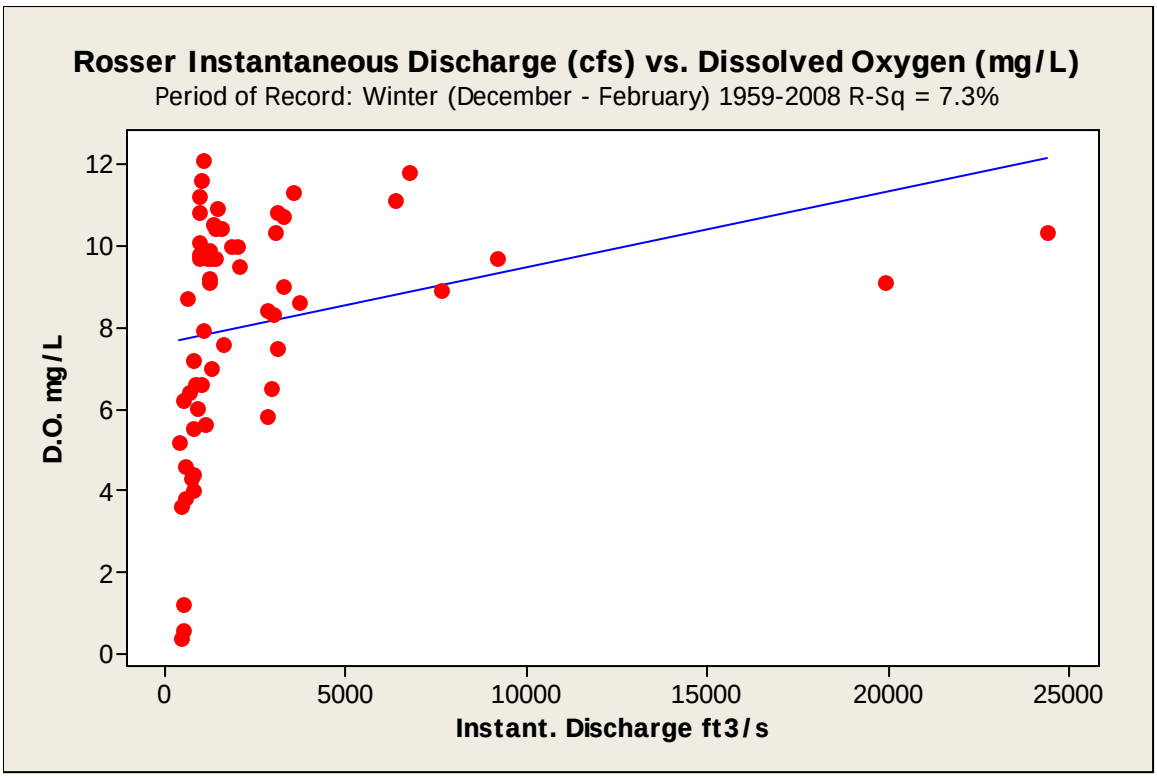


Figure 63. Flow versus winter dissolved oxygen at the Trinity River at Rosser 08062500 gage during 1959 through 2008.

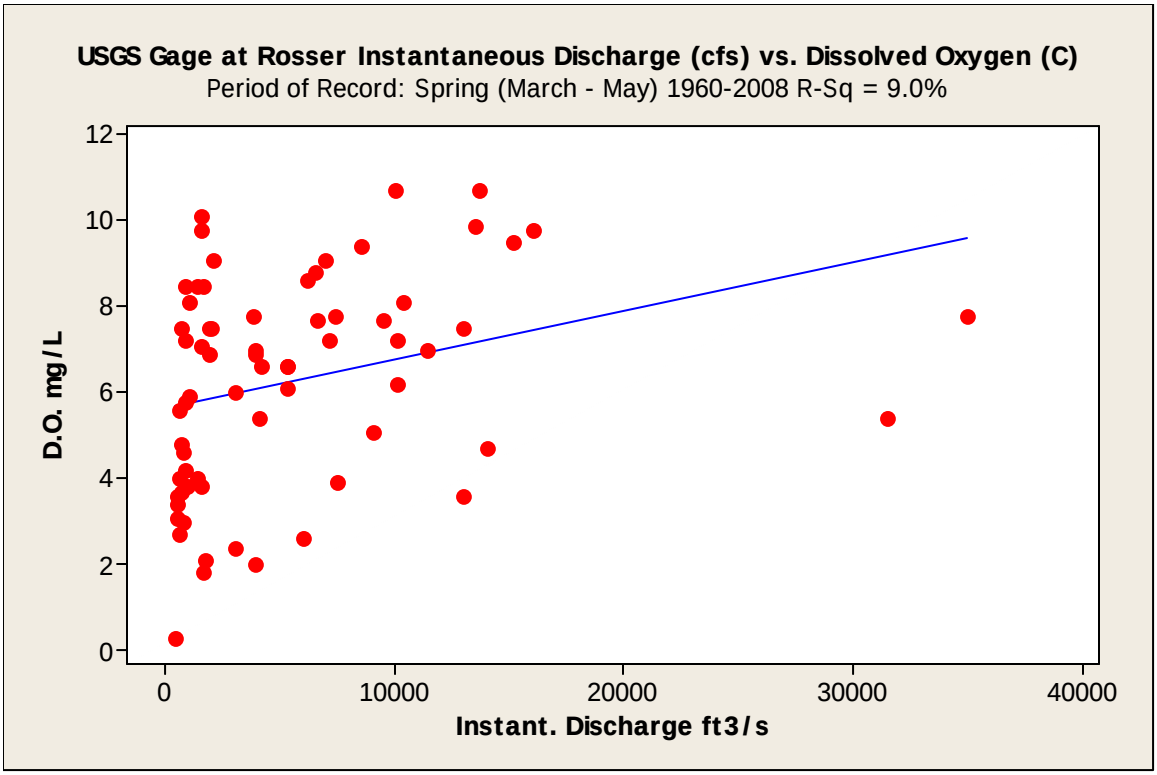


Figure 64. Flow versus spring dissolved oxygen at the Trinity River at Rosser 08062500 gage during 1960 through 2008.

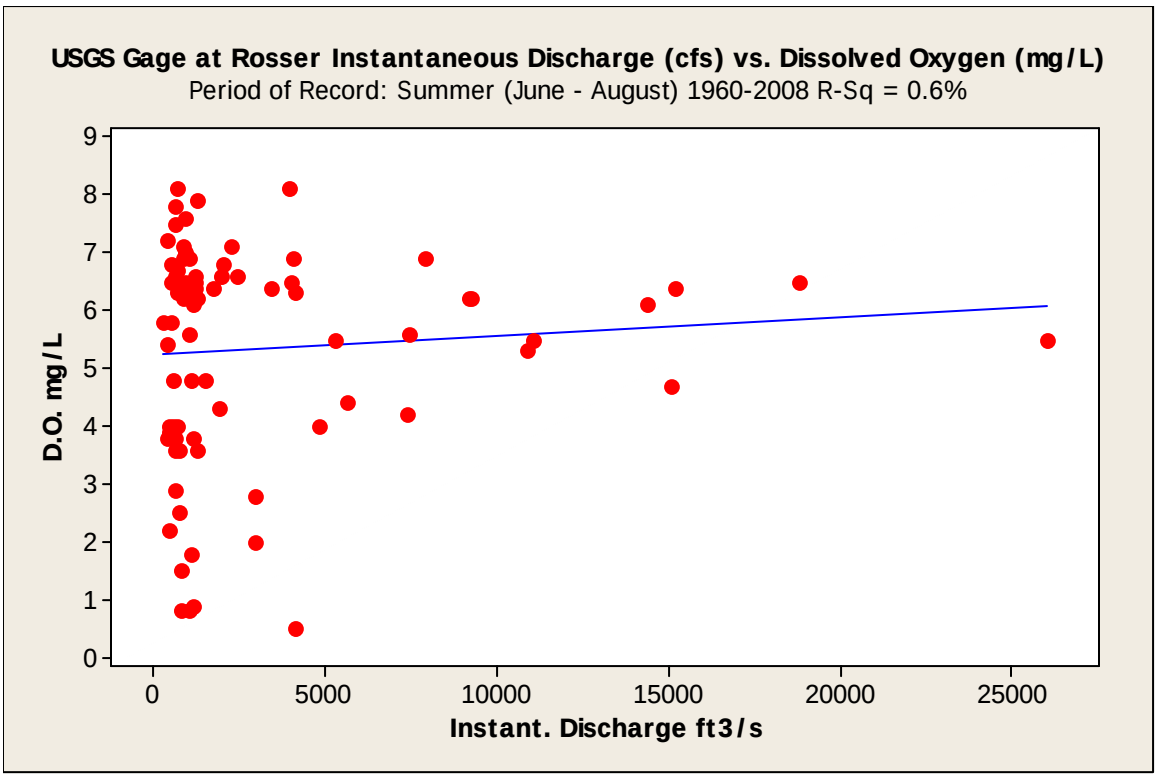


Figure 65. Flow versus summer dissolved oxygen at the Trinity River at Rosser 08062500 gage during 1960 through 2008.

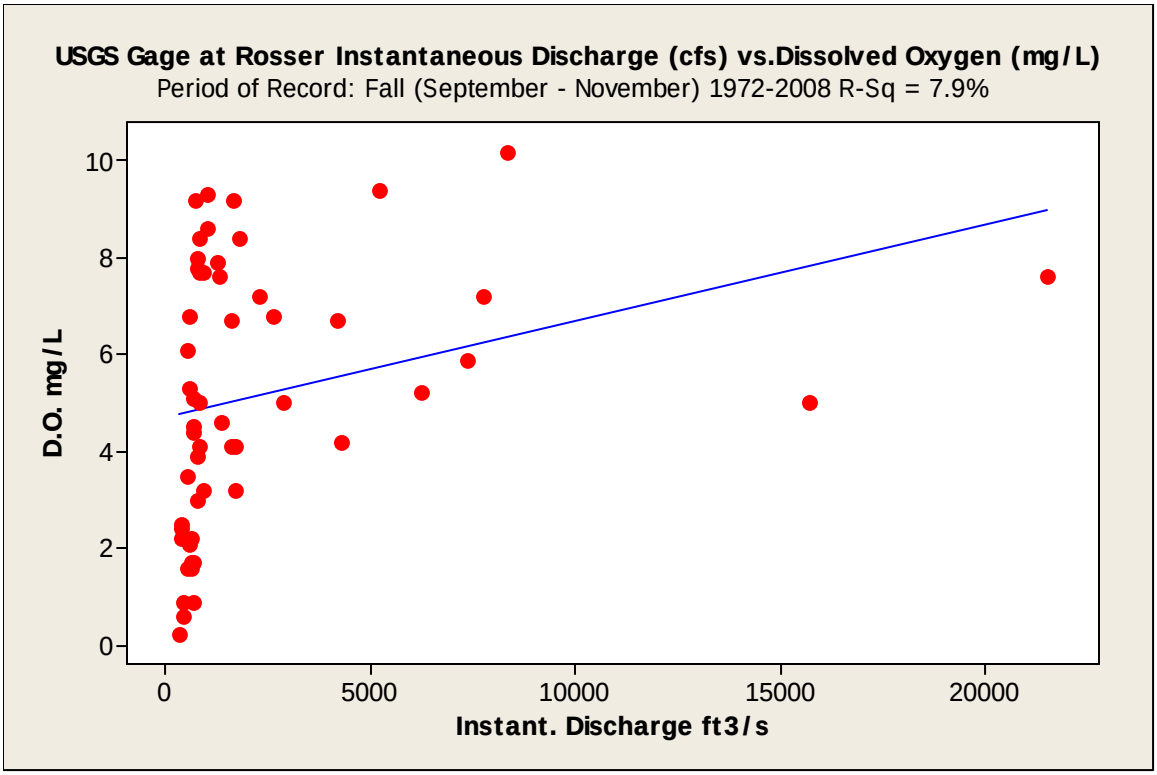


Figure 66. Flow versus fall dissolved oxygen at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

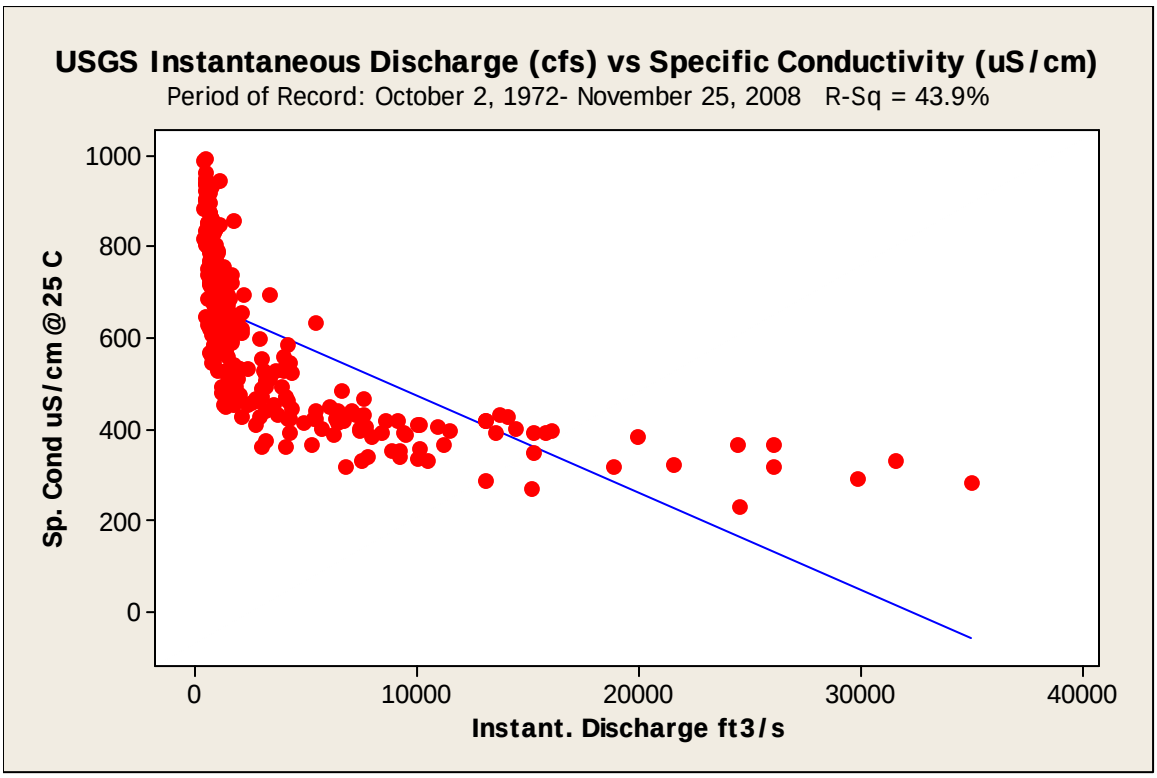


Figure 67. Flow versus specific conductance at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

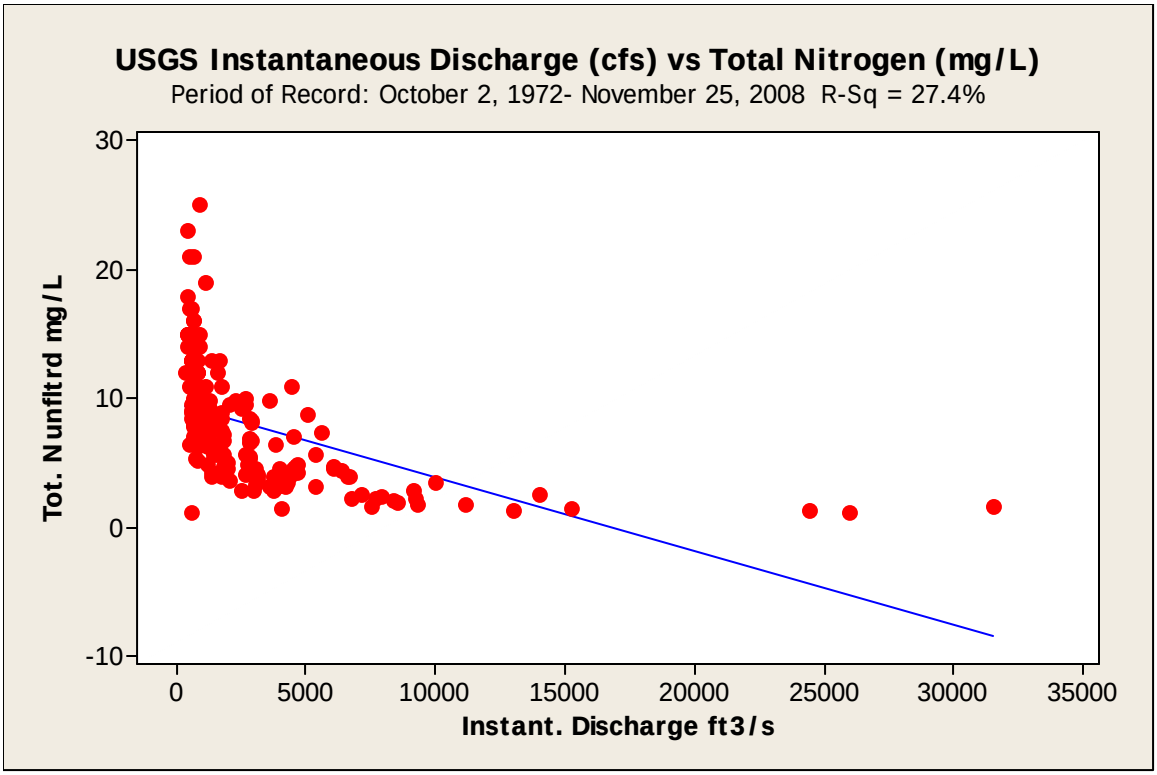


Figure 68. Flow versus total nitrogen (unfiltered) at the Trinity River at Rosser 08062500 gages during 1972 through 2008.

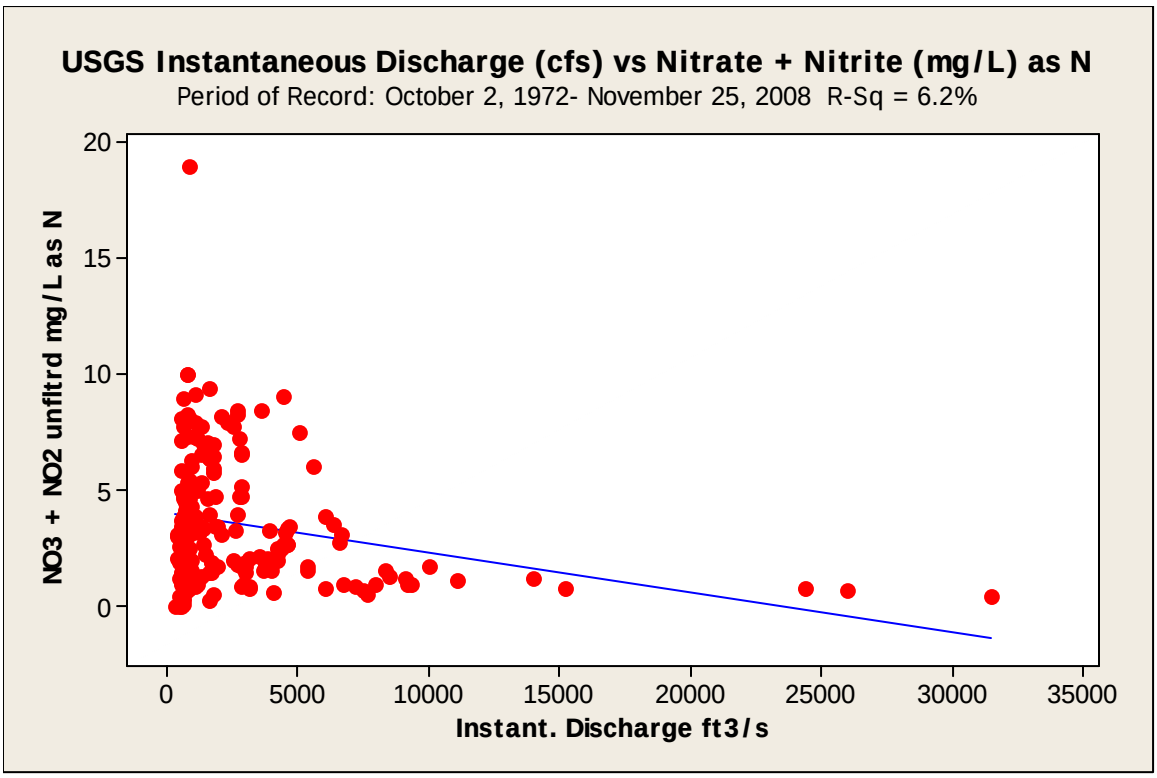


Figure 69. Flow versus nitrate + nitrite as N at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

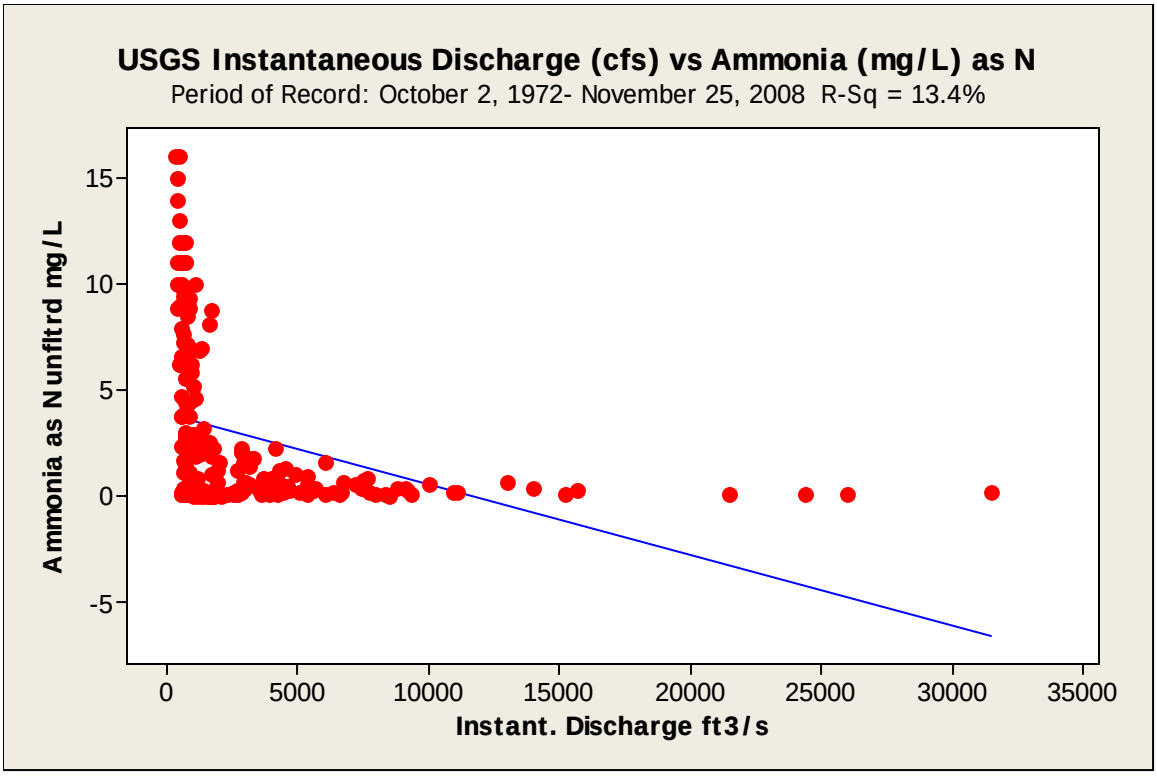


Figure 70. Flow versus ammonia as N unfiltered at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

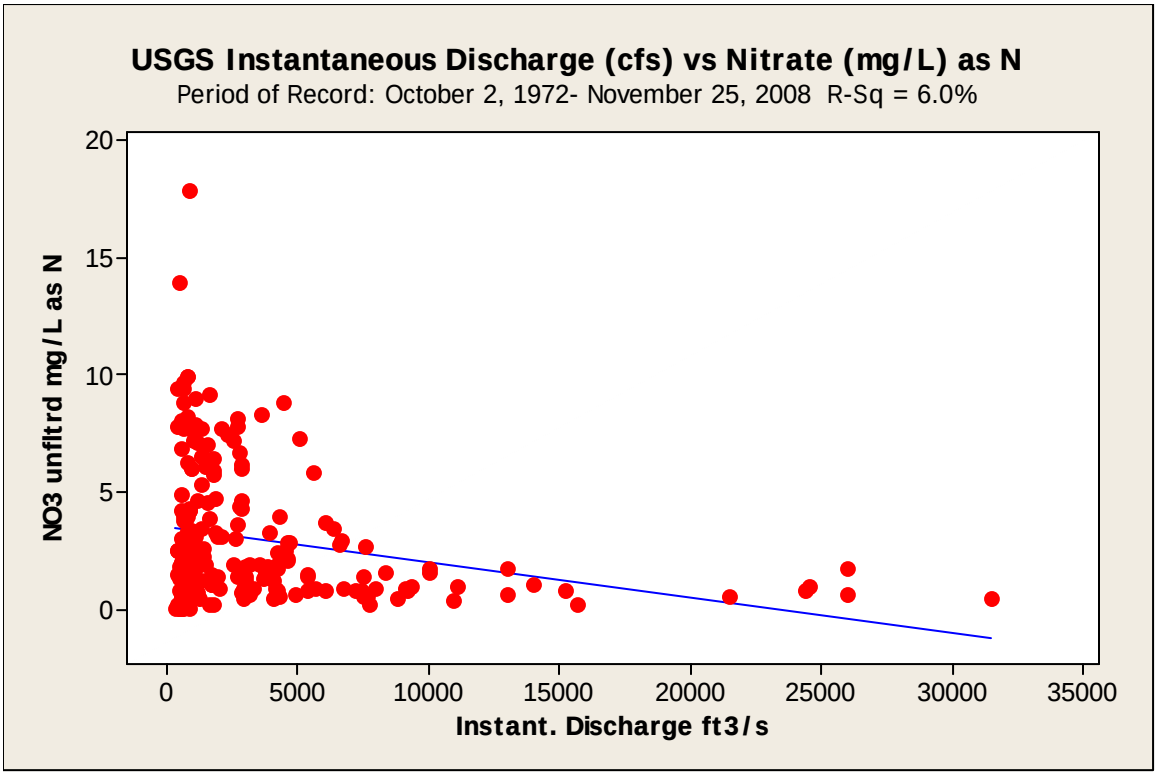


Figure 71. Flow versus nitrate as N unfiltered at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

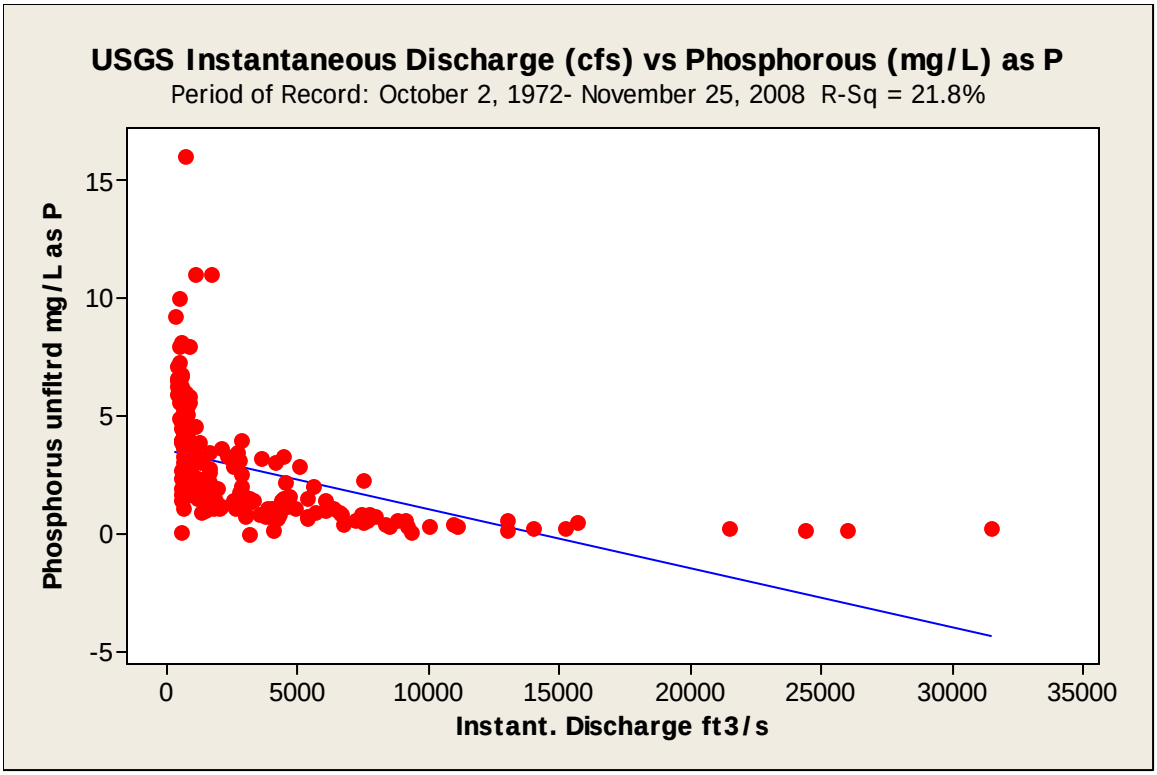


Figure 72. Flow versus phosphate as P unfiltered at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

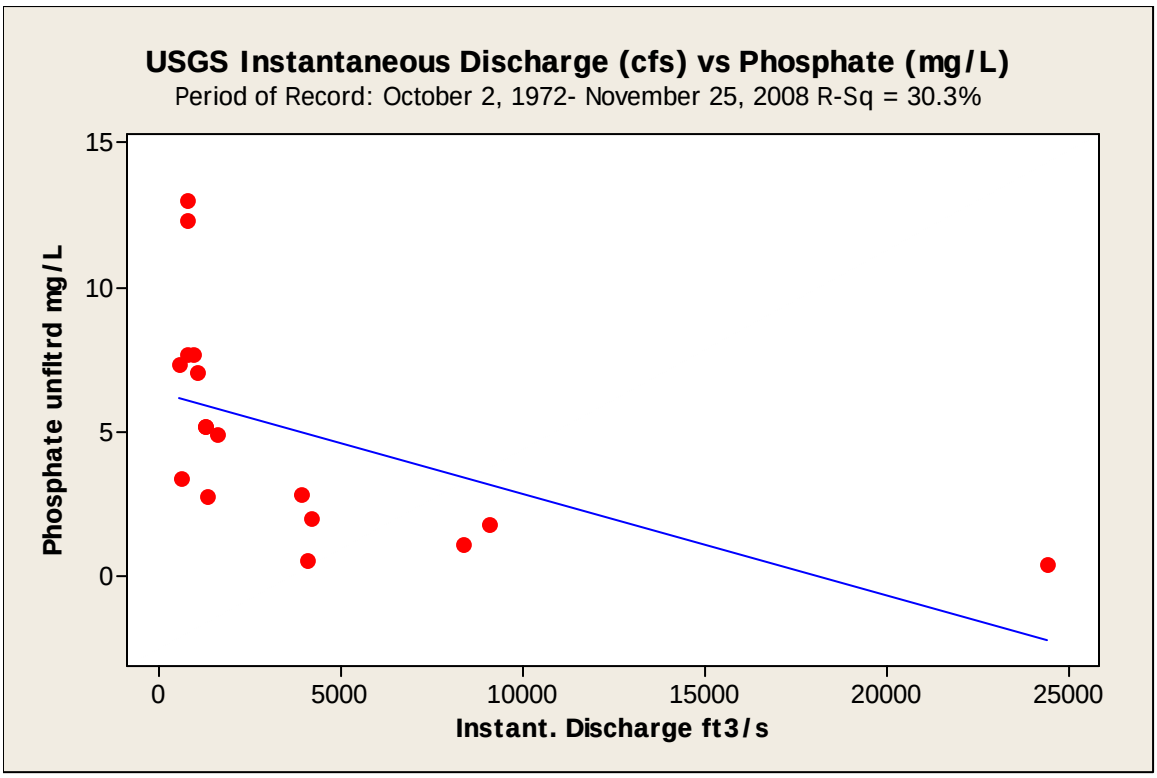


Figure 73. Flow versus phosphate unfiltered at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

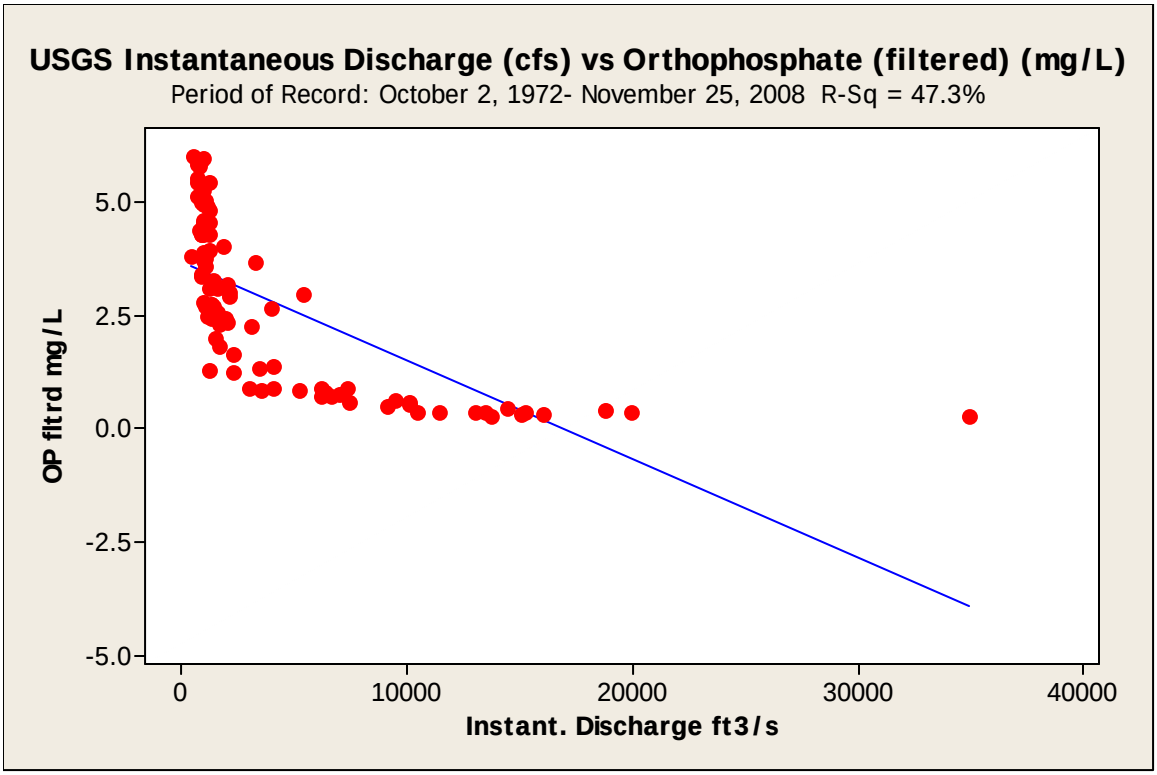


Figure 74. Flow versus filtered orthophosphate at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

During the period of record, summer and to a lesser extent fall water temperatures appear to respond negatively to increases discharges (Figures 75-78). In addition, dissolved oxygen appeared to be positively correlated with increased stream flows (Figures 79-82). This was most evident during the spring and summer months (Figure 81). At flows above 5000 cfs dissolved oxygen was seldom below 4.0 mg/l. The frequency of hypoxia increased when stream flows were below 2000 cfs. At low flows in the spring and summer we also observed very high (>10 mg/l) dissolved oxygen levels. This suggests the potential presence of algal blooms that can cause large diurnal fluctuations in dissolved oxygen. Specific conductance levels generally declined with higher flows reflecting dilutions of dissolved ions (Figure 80). Higher variability was observed at low to moderate flows (1000 to 5000 cfs) reflecting possible effects of increased stormwater runoff and loading of dissolved ions. Similar responses in nutrients were observed at this gage (Figures 84-90). In contrast suspended sediment concentrations increased between 500 and 7000 cfs and peaked at about 8000 cfs declining thereafter at higher flows (Figure 90). This suggests the maximum sediment transport is occurring at intermediate flows. We calculated sediment loading using the same data set and estimated using a quadratic equation that maximum sediment transport occurs at approximately 8000-12000 cfs (Figure 93). During these flows it is likely that erosion and downstream sediment transport would be maximized.

During the winter, spring and fall, water temperature did not fluctuate appreciably with changing flow levels within the river near the Trinity River near Crockett gage (08065350) (Figures 93-96). During the summer when flows were above 10000 cfs water temperature was generally lower (< 28 C). Water temperature during the summer was generally elevated above 28C when streamflow was below 2500 cfs (Figure 95).

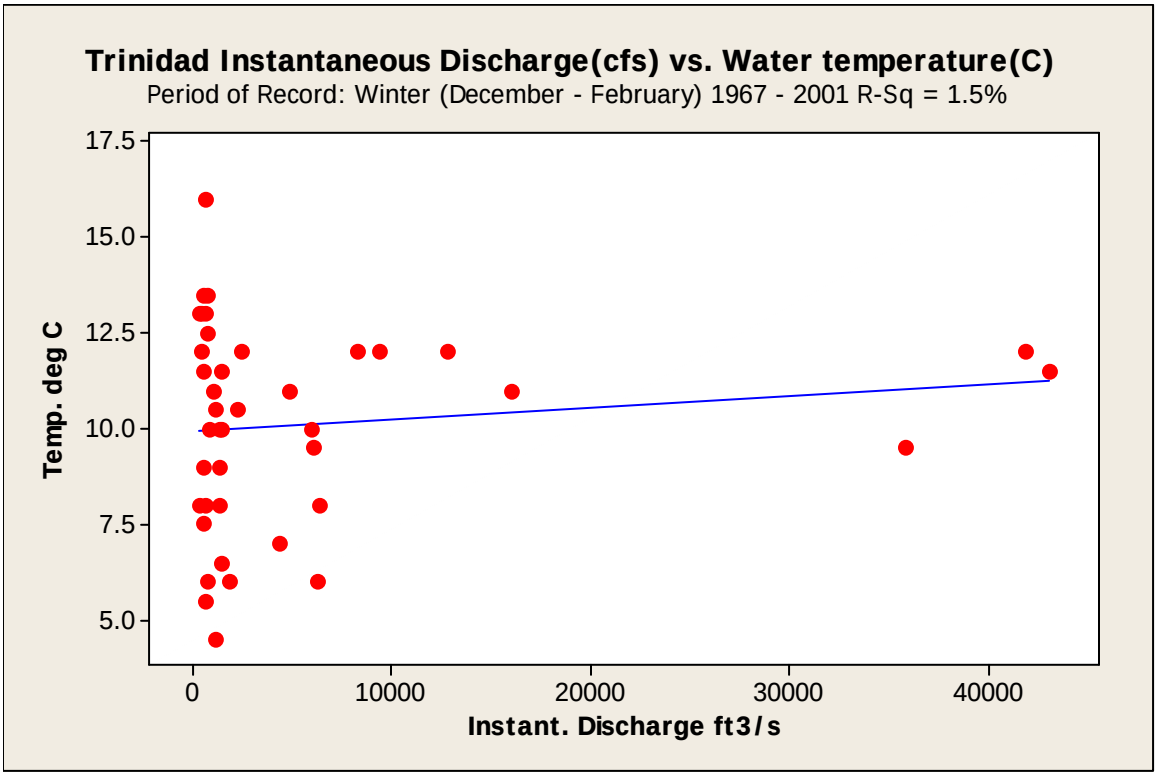


Figure 75. Flow versus winter water temperature at the Trinity River at Trinidad 08062700 gage during 1967 through 2001.

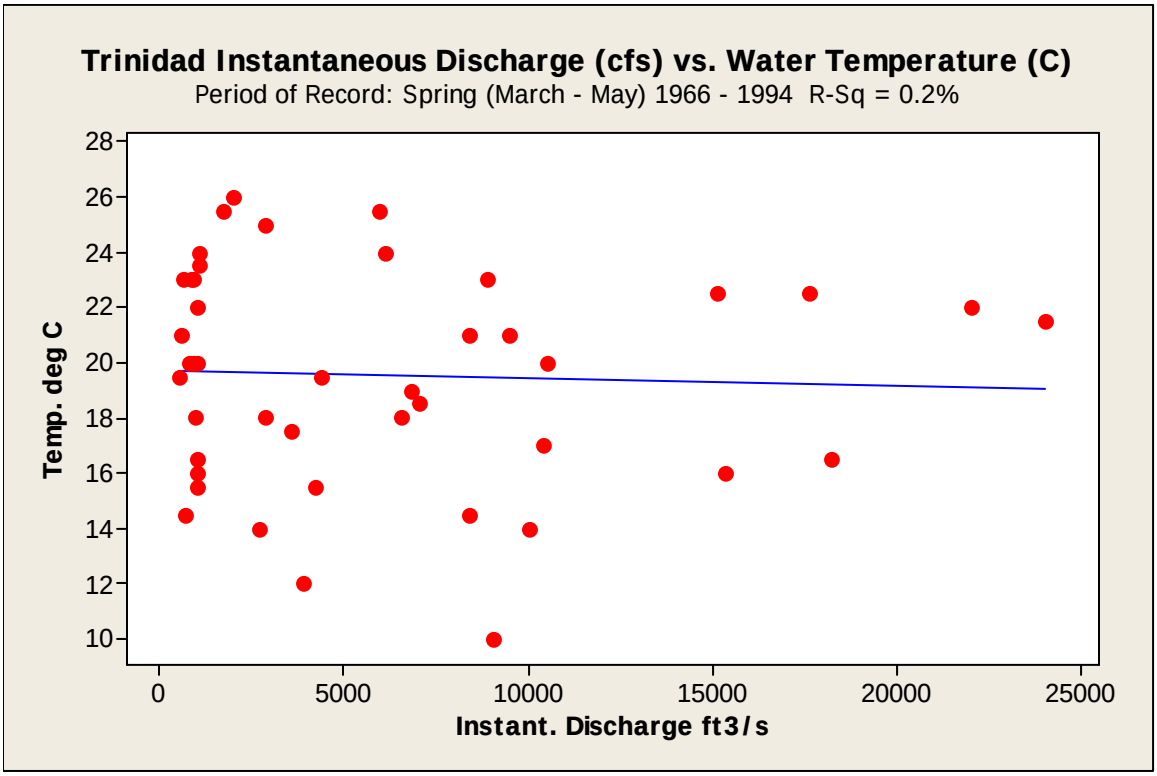


Figure 76. Flow versus spring water temperature at the Trinity River at Trinidad 08062700 gage during 1966 through 1994.

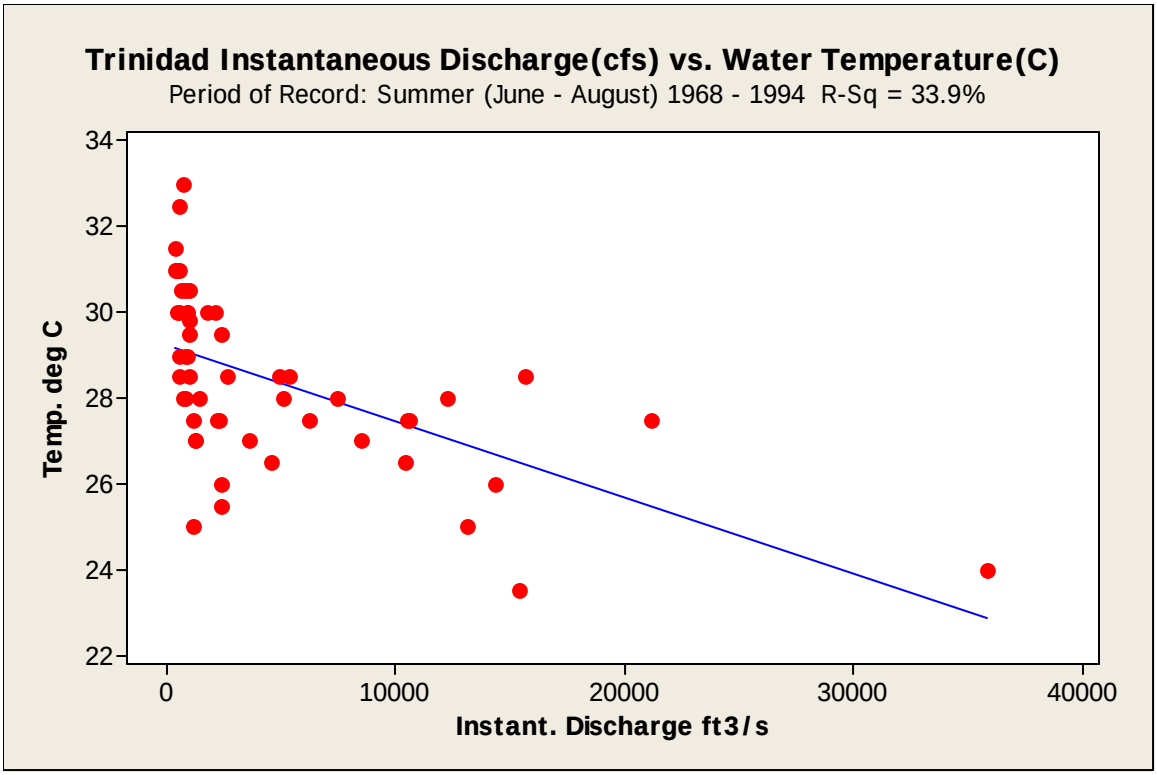


Figure 77. Flow versus summer water temperature at the Trinity River at Trinidad 08062700 gage during 1966 through 1994.

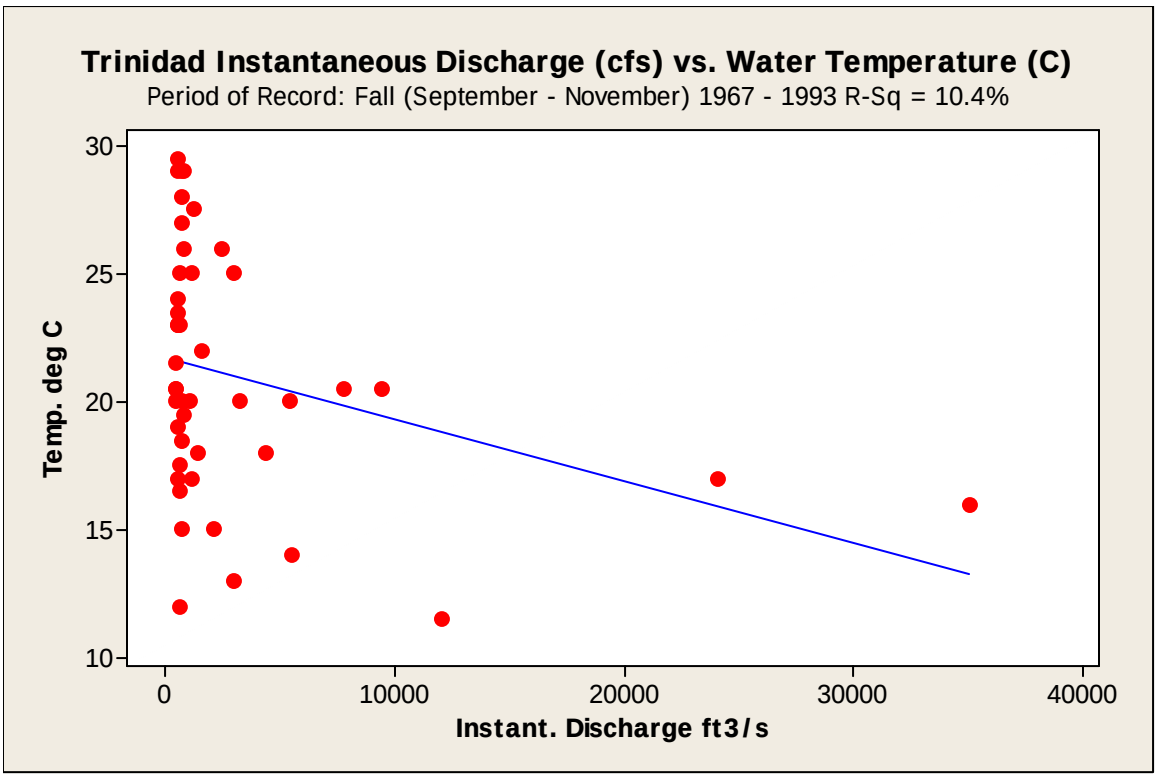


Figure 78. Flow versus fall water temperature at the Trinity River at Trinidad 08062700 gage during 1967 through 1993.

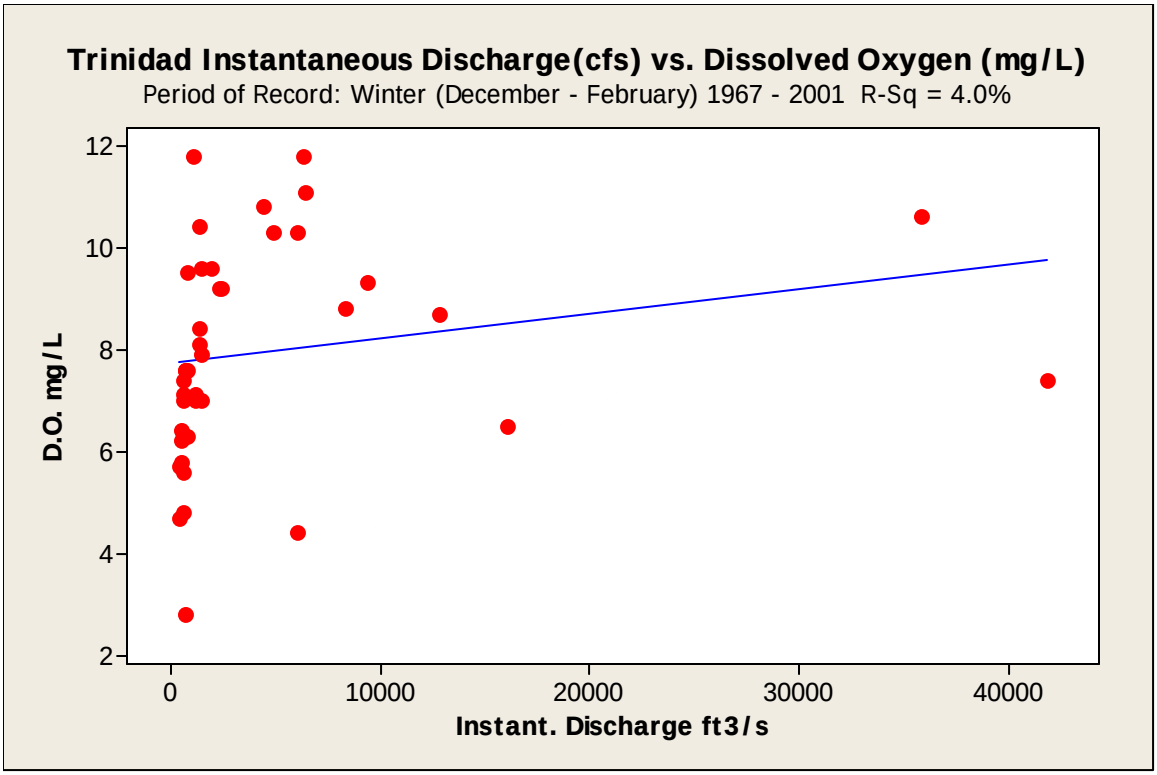


Figure 79. Flow versus winter dissolved oxygen at the Trinity River at Trinidad 08062700 gage during 1967 through 2001.

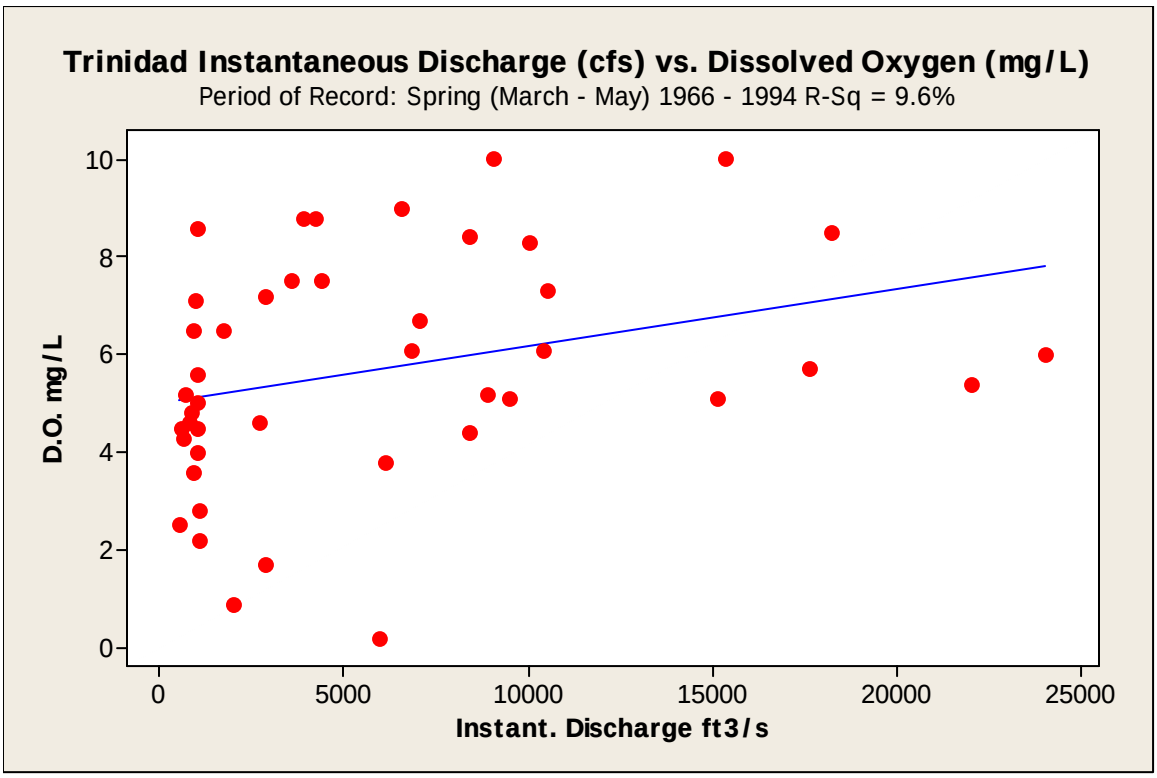


Figure 80. Flow versus spring dissolved oxygen at the Trinity River at Trinidad 08062700 gage during 1967 through 2001.

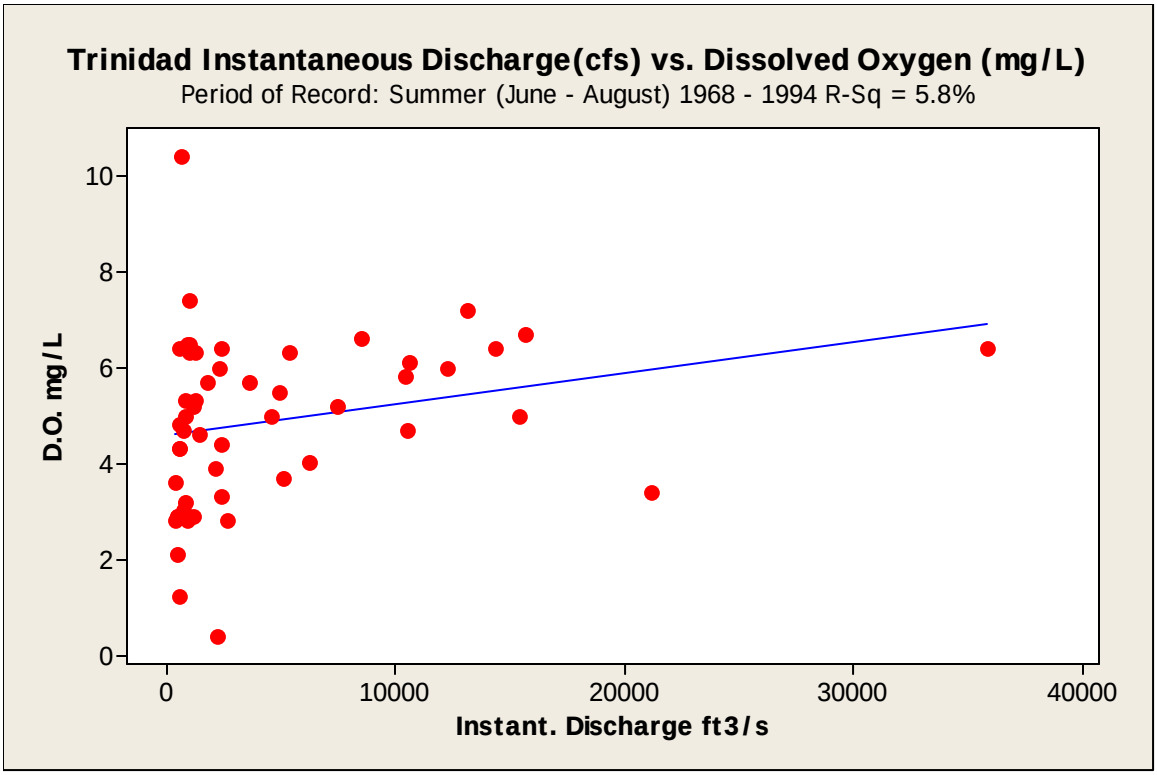


Figure 81. Flow versus summer dissolved oxygen at the Trinity River at Trinidad 08062700 gage during 1968 through 1994.

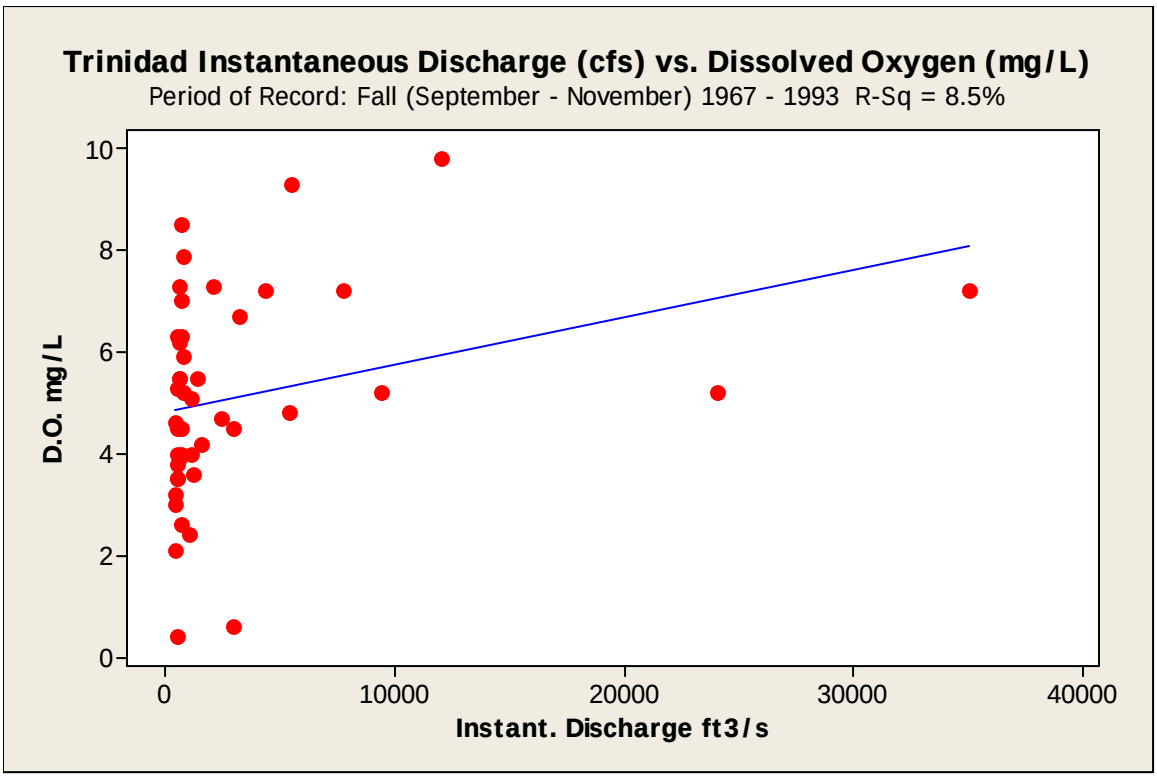


Figure 82. Flow versus fall dissolved oxygen at the Trinity River at Trinidad 08062700 gage during 1968 through 1994.

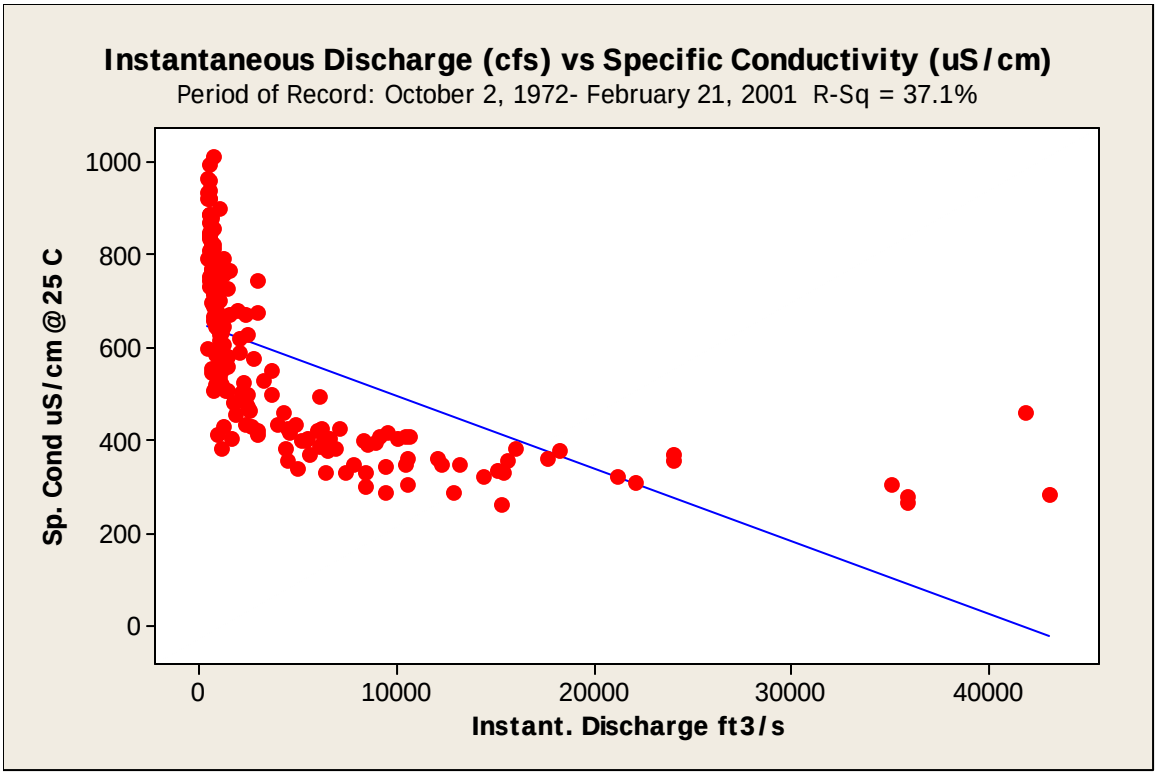


Figure 83. Flow versus specific conductance at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

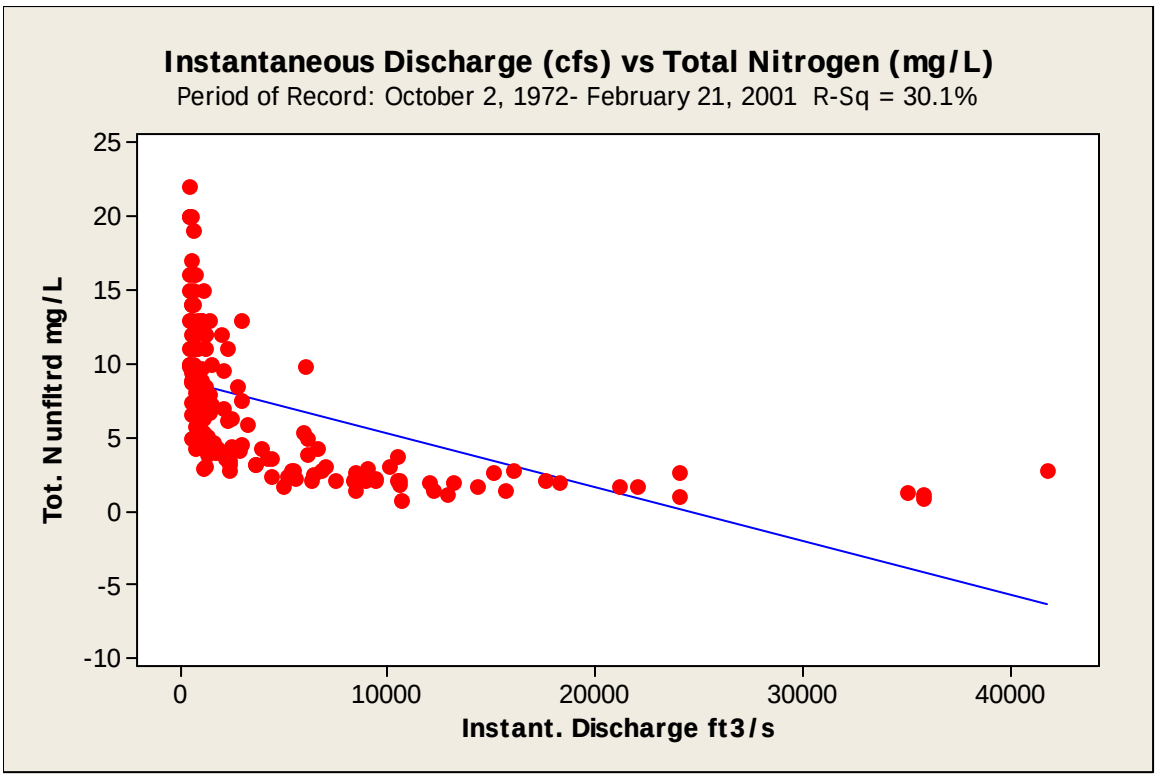


Figure 84. Flow versus total nitrogen unfiltered at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

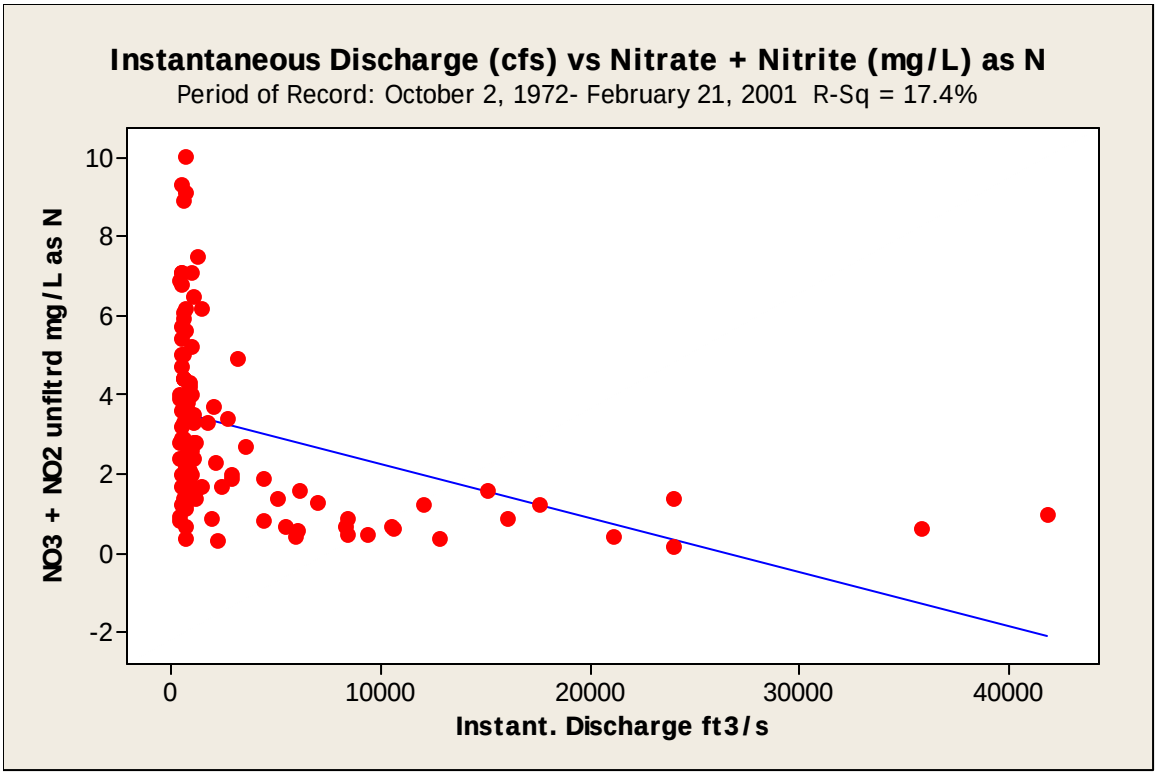


Figure 85. Flow versus nitrate + nitrite as N unfiltered at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

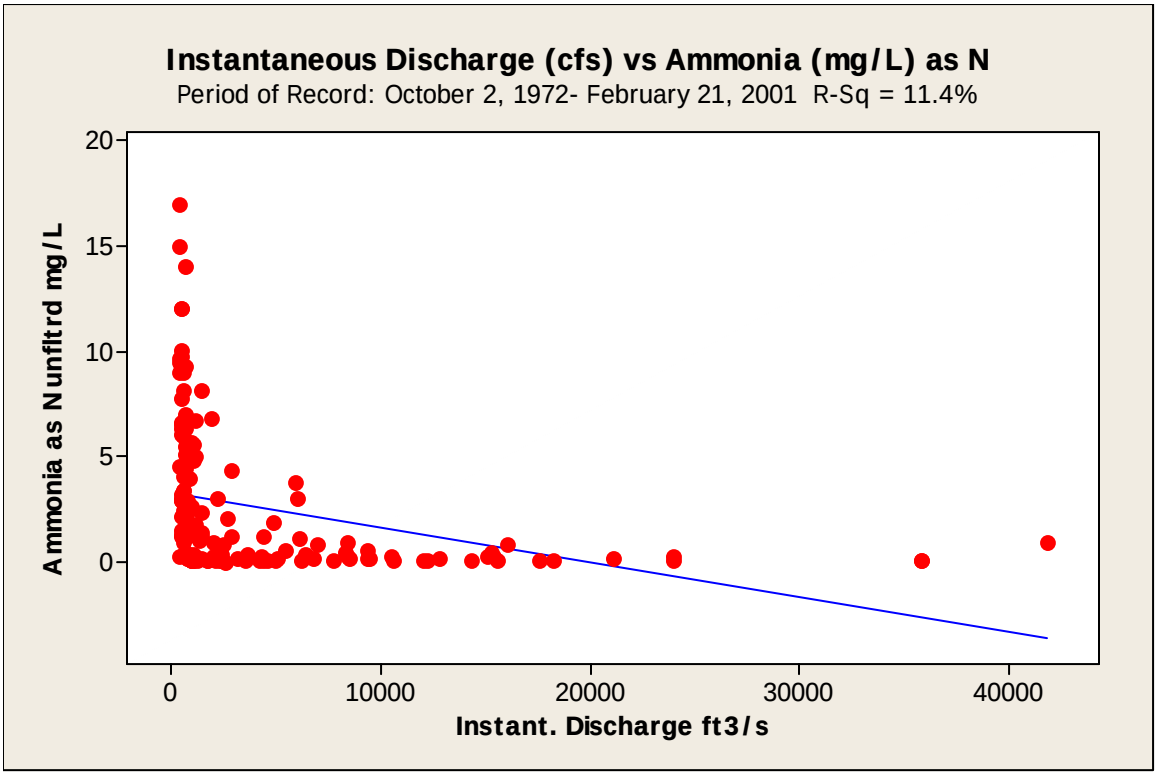


Figure 86. Flow versus ammonia as N unfiltered at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

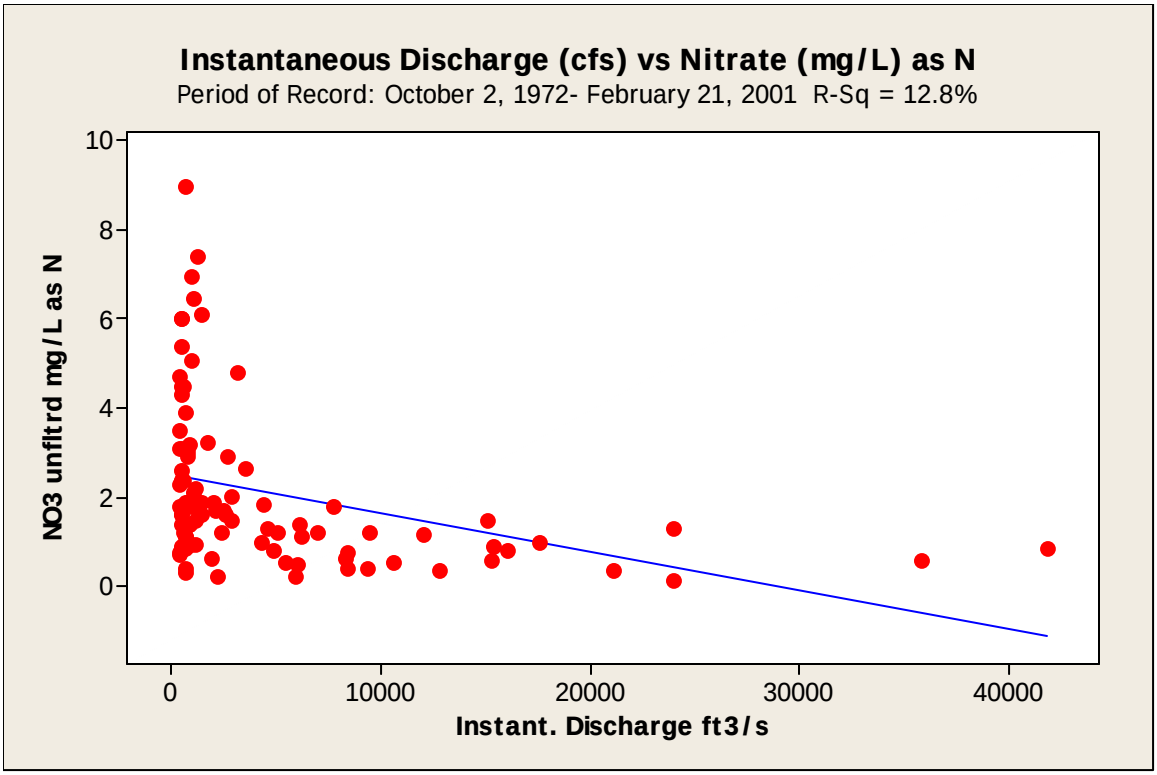


Figure 87. Flow versus nitrate as N unfiltered at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

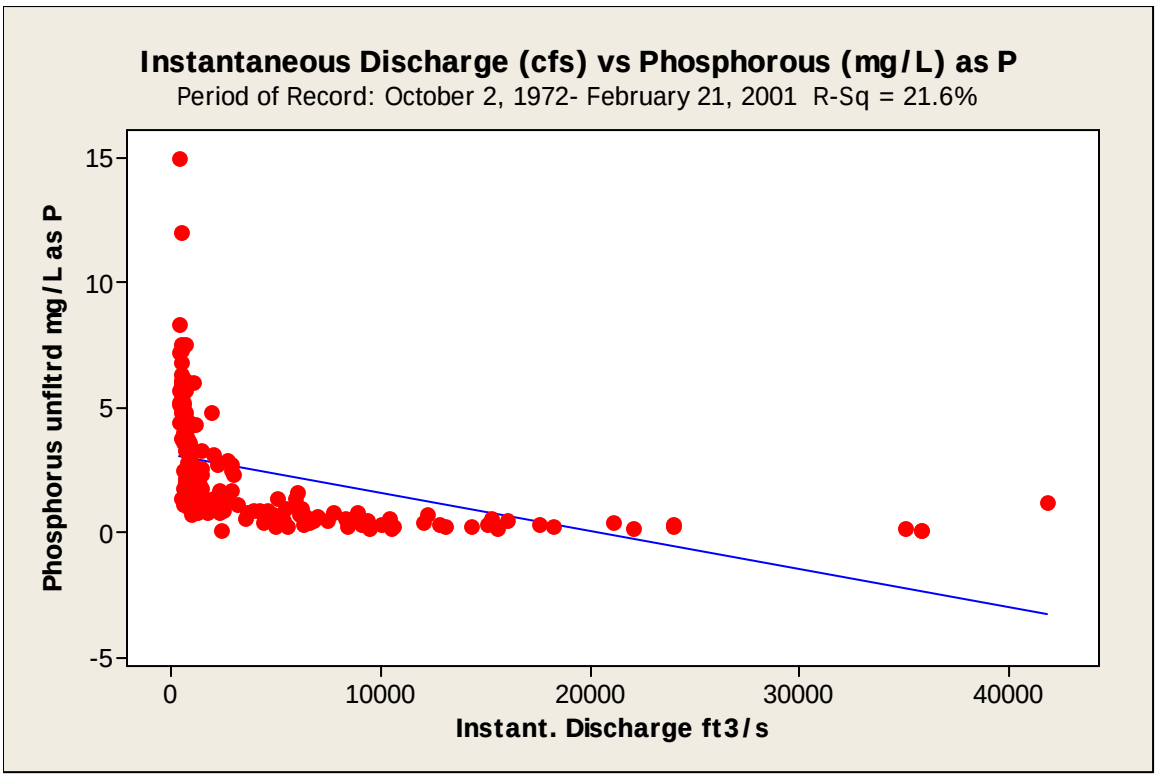


Figure 88. Flow versus phosphorus unfiltered at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

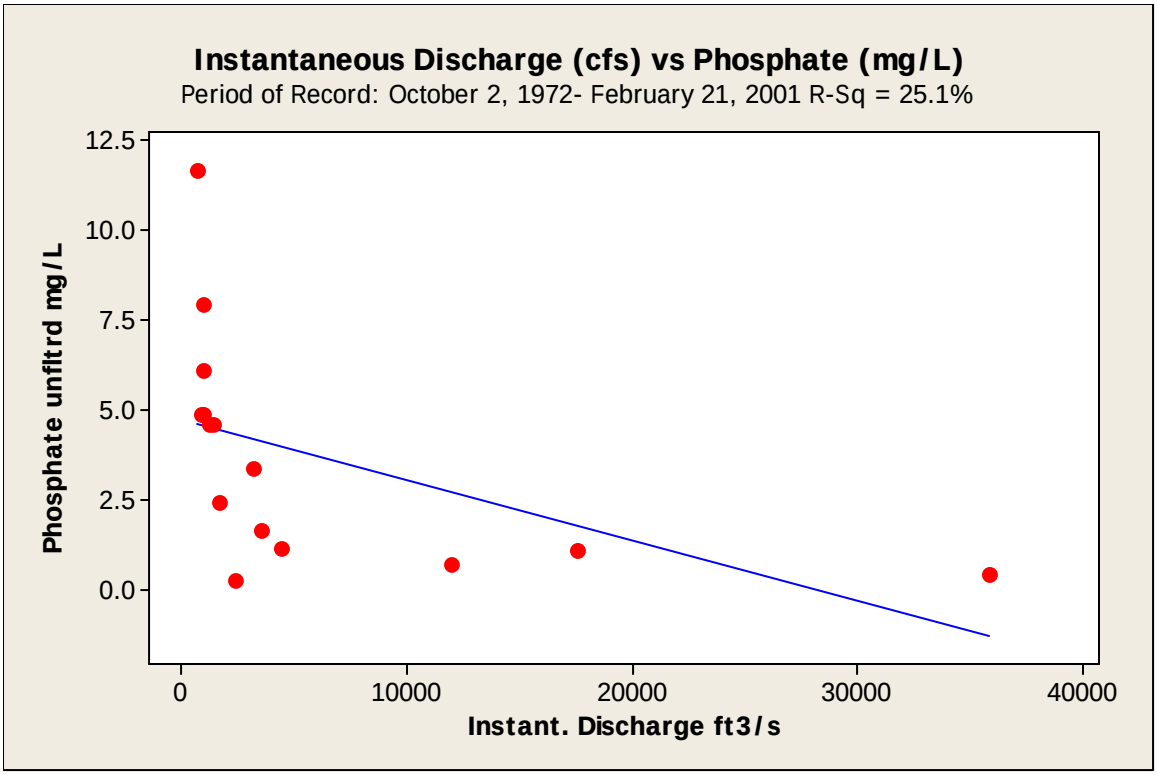


Figure 89. Flow versus phosphate unfiltered at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

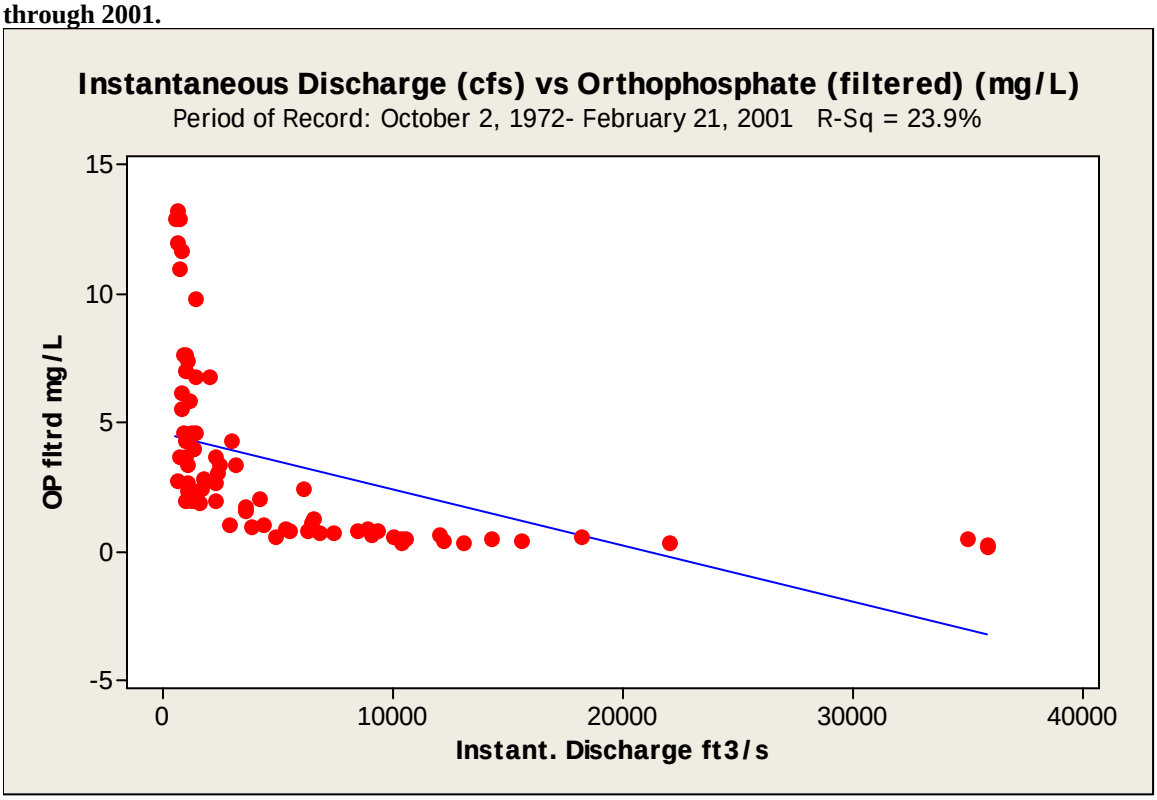


Figure 90. Flow versus orthophosphate filtered at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

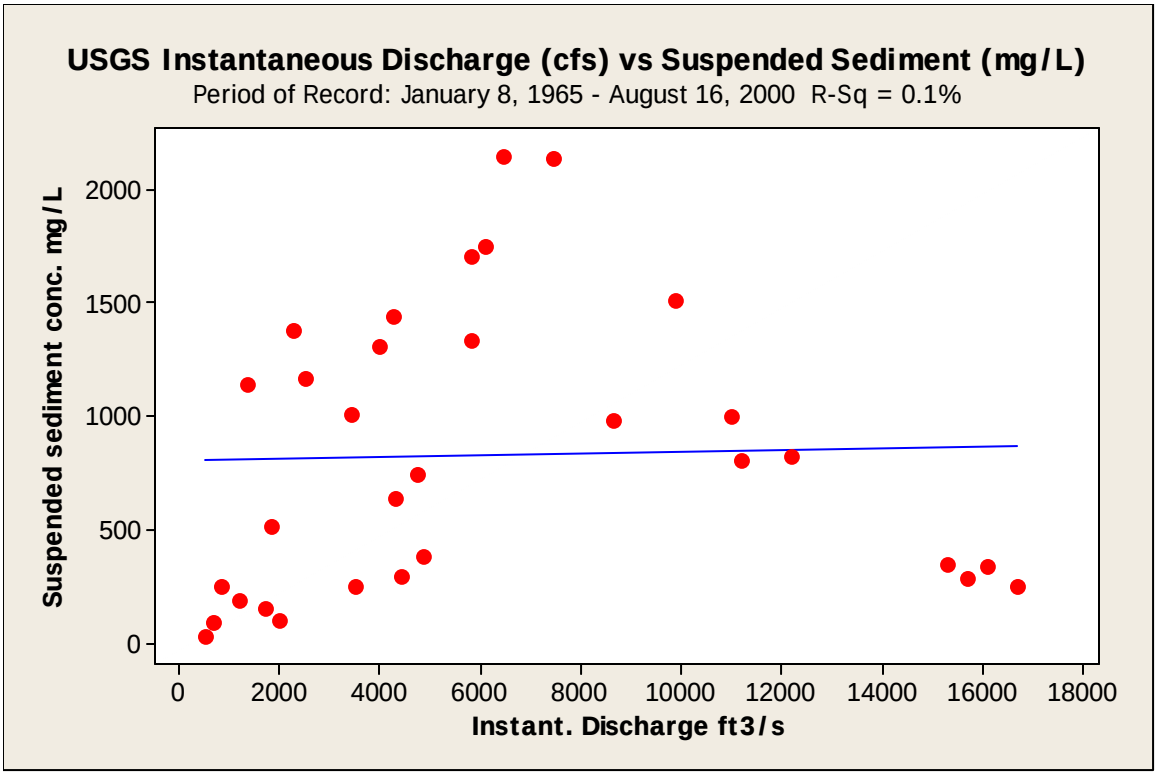


Figure 91. Flow versus suspended sediment concentrations at the Trinity River near Oakwood 08065000 gage during 1965 through 2000.

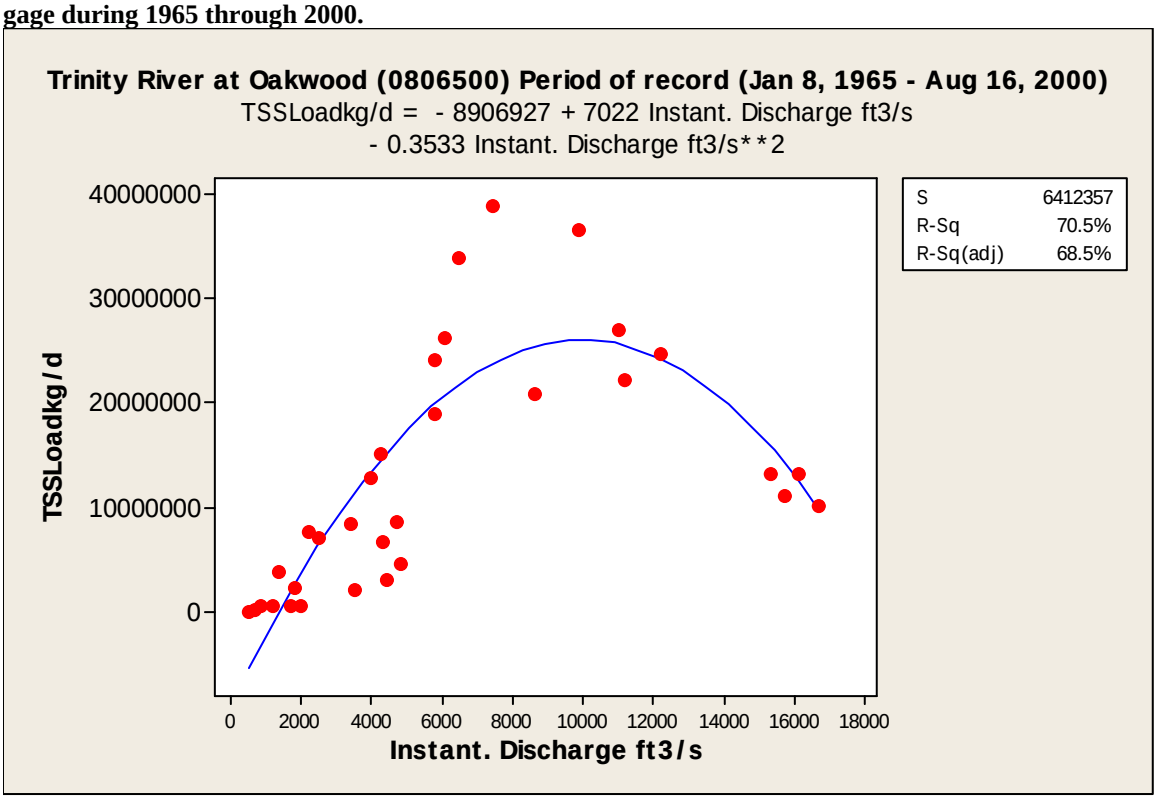


Figure 92. Flow versus suspended sediment load at the Trinity River near Oakwood 08065000 gage during 1965 through 2000.

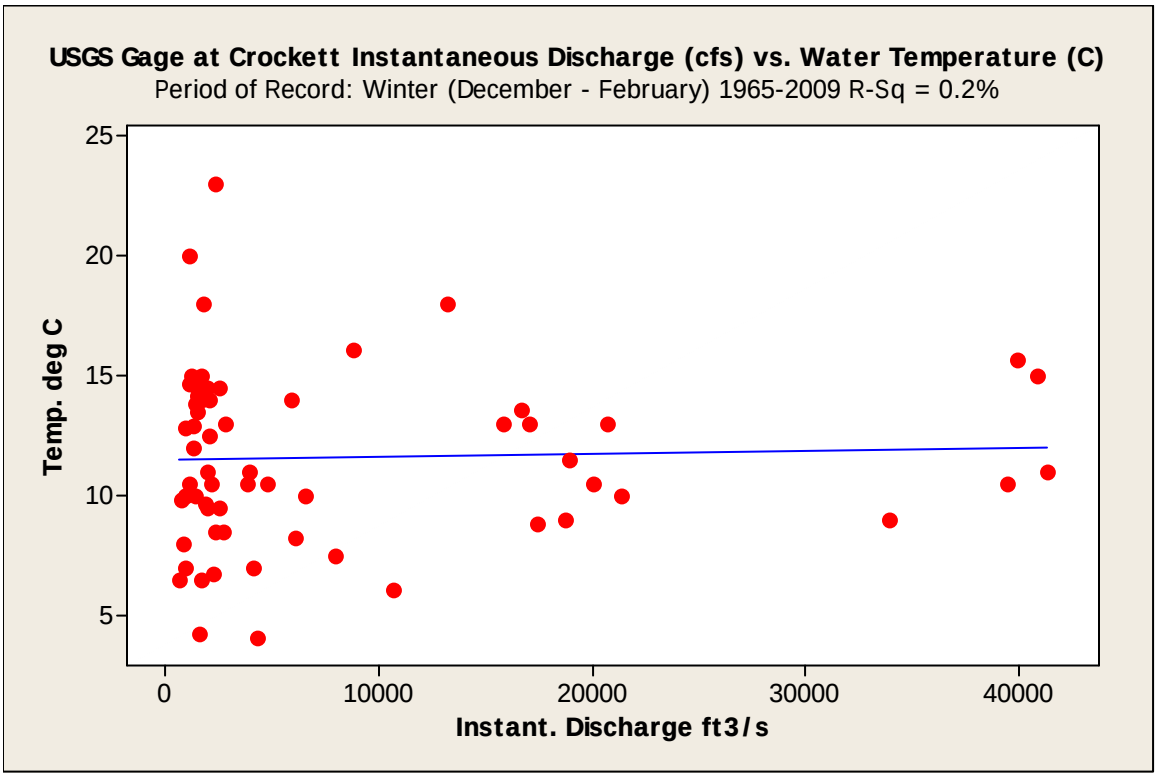


Figure 93. Flow versus winter water temperature at the Trinity River near Crockett 08065350 gage during 1965 through 2009.

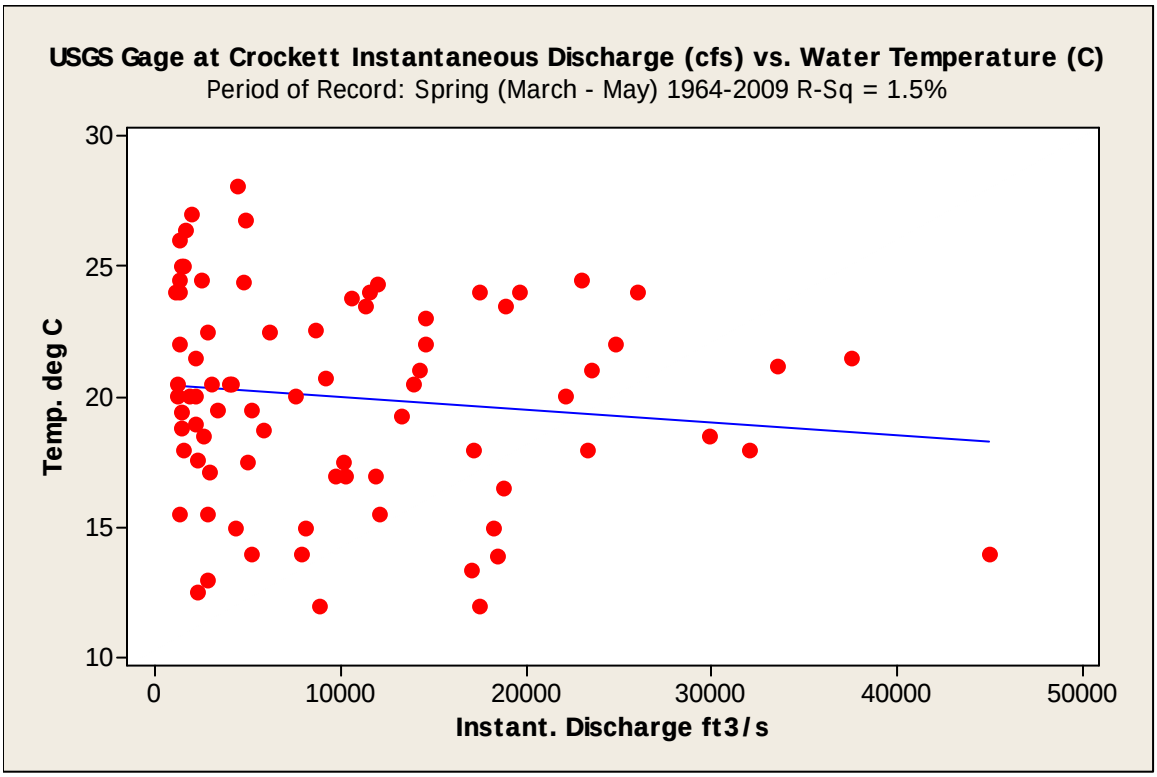


Figure 94. Flow versus spring water temperature at the Trinity River near Crockett 08065350 gage during 1964 through 2009.

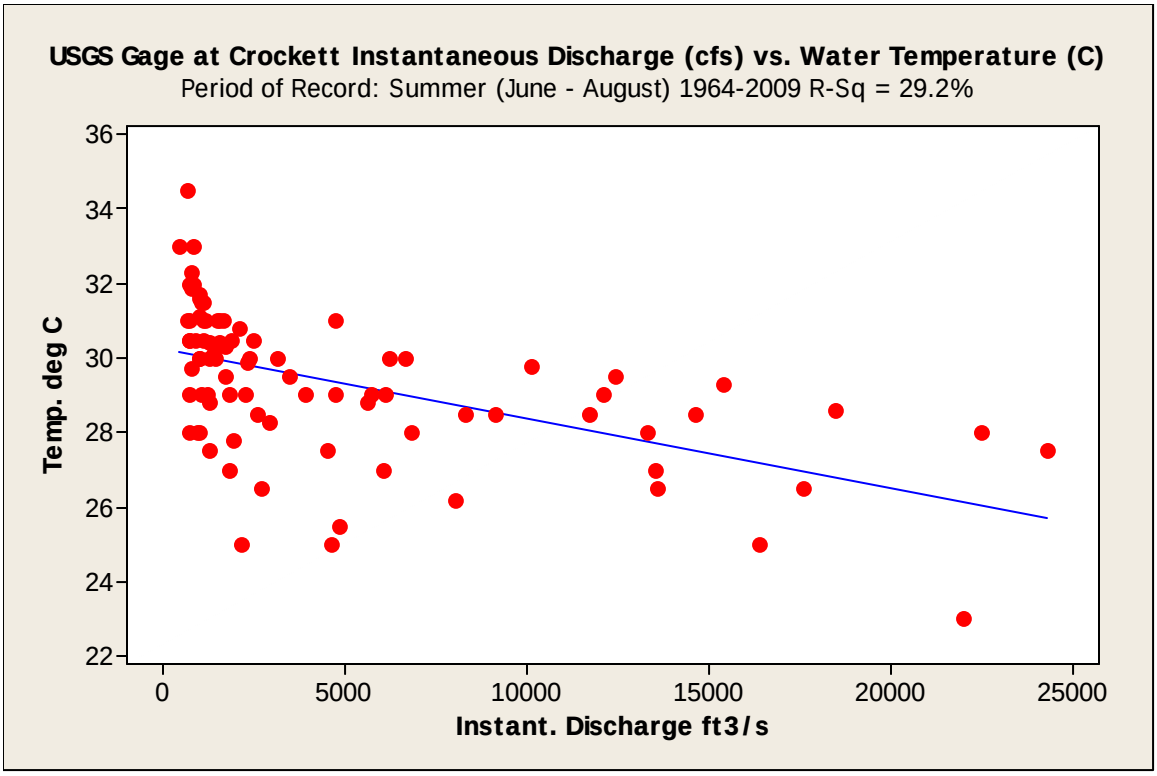


Figure 95. Flow versus summer water temperature at the Trinity River near Crockett 08065350 gage during 1964 through 2009.

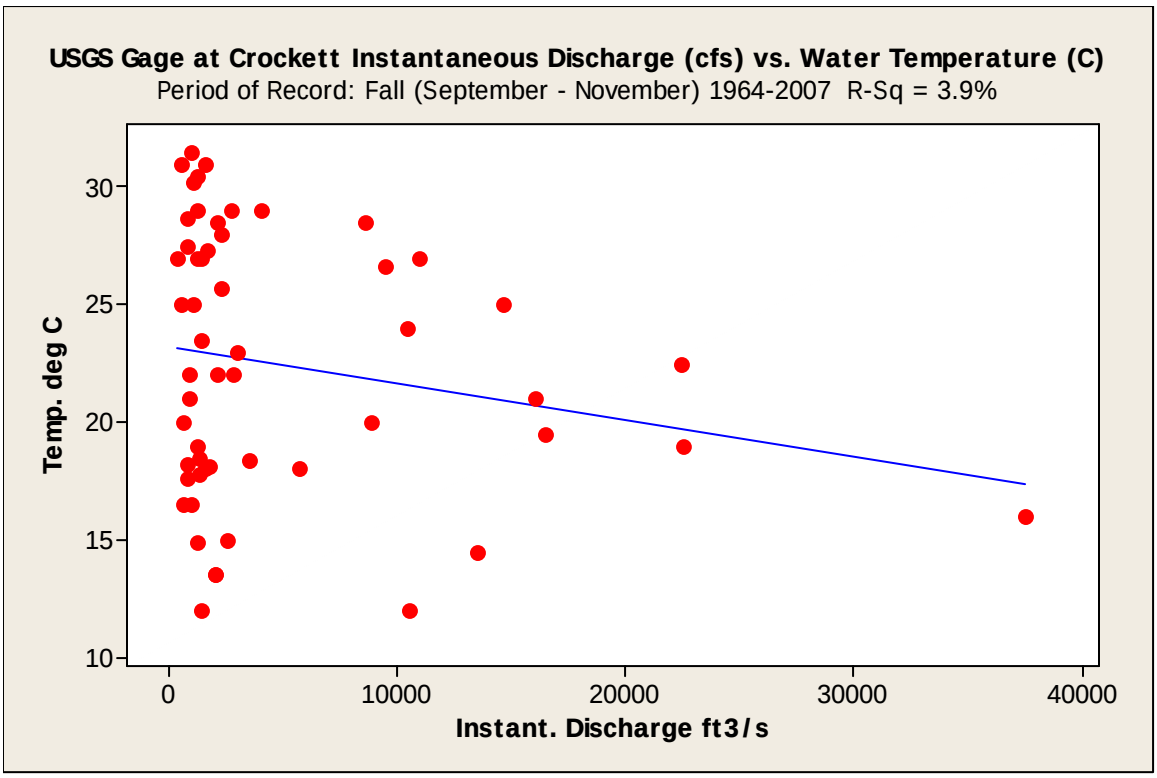


Figure 96. Flow versus fall water temperature at the Trinity River near Crockett 08065350 gage during 1964 through 2007.

The Crockett gage is an important gage that measures streamflow immediately upstream of Lake Livingston (Figure 1). A comparison of data between this site and the next gage located below Lake Livingston at Romayor provides useful information on the possible influence of Lake Livingston on downstream transport of sediment and nutrients. Unfortunately historical paired data sets containing instantaneous discharge and sediment data were largely lacking. Strong seasonal patterns in dissolved oxygen were observed at the Crockett gage (Figure 97-100). Unlike the previous upstream gages, dissolved oxygen levels actually decreased with increasing flows during the summer. This may be due to the fact that the period of record includes data from the 1960s through 2009 which includes the period (late 1980s) when fish kills had become more common due to periodic anoxic episodes associated with the release of improperly treated wastewater and runoff during storms. Many of the lowest dissolved oxygen values were associated with high flow events that occurred between 1982 and 1989. Specific conductance and nutrient concentrations generally declined rapidly when flows increased above 2000 cfs at the Crockett gage (Figures 101-105, 107, 109-110). As with many of the upstream gages, maximum variability of these variables occurred more frequently at lower stream flows. Since the Crockett gage is the last long term monitoring site for hydrology above Lake Livingston, the lowest reservoir in the watershed, we also calculated total nitrogen and phosphorus loading at this gage to later compare with values at the river downstream of the reservoir (Figures 106 and 108). The log-log model generated the best fit for total nitrogen loading at this site while the cubic model fit the phosphorus data best. At flows of approximately 1000 cfs, the corresponding loading was 12,340 kg/d total nitrogen. At flows of 14,600 the total nitrogen loading was 57,152 kg/d (Figure 106). The maximum phosphorus levels, 18,000 kg/d occurred when discharges were approximately 15,000 cfs (Figure 108).

The final priority gage on the non-tidal portion of the Trinity River provides useful information on the chemical characteristics of water entering the Galveston Bay system (Trinity Bay) (Figure 1). The construction of Lake Livingston dam in 1969 is often considered to be one of the major alterations in hydrology in the lower Trinity River. However, annual average flows did not decline after construction of the reservoir (Figure 111). Using a non-parametric Mann-Whitney t-test we also found that the two time periods were not statistically different at the $p = 0.104$ level. The overall median of mean flows was however 8905.5 cfs after dam construction versus 7303.0 cfs before. Based on a very limited analysis of the historical record using the IHA software we found that minimum flows actually increased after construction of the dam whereas there appeared to be little effect on maximum flows (Figure 112). This agrees with previous geomorphological studies which documented no changes in high flow conditions following impoundment, while low flows became elevated (Wellmeyer et al. 2005). They indicated that increased precipitation rates during the period after dam construction may explain some of this variation. Based on this information we felt that it was unnecessary to segregate loading estimates into Galveston Bay into two time periods based on changes in hydrology.

Only summer water temperatures appear to be strongly influenced by increasing flows (Figures 113 – 116). At levels above 50,000 cfs water temperatures consistently declined (Figure 115). However under most conditions there is not a strong relationship between flow and water temperature. Similar patterns were exhibited between flow and dissolved oxygen levels (Figures 117-118). The influence of flow on specific conductance also indicates that there is considerable variation in the amount of dissolved ions unrelated to flow (Figure 121). However, these values are relatively low (<500 uS). Most nutrients increased in concentration as flows increased (Figures 122-128).

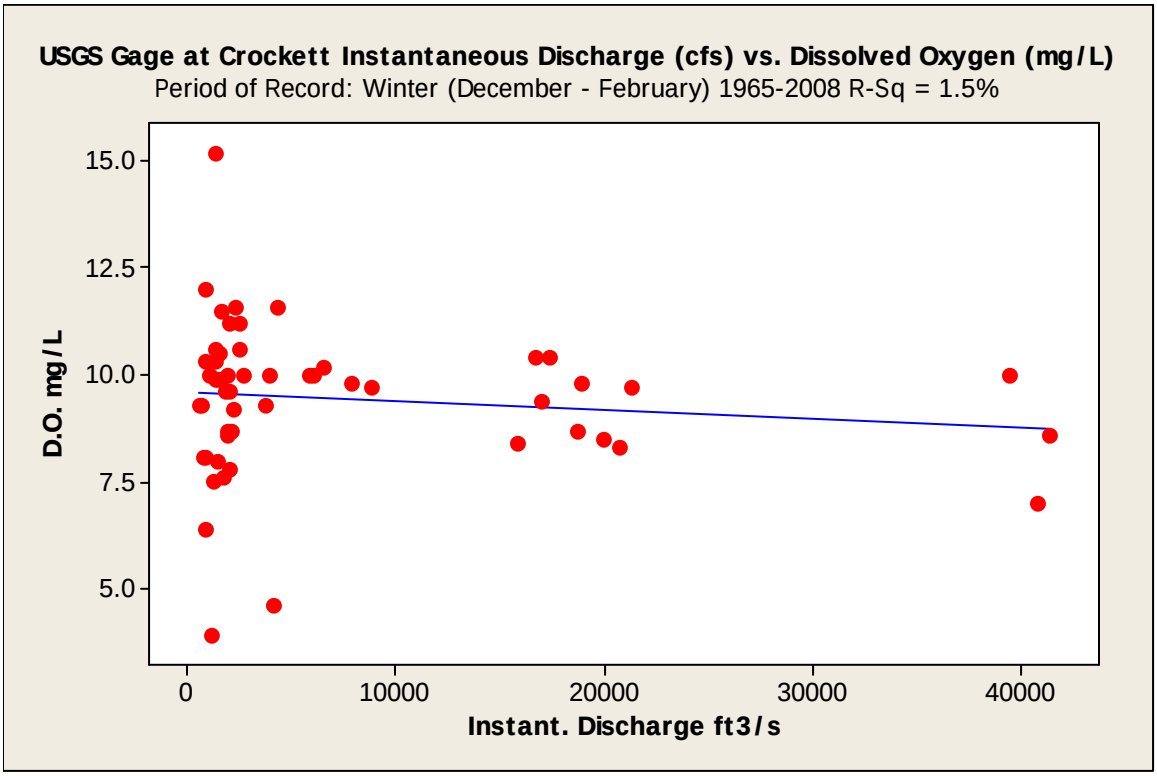


Figure 97. Flow versus winter dissolved oxygen at the Trinity River near Crockett 08065350 gage during 1965 through 2008.

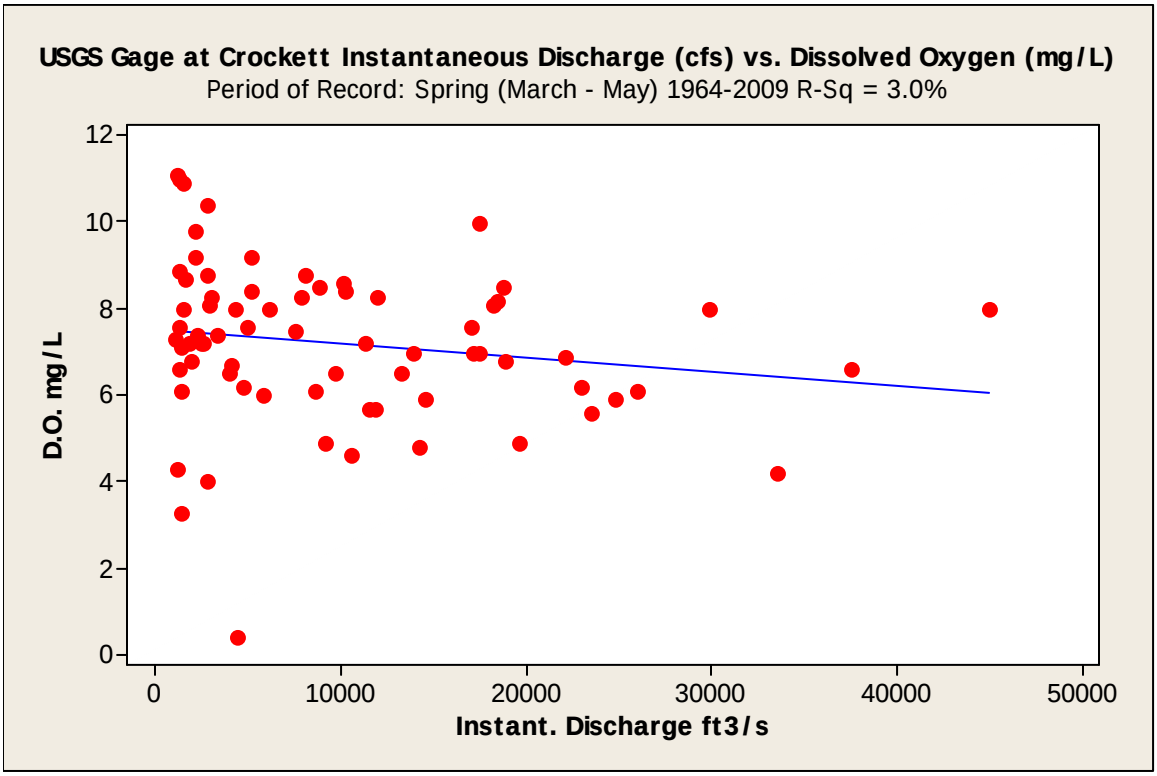


Figure 98. Flow versus spring dissolved oxygen at the Trinity River near Crockett 08065350 gage during 1964 through 2009.

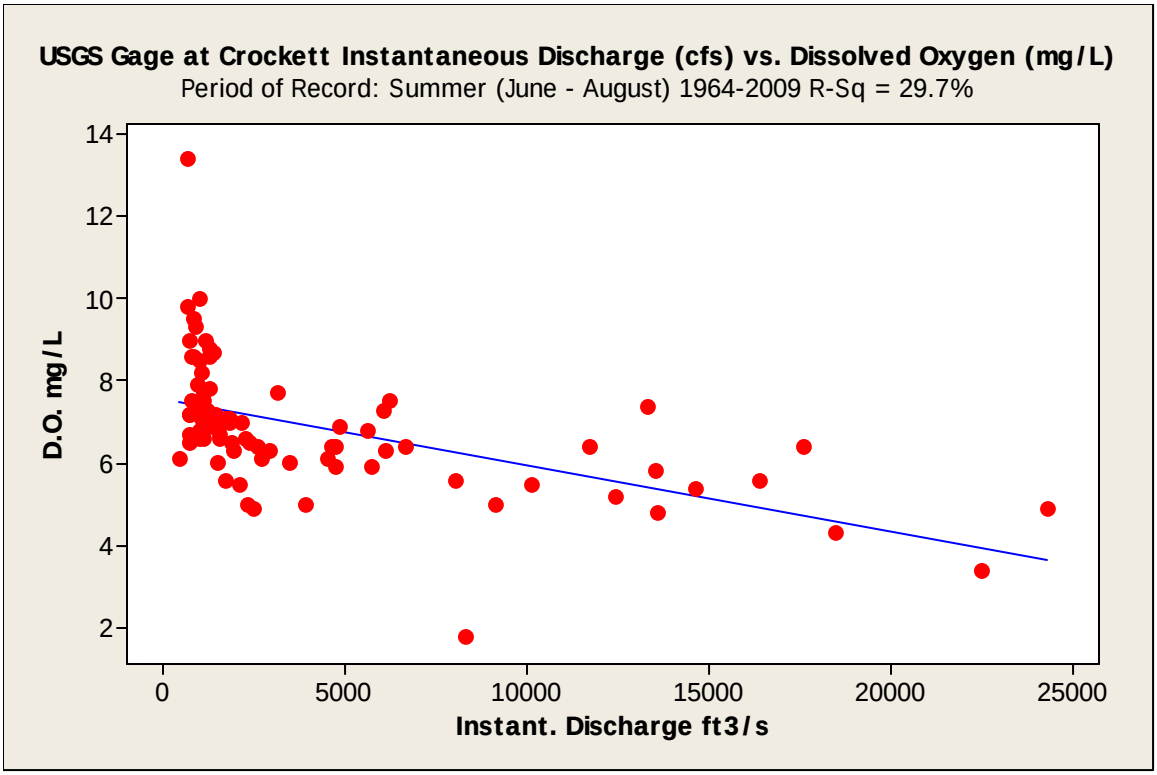


Figure 99. Flow versus summer dissolved oxygen at the Trinity River near Crockett 08065350 gage during 1965 through 2008.

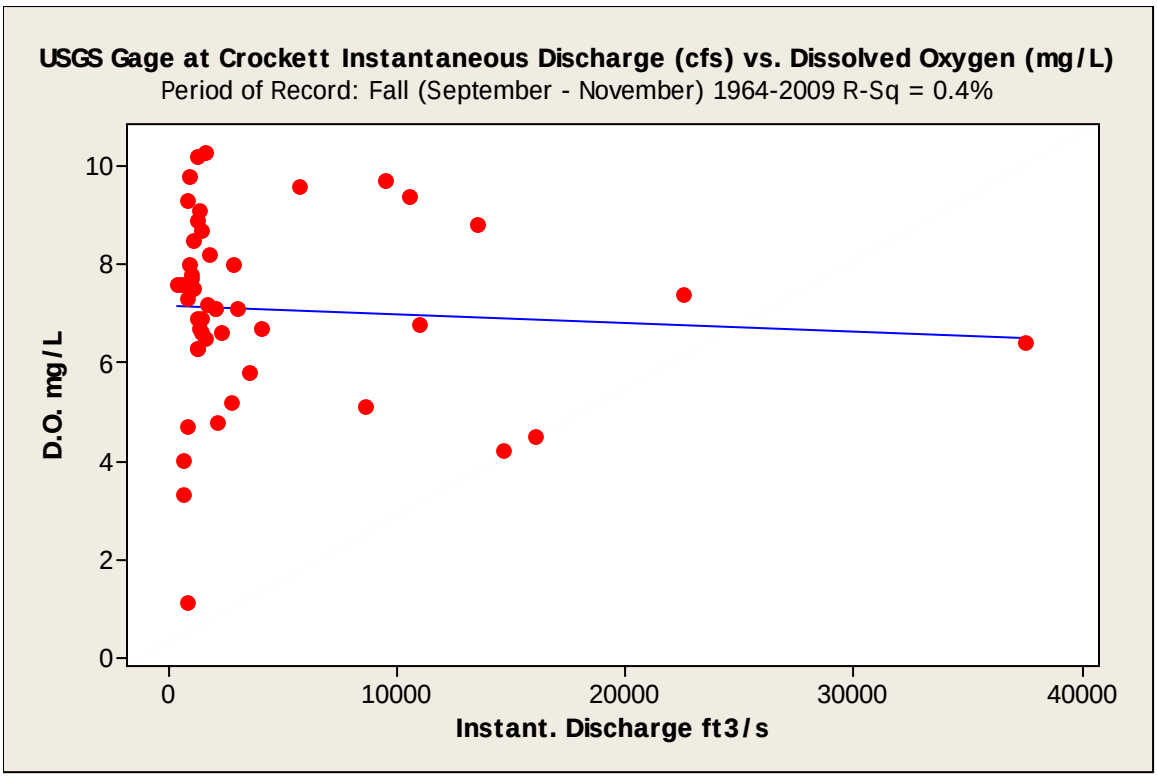


Figure 100. Flow versus fall dissolved oxygen at the Trinity River near Crockett 08065350 gage during 1964 through 2009.

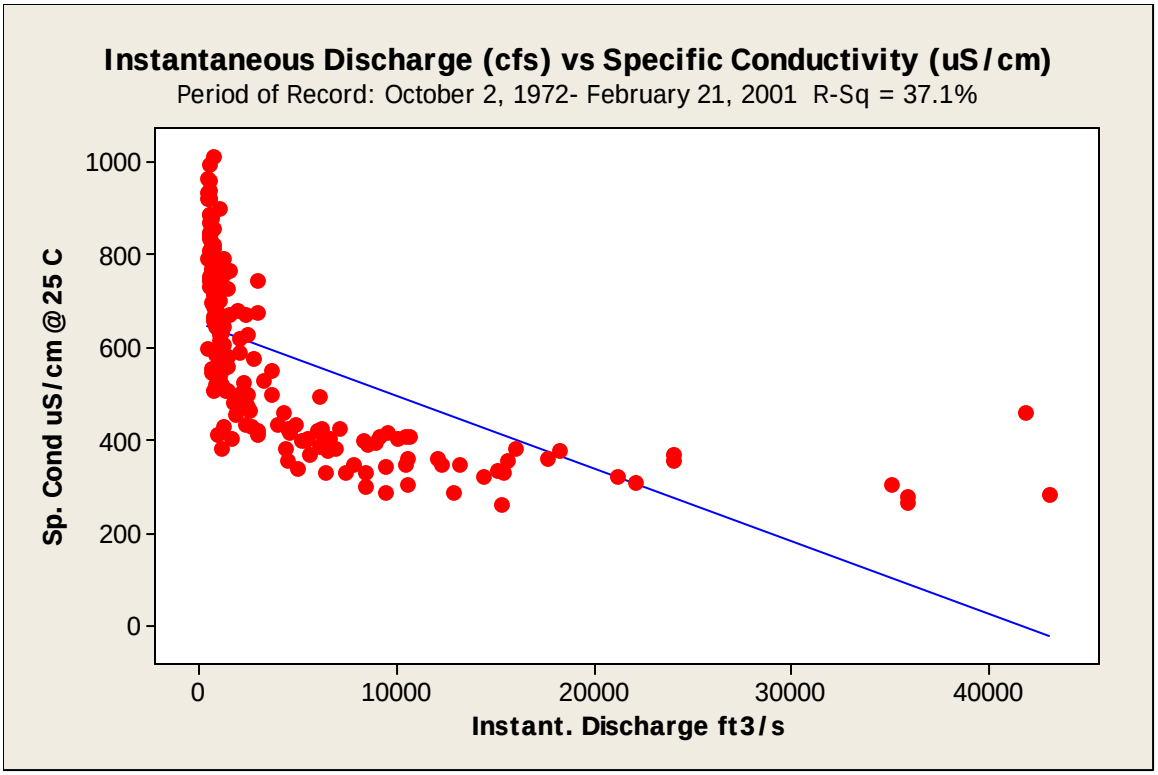


Figure 101. Flow versus specific conductance at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

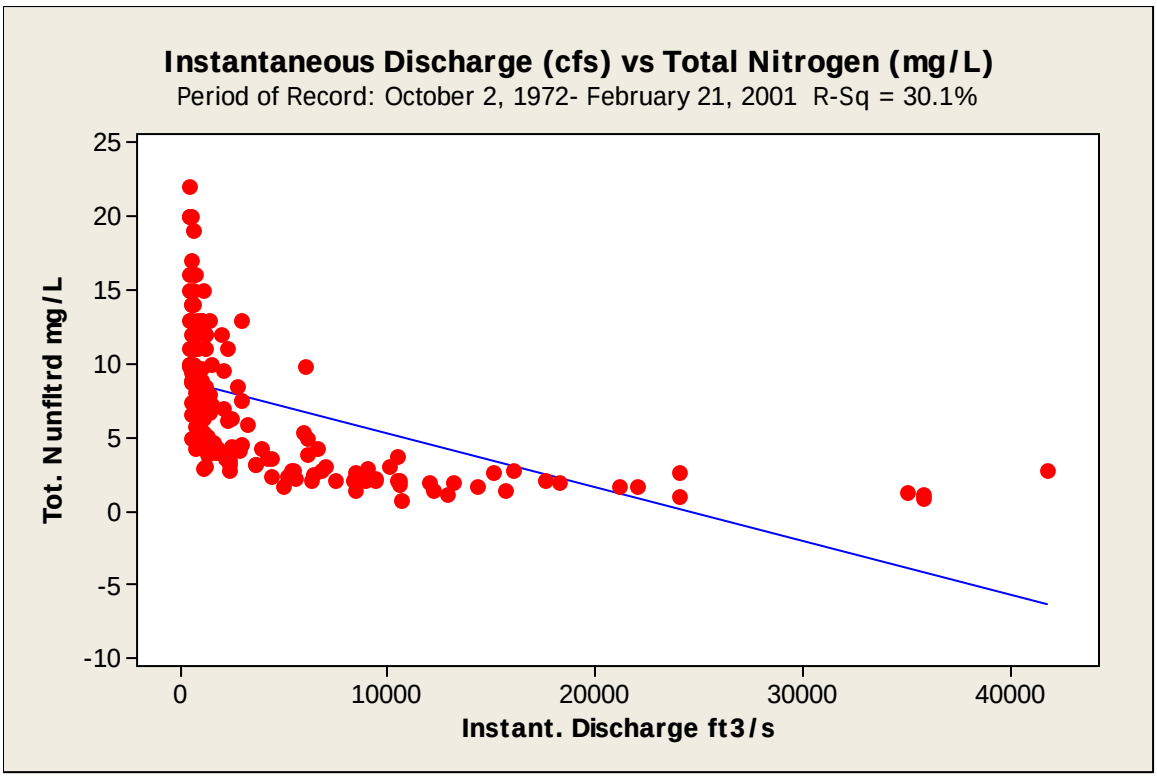


Figure 102. Flow versus total nitrogen concentration at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

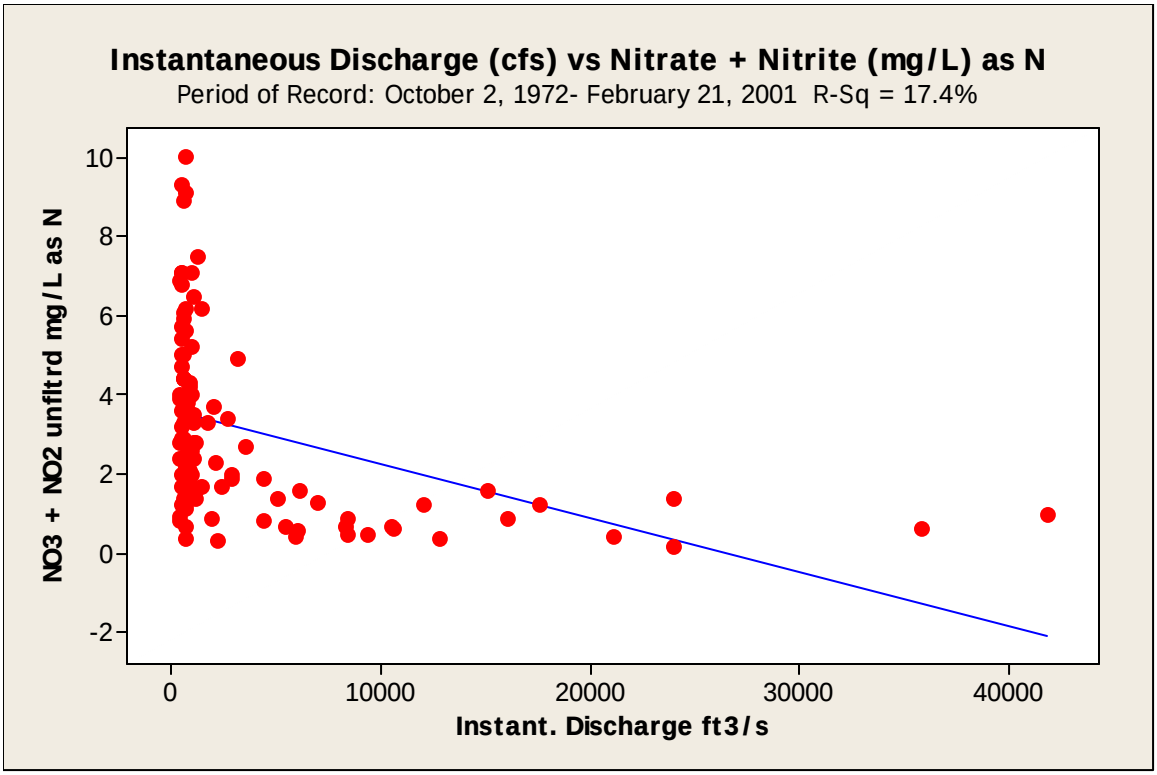


Figure 103. Flow versus nitrate and nitrite as nitrogen concentration at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

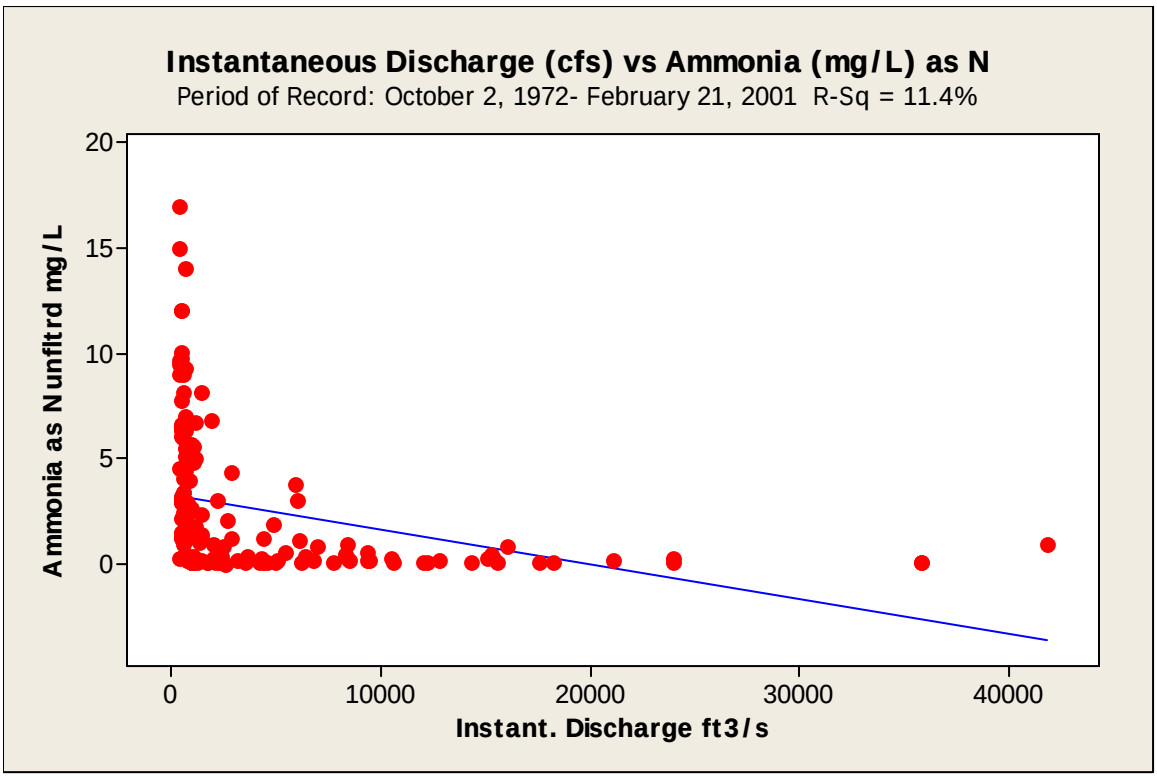


Figure 104. Flow versus ammonia as nitrogen concentration at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

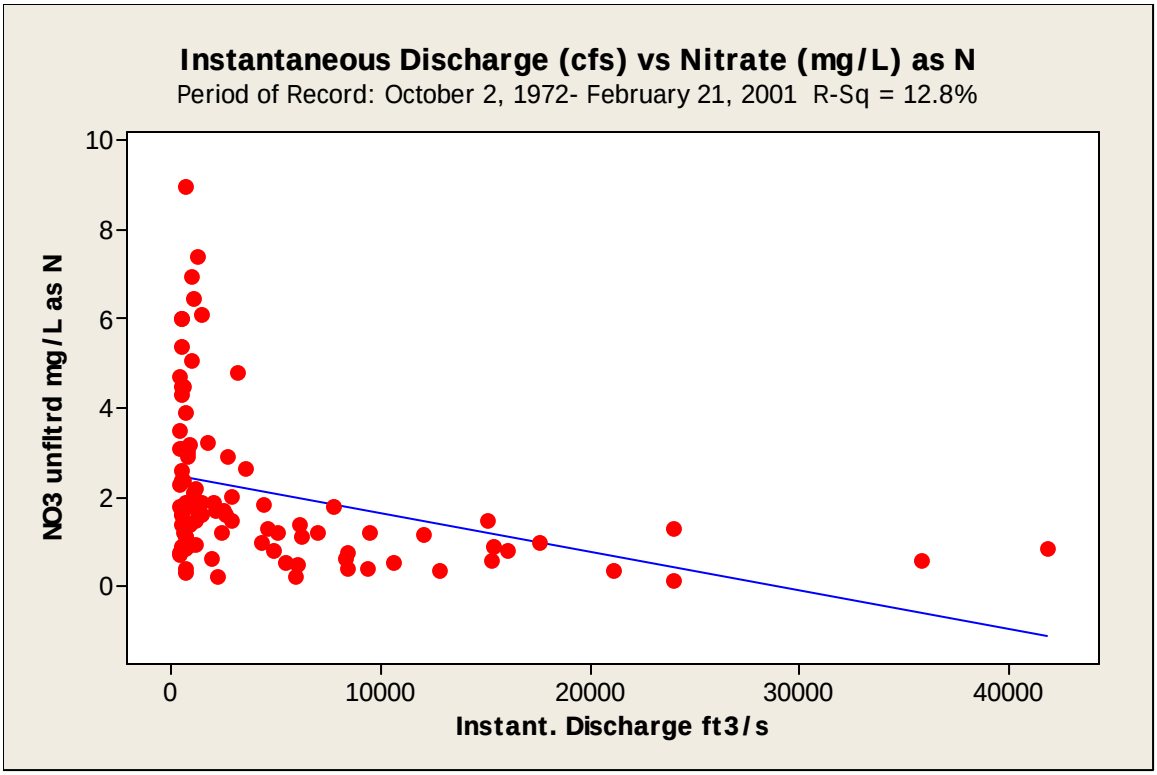


Figure 105. Flow versus nitrate as nitrogen concentration at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

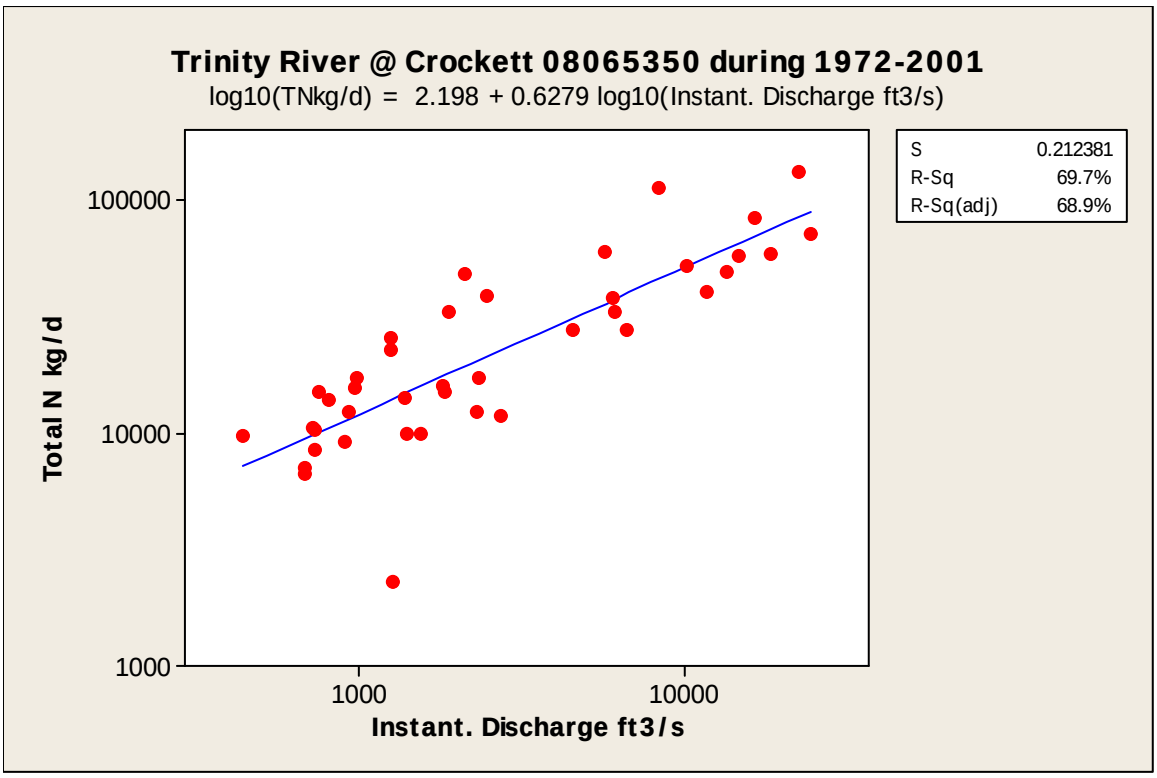


Figure 106. Flow versus total nitrogen loading at the Trinity River at Crockett 08065350 gage during 1972 through 2001.

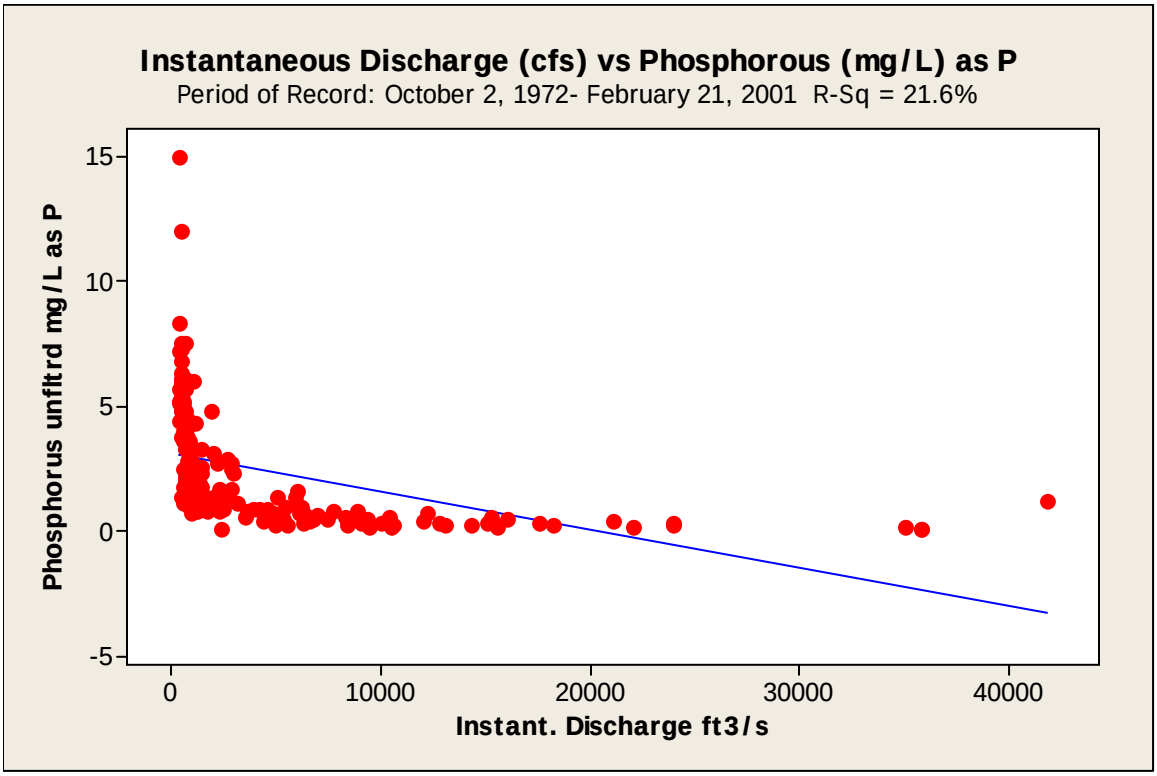


Figure 107. Flow versus phosphorus unfiltered at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

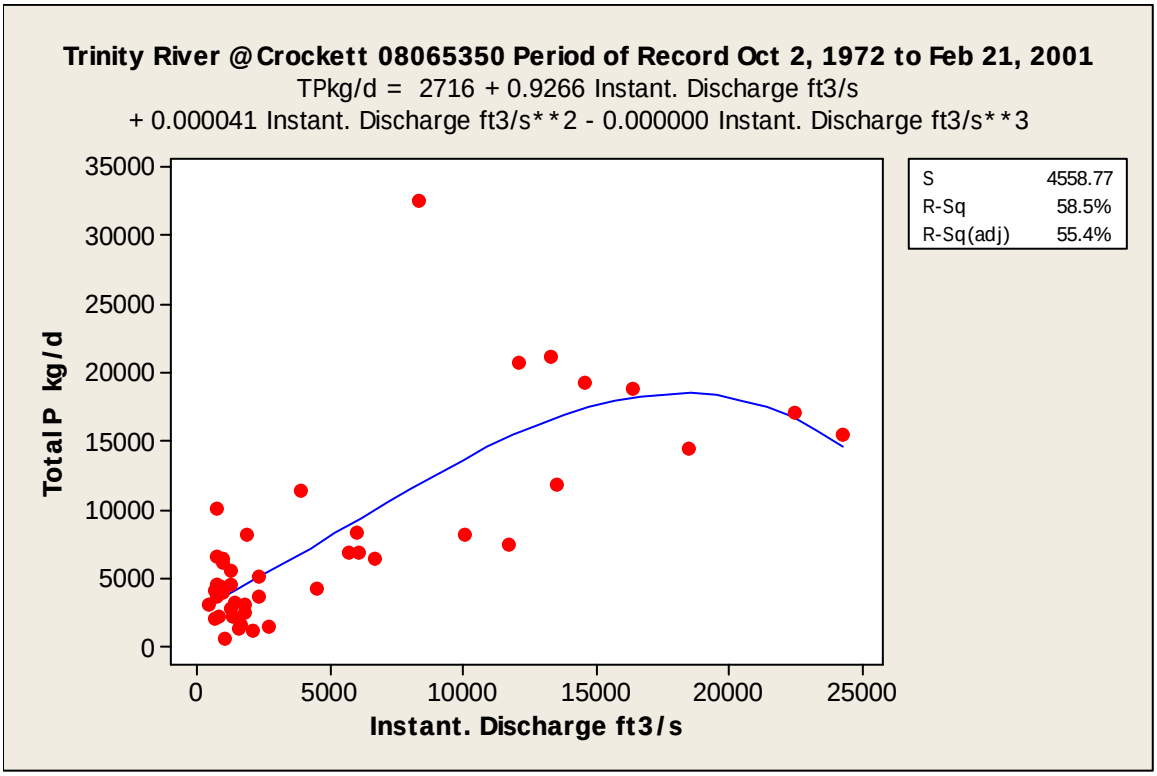


Figure 108. Flow versus total phosphorus loading (unfiltered) at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

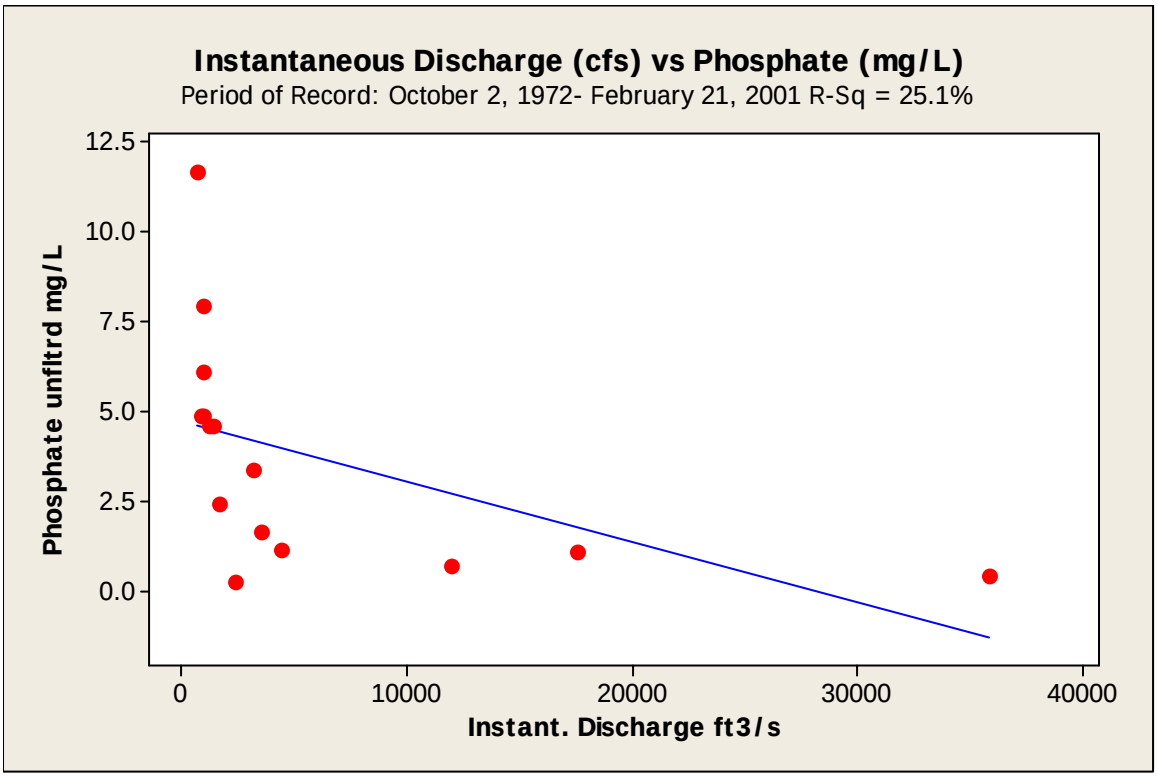


Figure 109. Flow versus phosphate concentration at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

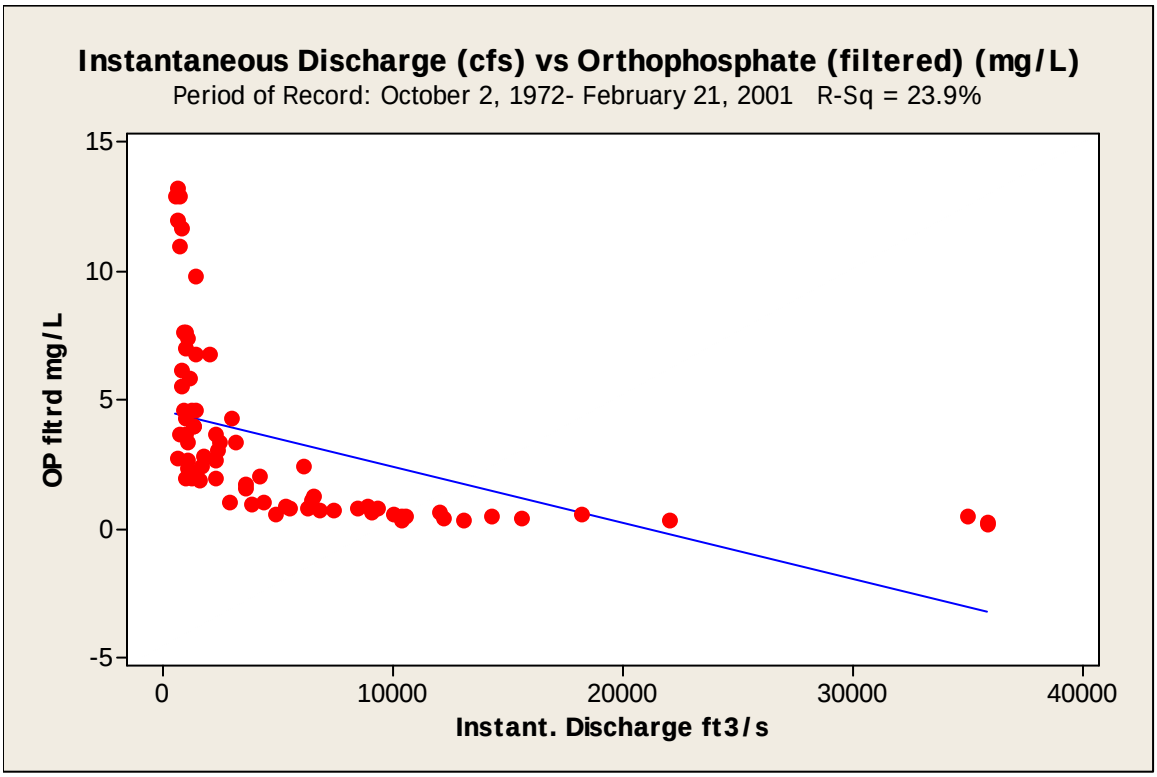


Figure 110. Flow versus orthophosphate concentration at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

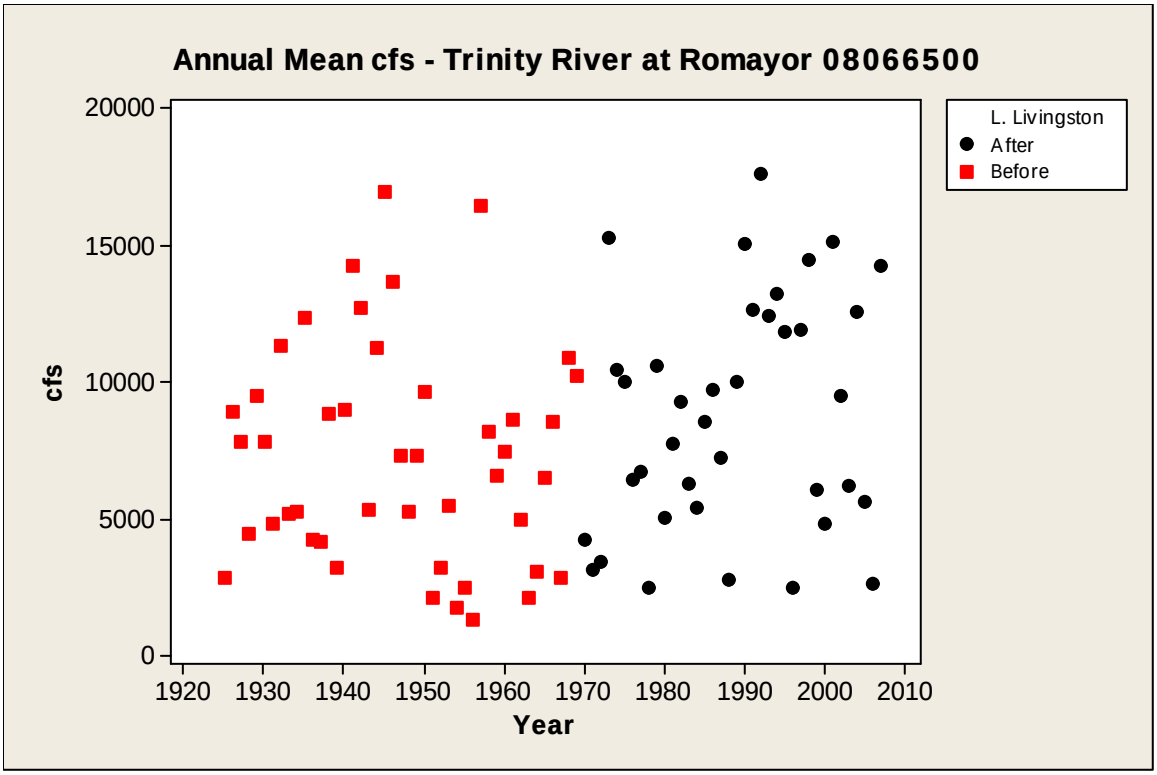
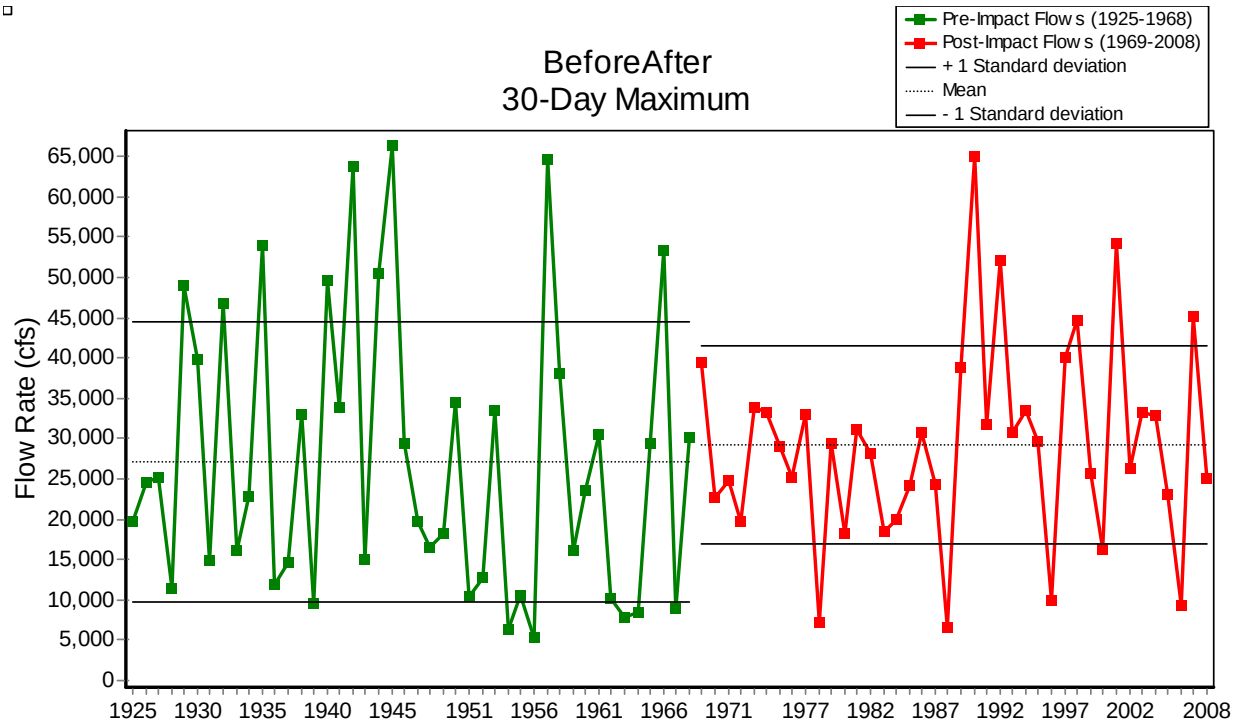


Figure 111. Comparison of annual flow (cfs) statistics for the Trinity River at Romayor (08066500) gage before and after construction of Lake Livingston. Period of record: 1925 through 2007. Source: USGS



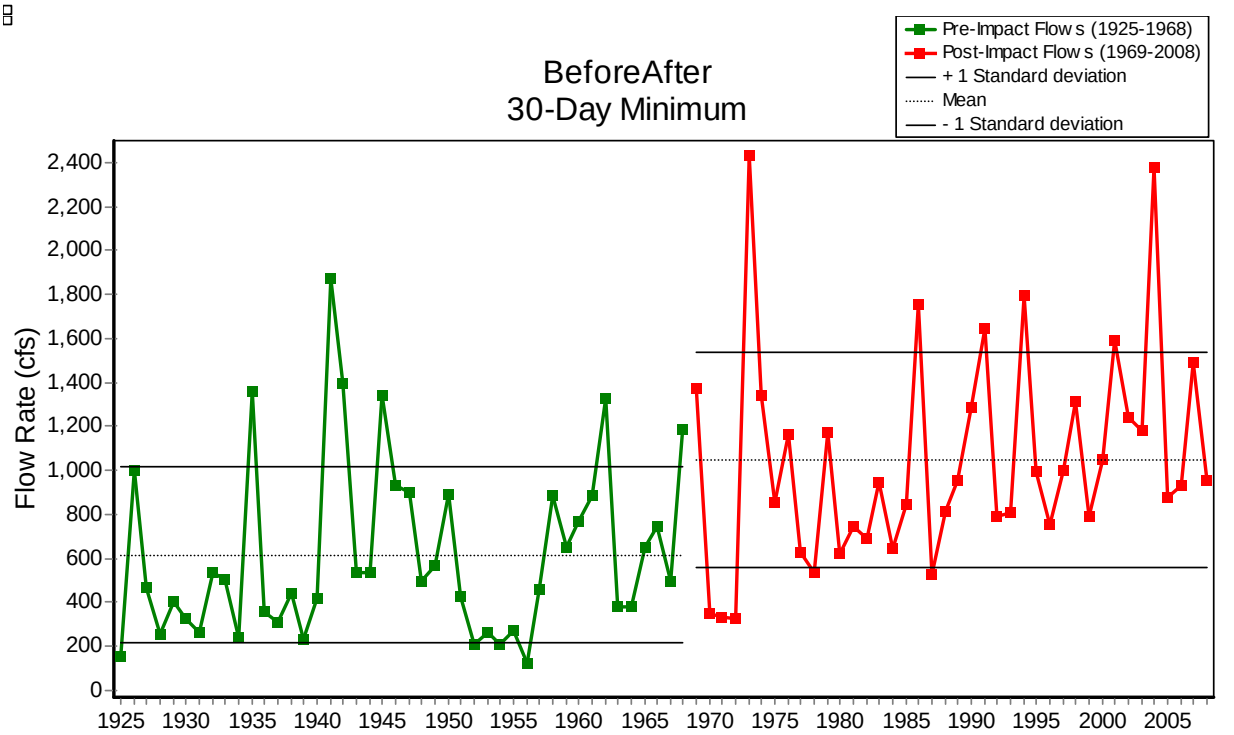


Figure 112. Effects of construction of the Lake Livingston dam on 30 day maximum and minimum flows after 1969. Similar patterns were observed for 1, 3, 7 and 90 day intervals. Data generated using IHA software. Period of record 1925-2008. Data Source: USGS

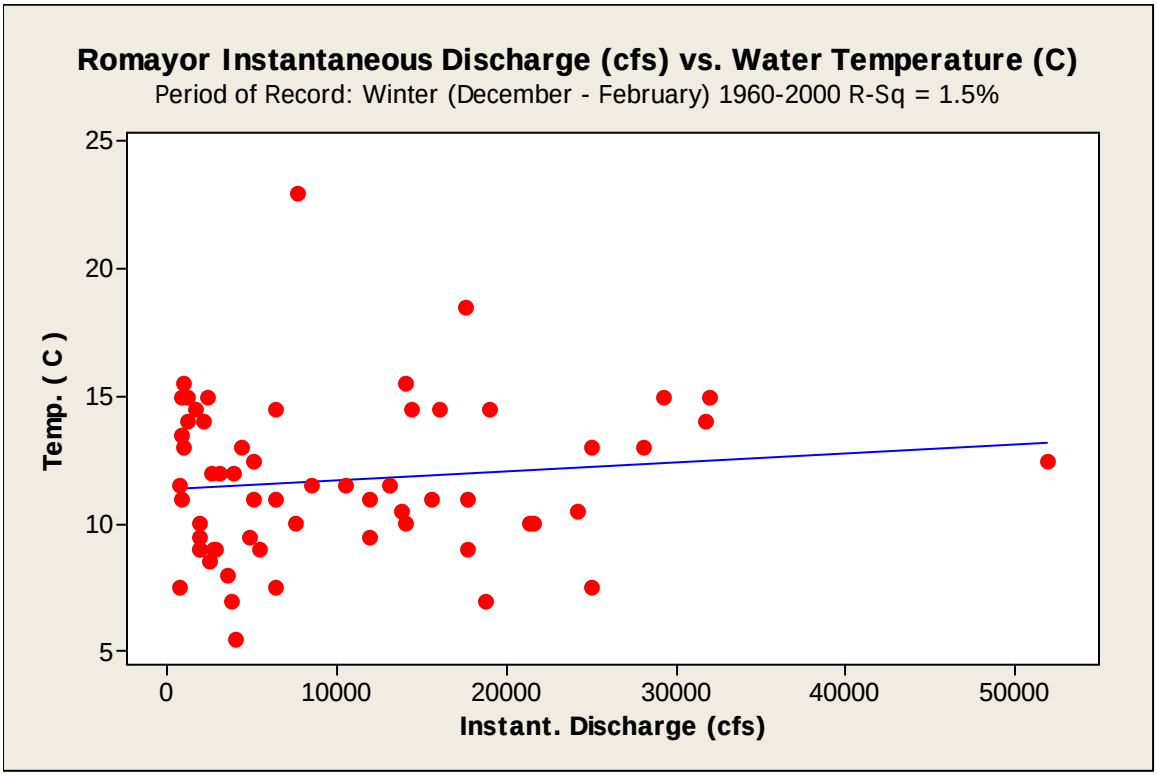


Figure 113. Flow versus winter water temperature at the Trinity River at Romayor 08066500 gage during 1960 through 1995.

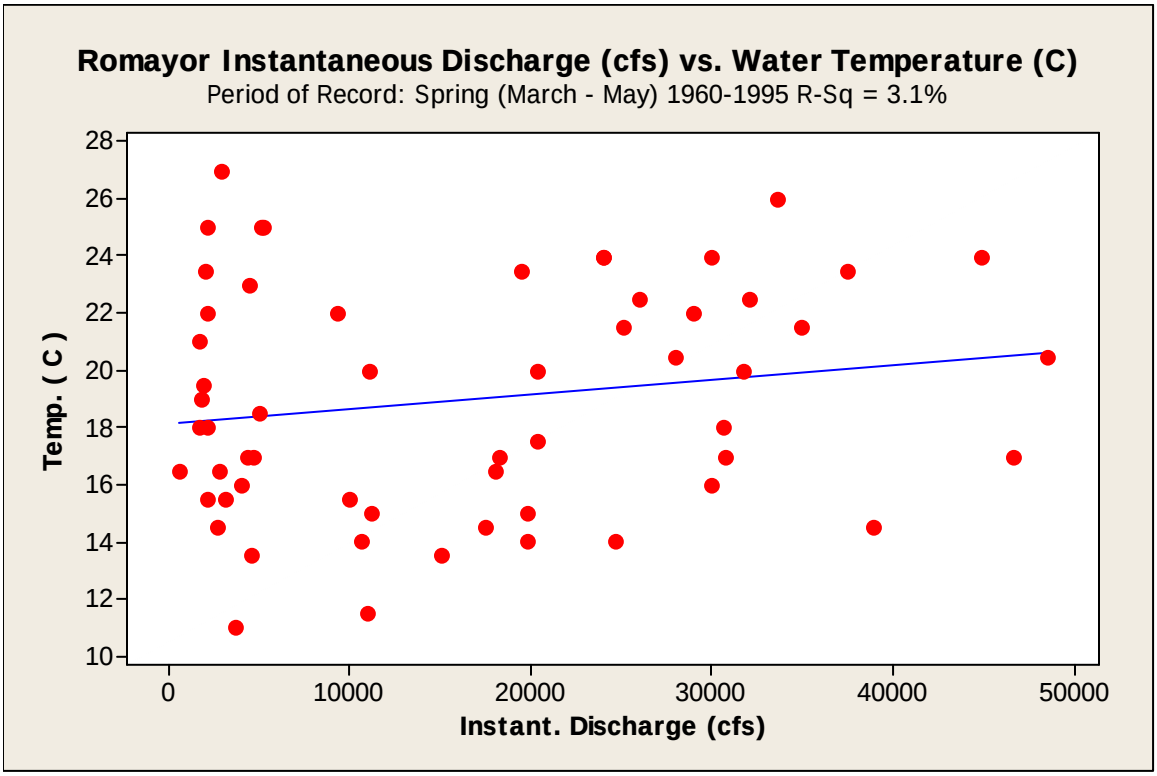


Figure 114. Flow versus spring water temperature at the Trinity River at Romayor 08066500 gage during 1960 through 1995.

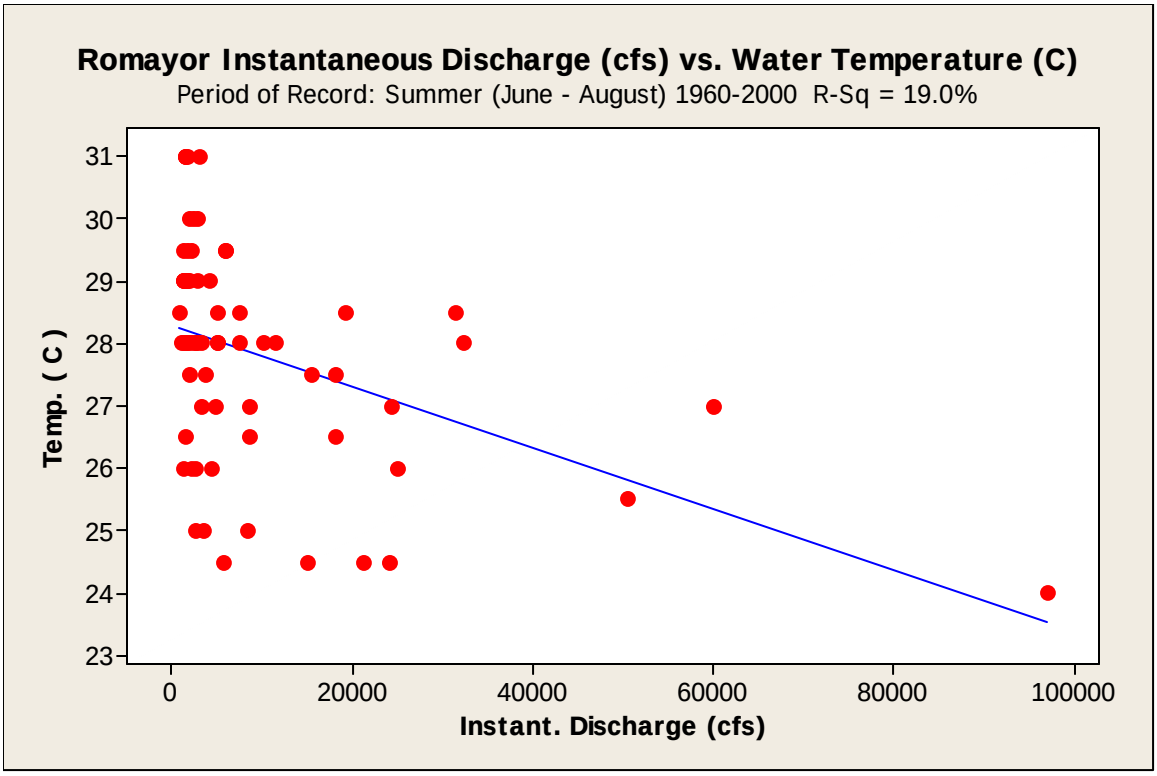


Figure 115. Flow versus summer water temperature at the Trinity River at Romayor 08066500 gage during 1960 through 2000.

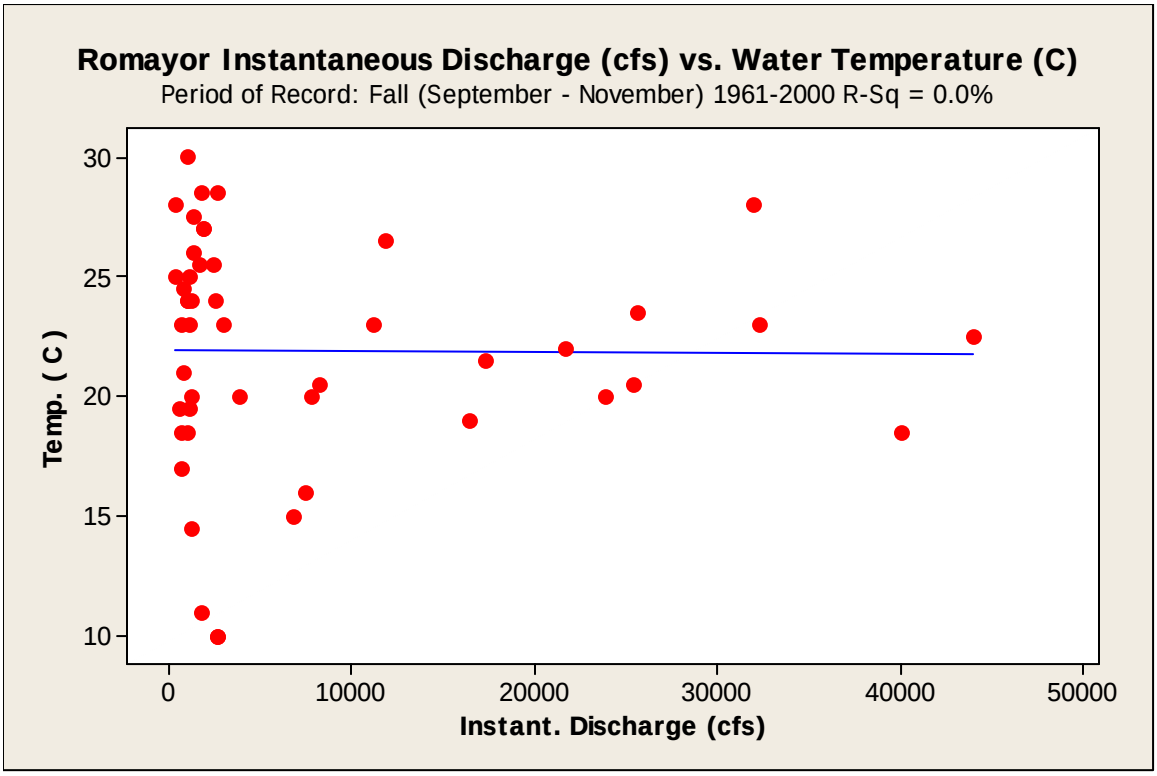


Figure 116. Flow versus fall water temperature at the Trinity River at Romayor 08066500 gage during 1961 through 2000.

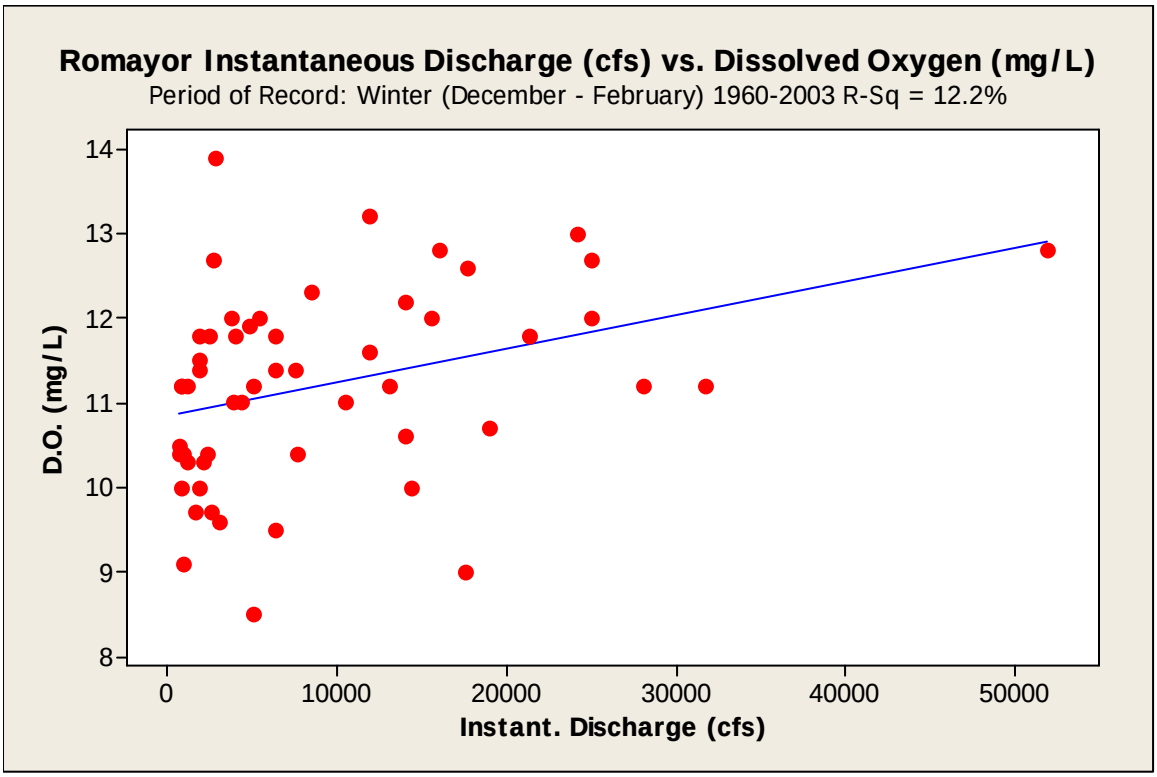


Figure 117. Flow versus winter dissolved oxygen at the Trinity River at Romayor 08066500 gage during 1960 through 2003.

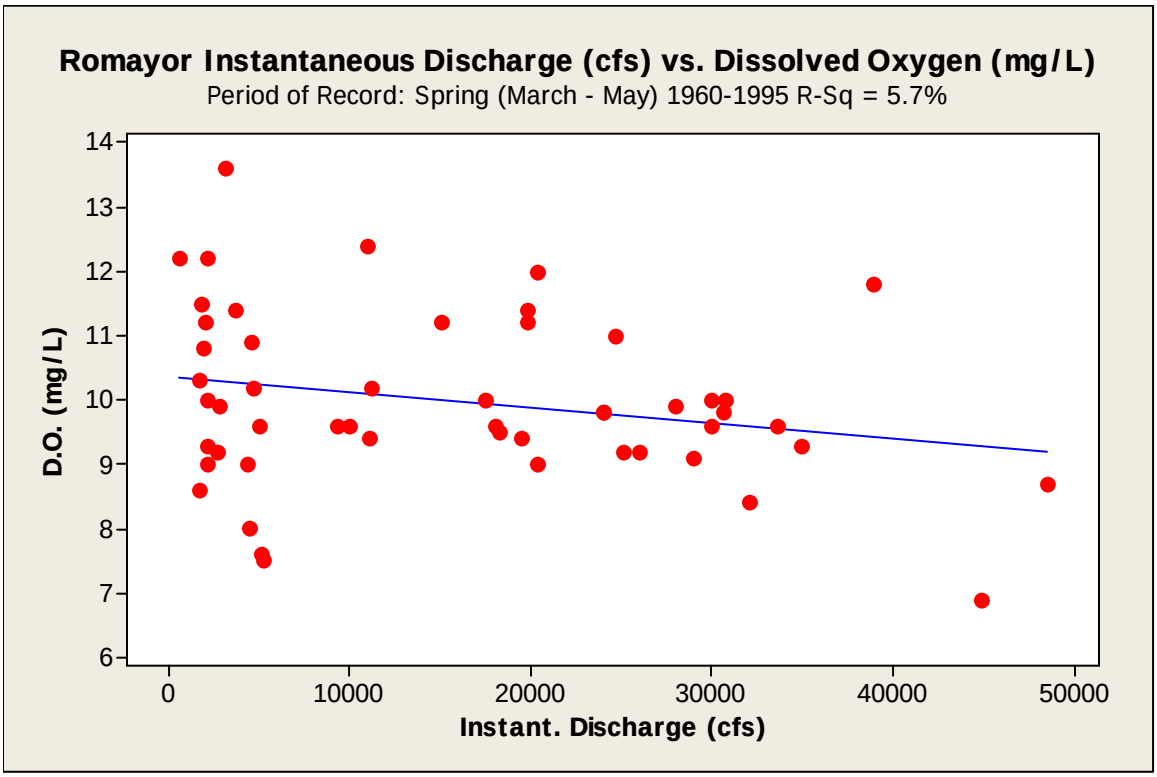


Figure 118. Flow versus spring dissolved oxygen at the Trinity River at Romayor 08066500 gage during 1960 through 1995.

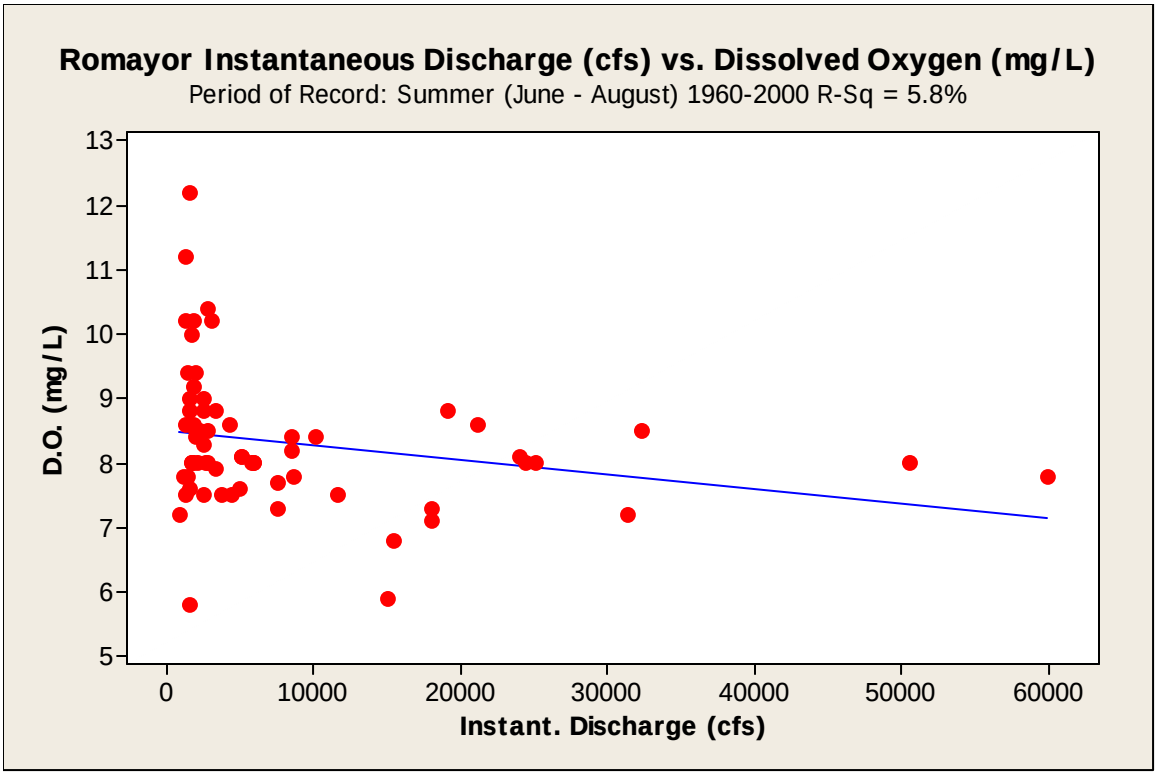


Figure 119. Flow versus summer dissolved oxygen at the Trinity River at Romayor 08066500 gage during 1960 through 2000.

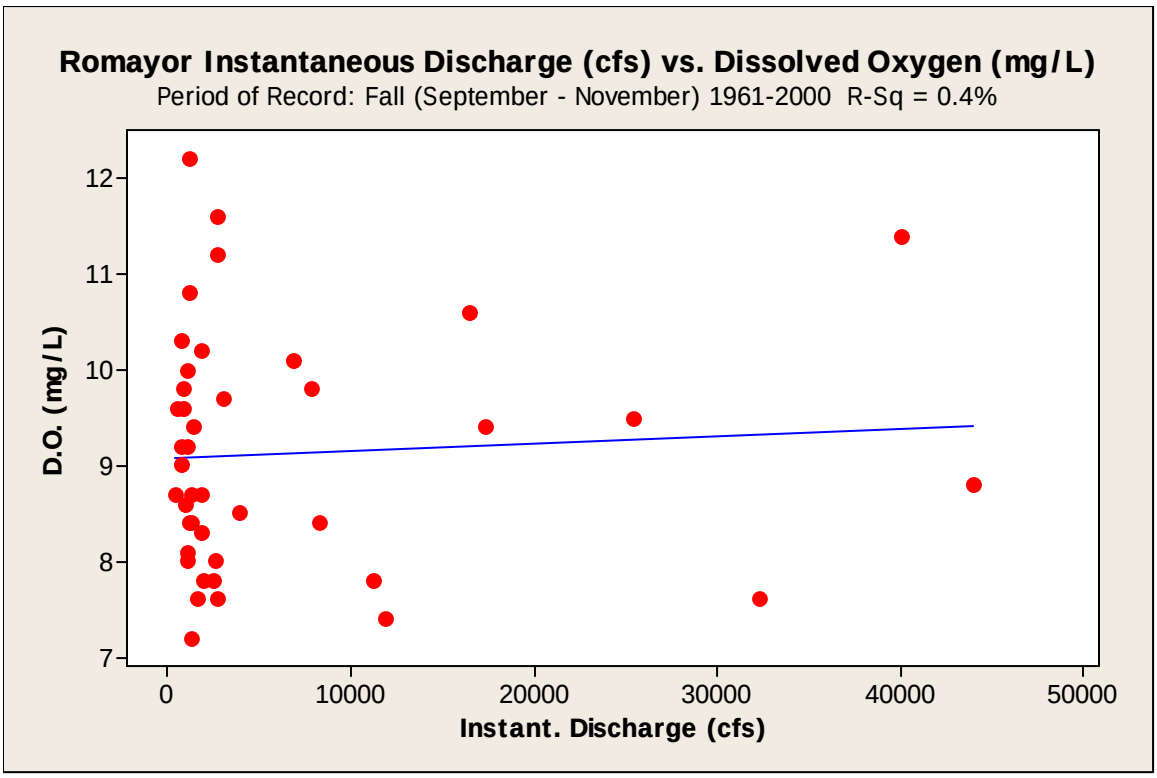


Figure 120. Flow versus fall dissolved oxygen at the Trinity River at Romayor 08066500 gage during 1961 through 2000.

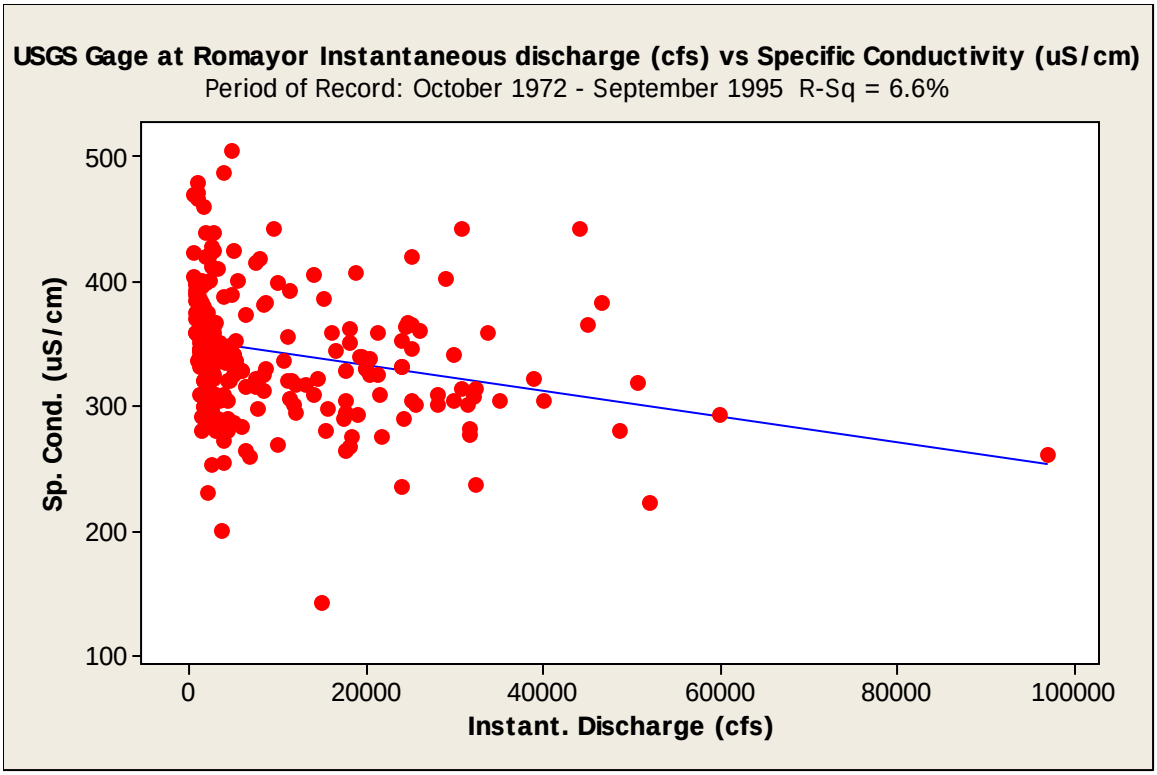


Figure 121. Flow versus specific conductance at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

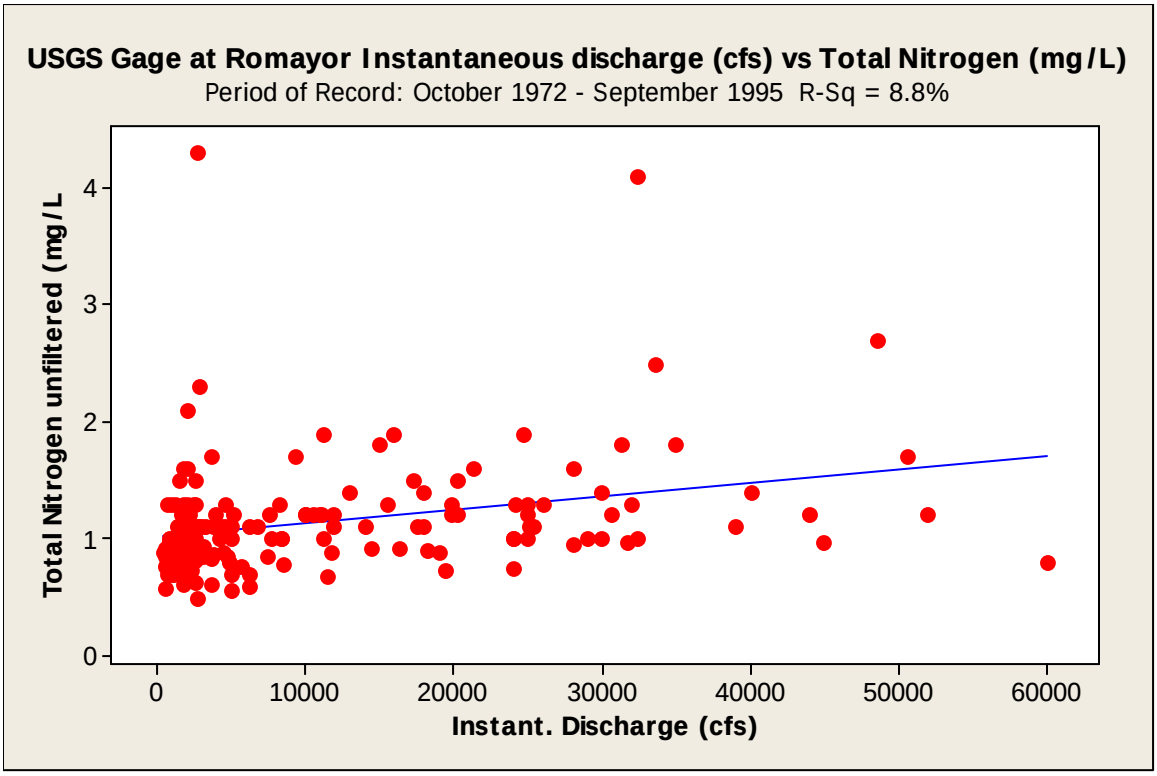


Figure 122. Flow versus specific conductance at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

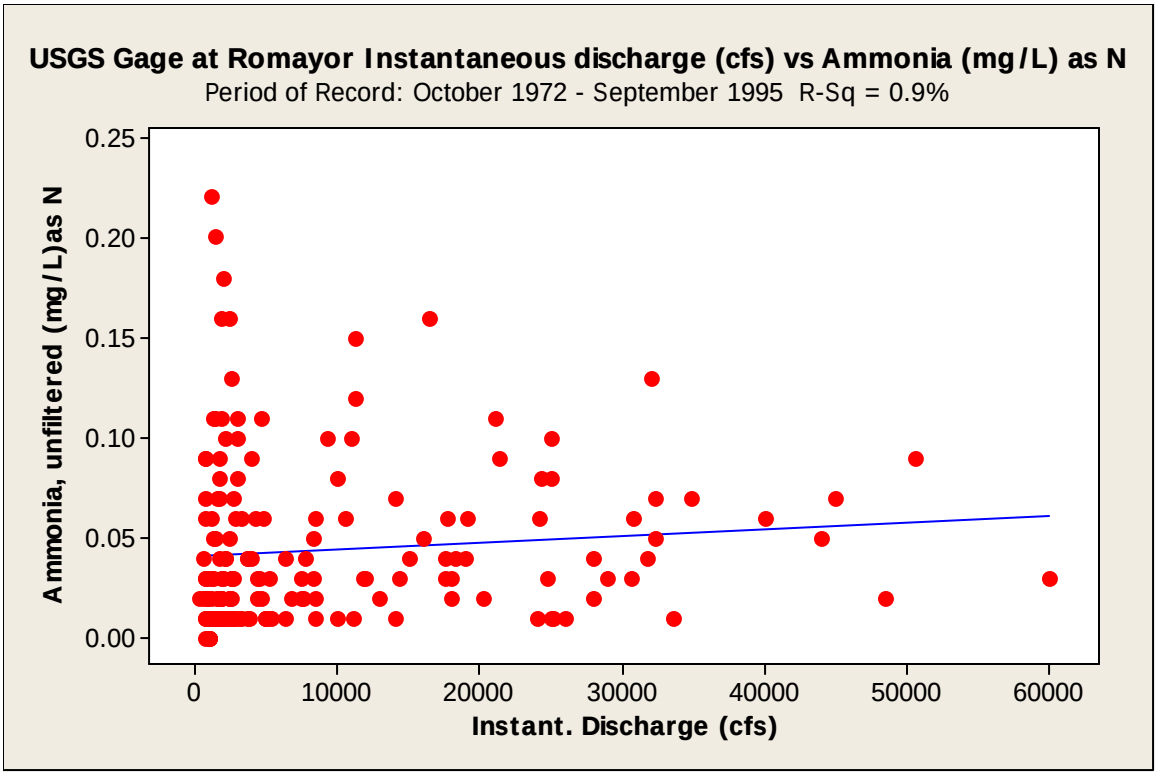


Figure 123. Flow versus ammonia nitrogen at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

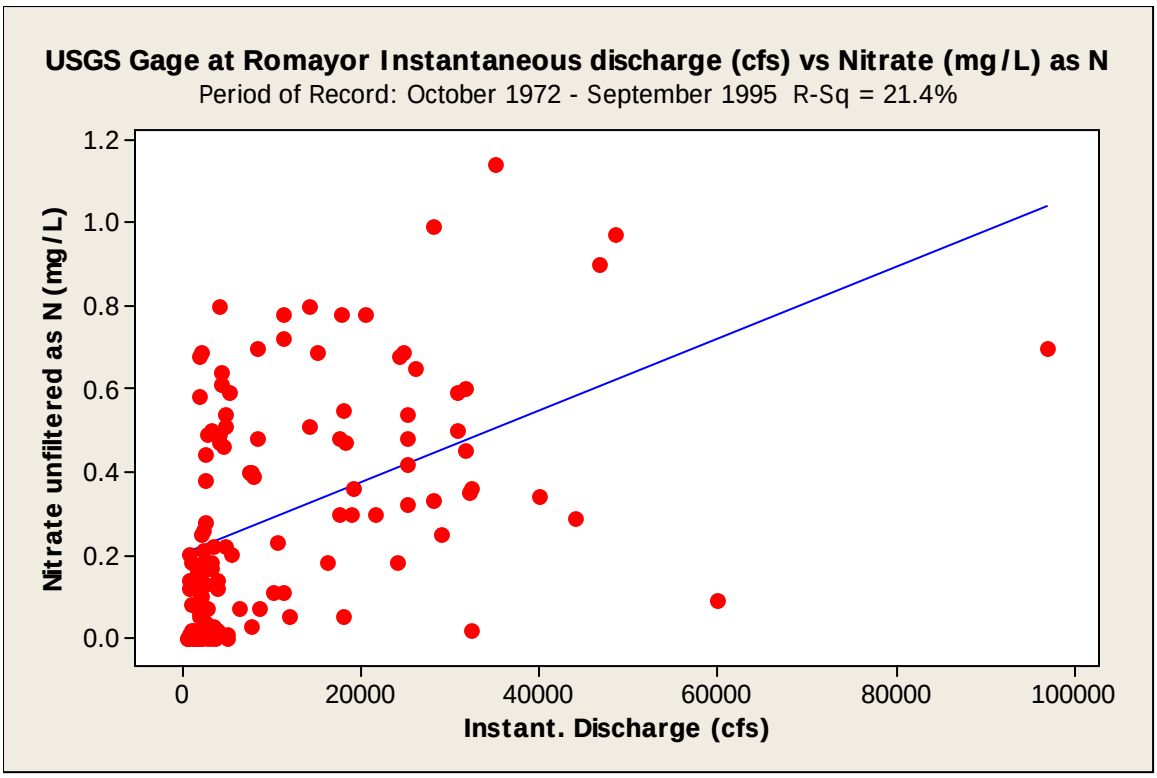


Figure 124. Flow versus nitrate nitrogen at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

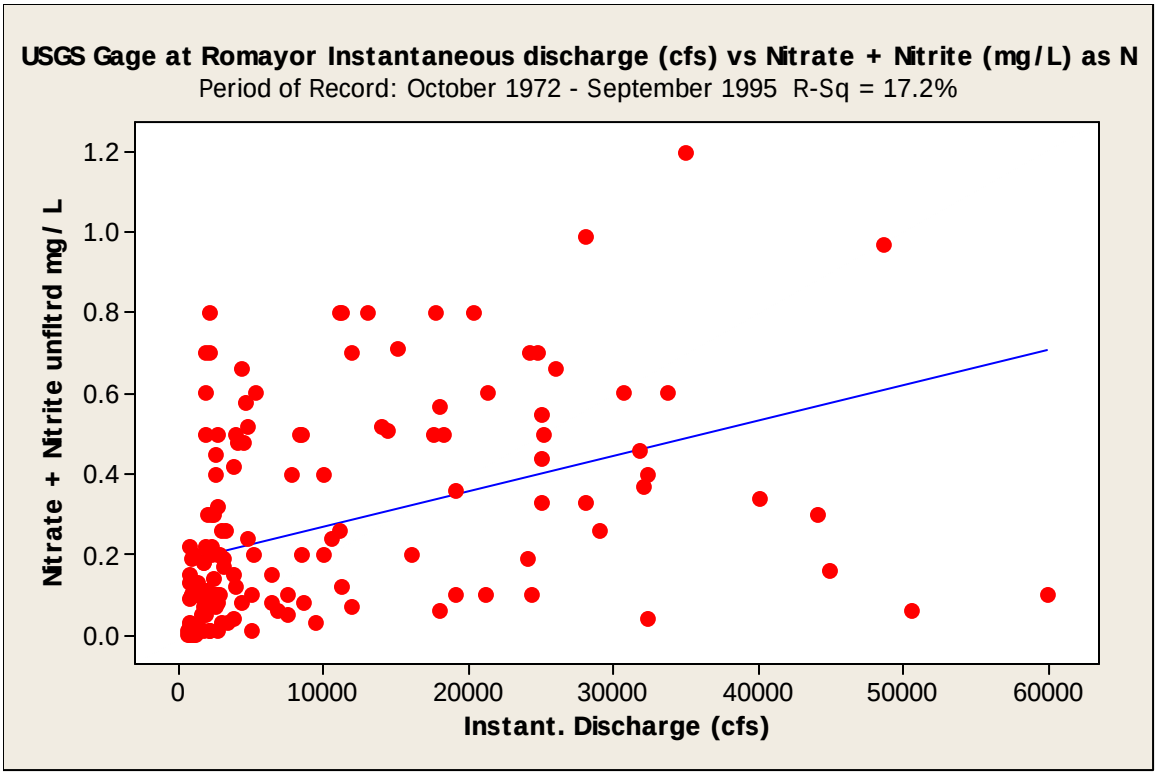


Figure 125. Flow versus nitrate+nitrite nitrogen at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

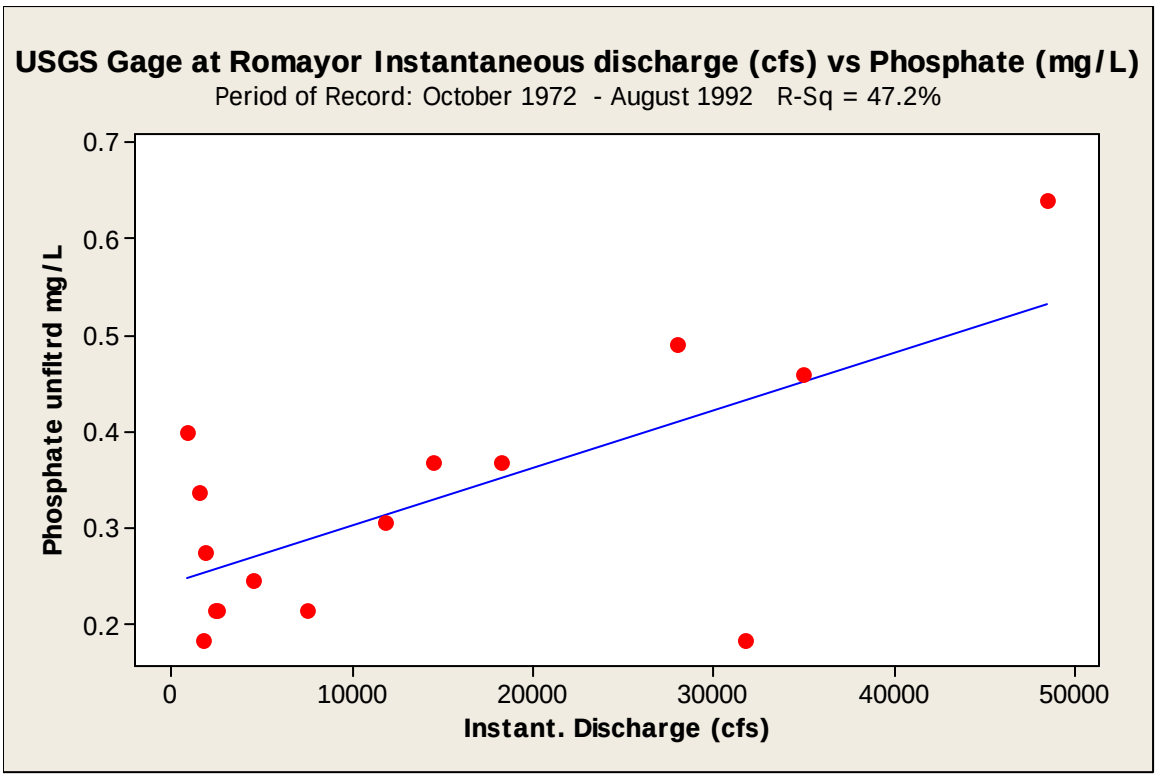


Figure 126. Flow versus phosphate at the Trinity River at Romayor 08066500 gage during 1972 through 1992.

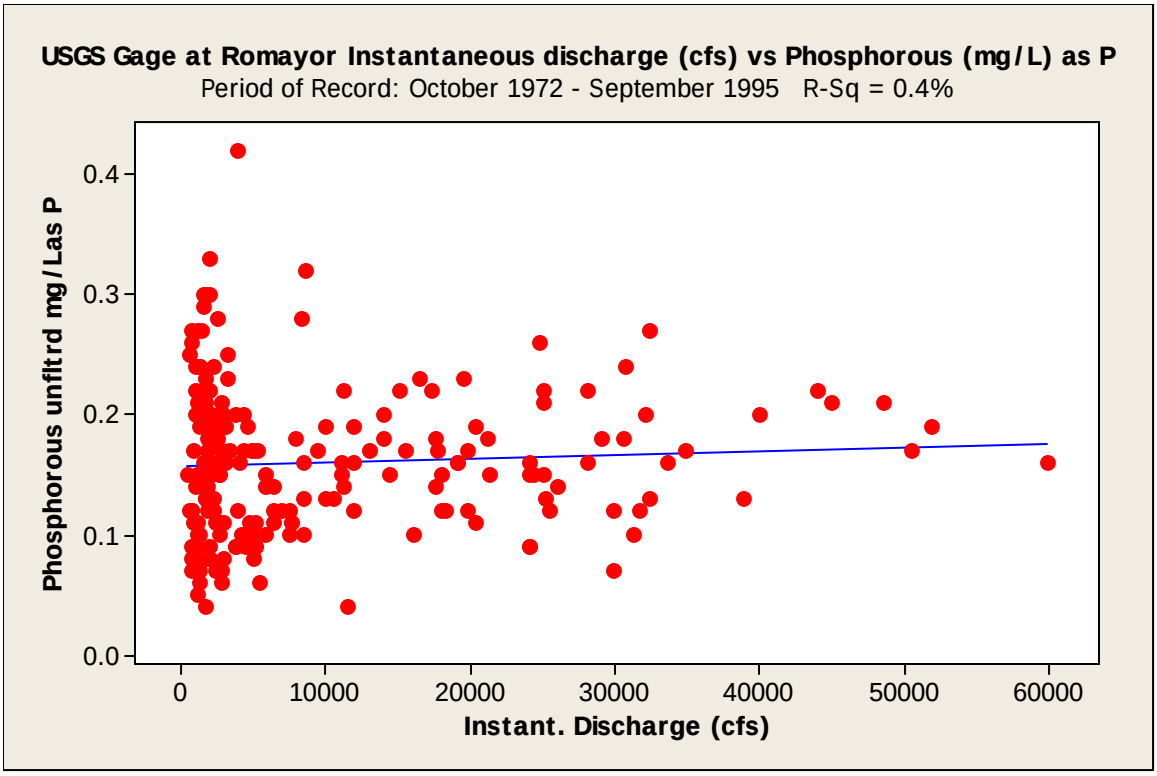


Figure 127. Flow versus phosphorus at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

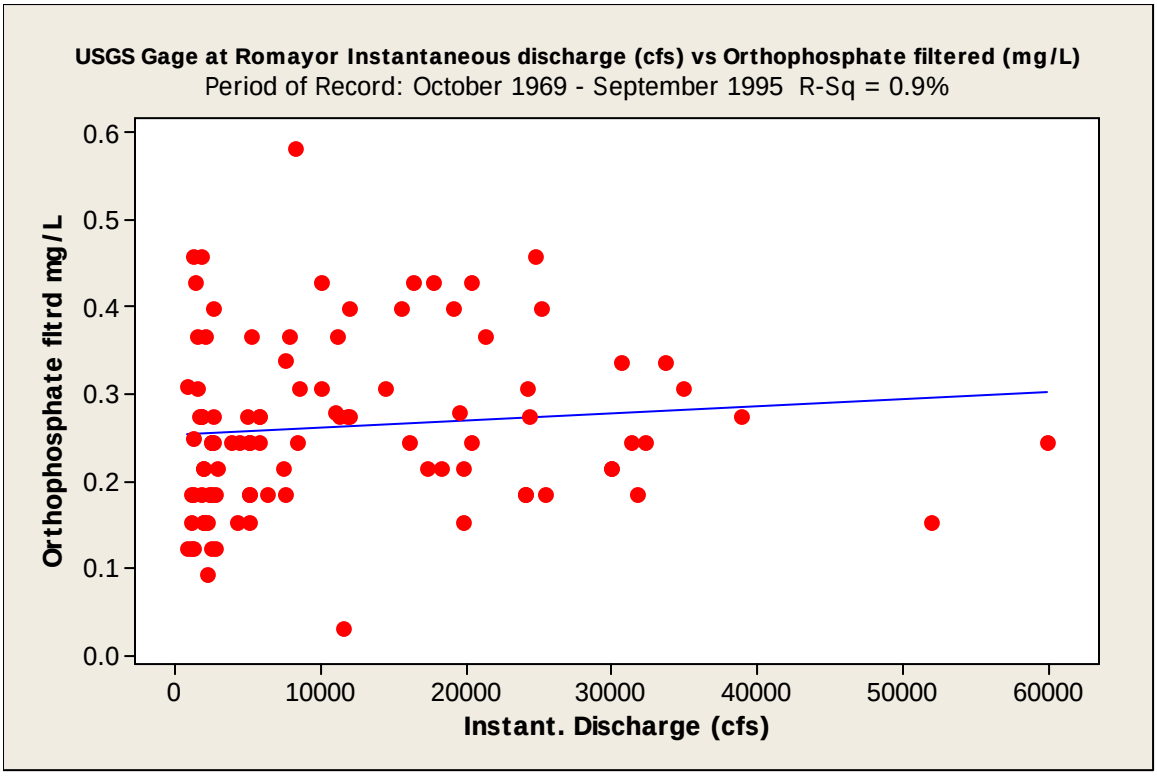


Figure 128. Flow versus orthophosphate at the Trinity River at Romayor 08066500 gage during 1969 through 1995.

Loading estimates for total nitrogen and phosphorus were best fit by a log-log regression model (Figures 129 and 130). By comparing these estimates to those previously generated for the upstream Crockett gage we can easily observe that comparable flow rates below Lake Livingston produced lower loading rates (Figures 106, 108, 129 and 130). For example at 1,000 cfs total nitrogen loads were 12,340 and approximately 2,000 kg/d respectively (Figures 106 and 129). At higher flow rates such as 14,600 cfs we see values decline from approximately 57,000 kg/d to 37,600 kg/d total nitrogen. Similarly at 15,000 cfs maximum total phosphorus levels at the Crockett gage were approximately 18,000 kg/d in contrast to only 6446 kg/d at the downstream Romayor gage. Although there are contributing tributaries between the two gages, these data indicate that Lake Livingston is likely reducing the downstream transport of nutrients to Galveston Bay. USGS data on TSS at the gage sites were limited above and below Lake Livingston. We therefore utilized historical TCEQ data. We observed a general downstream decline in total suspended solids (TSS) within the Trinity River basin (Figures 131 and 132). In general TSS declined downstream from the upper Trinity River (segment 0805) and was lowest downstream of Lake Livingston (0802).

Past Studies – Water Quality

In addition to the historical water quality data obtained from USGS priority gage sites and the TCEQ/CRP water quality monitoring network we also reviewed available studies that were compiled as part of the EIH Trinity River literature review. This included both peer reviewed articles and agency reports. We have plotted the location of these studies on Figure 132. Although there have been numerous studies on water quality and geomorphology in the basin, many are limited to specific issues or projects such as a receiving water assessments aimed at meeting a regulatory requirement, and therefore have limited system wide application. In addition, some studies focused on specific problems that are unlikely to be influenced by instream flow recommendations and/or cannot be significantly influenced or managed by manipulation of flow regimes. This includes persistent organic and metals contaminations related to aerial deposition such as mercury or pesticides. Even though extensive data exists on these subjects we will not spend any time discussing them (Chief Engineers Office 2006; Land and Brown 1996; Twidwell 2000) It should be noted that some of these stressors may in some cases limit aquatic life and may represent a limiting factor on their population viability. Similarly, one of the most cited causes for water quality impairment in the Trinity River basin was violation of recreational use criteria, that is elevated indicator bacteria (Texas Commission on Environmental Quality (TCEQ) 2009). This criteria is for protection of human contact recreation and not aquatic life use. In addition, instream flow criteria development would not be influenced by this water quality standard. The causes of violation of indicator bacteria based standards are varied and complex and include improperly operated wastewater treatment systems, livestock, malfunctioning septic systems, and wildlife.

Based on our review the three water quality variables that are influenced by changes in hydrology and in turn can potentially affect instream and downstream estuarine biological communities, or basin geomorphology are dissolved oxygen, nutrients and sediments. The lack of sediment supply due to dam construction, water diversion, and sea-level rise is a serious problem in some areas, leading to loss of wetlands ((Boesch et al. 1994). Since very few studies have found organisms with a need or even a preference for increased suspended sediment or sedimentation in the field or laboratory we will concentrate our data presentation and analysis on the effects of decreases in sediment supply to estuaries and watersheds (Berry et al. 2003; Newcombe and MacDonald 1991).

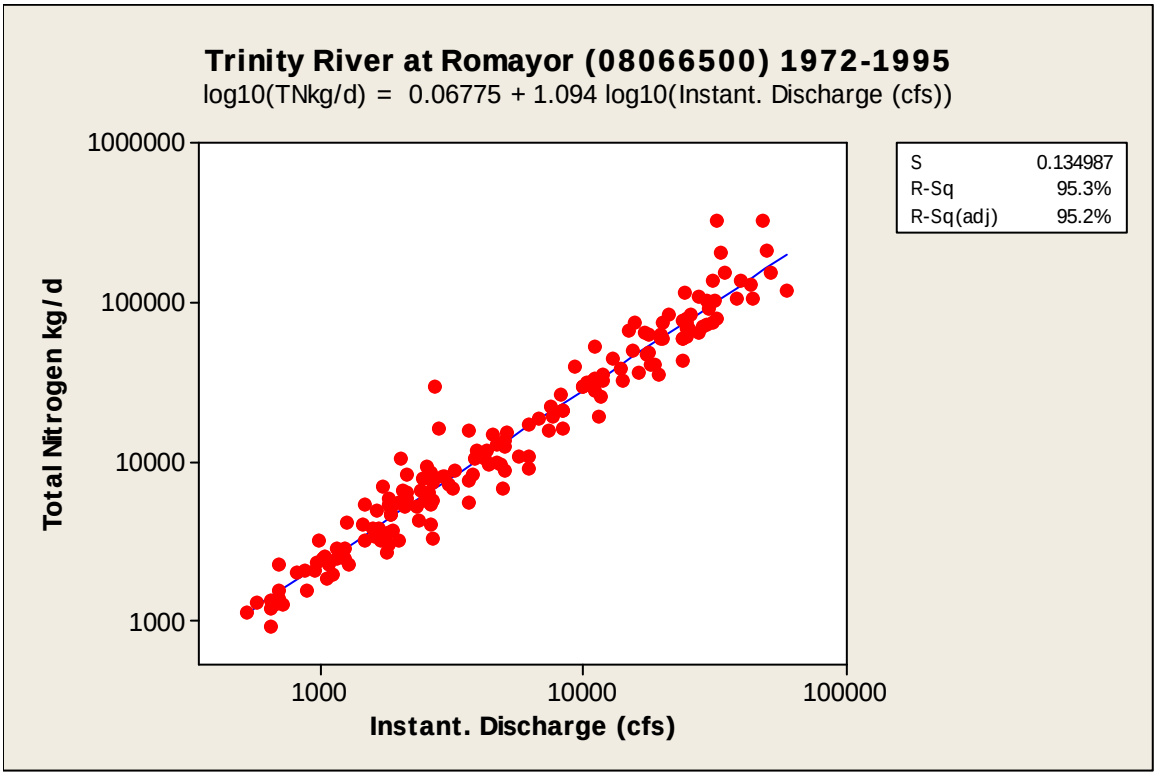


Figure 129. Flow versus total nitrogen loading at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

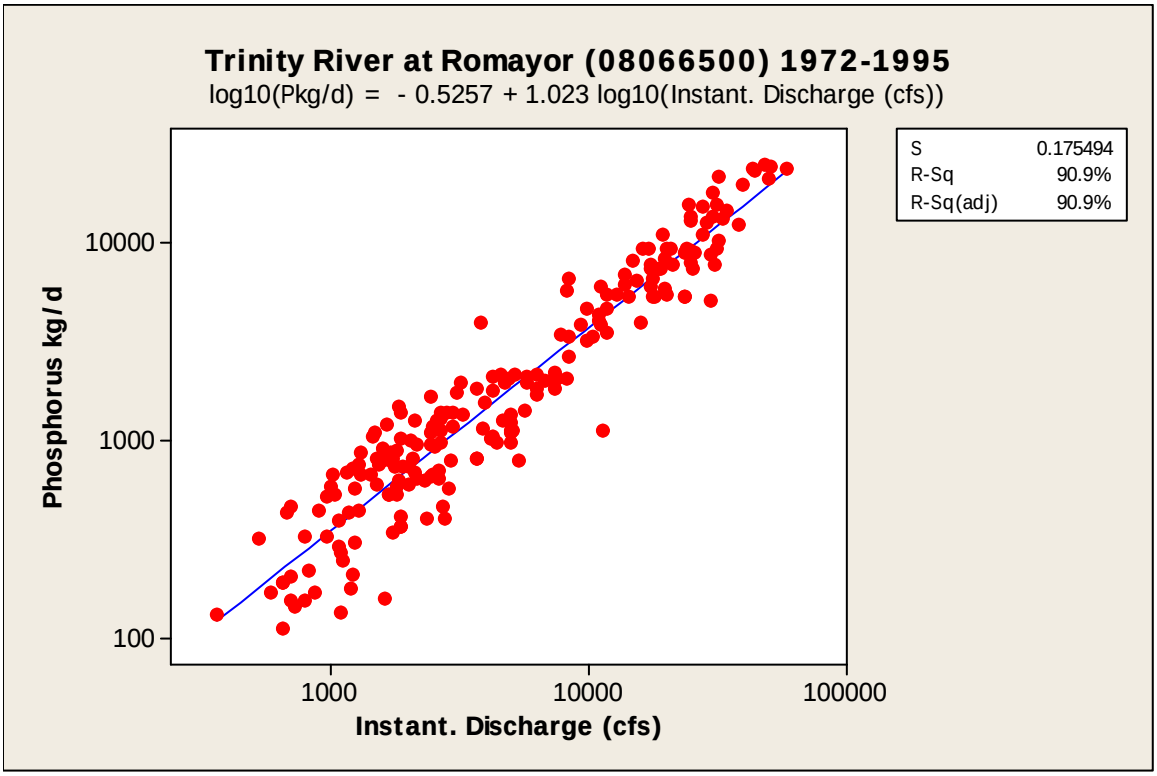


Figure 130. Flow versus total nitrogen loading at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

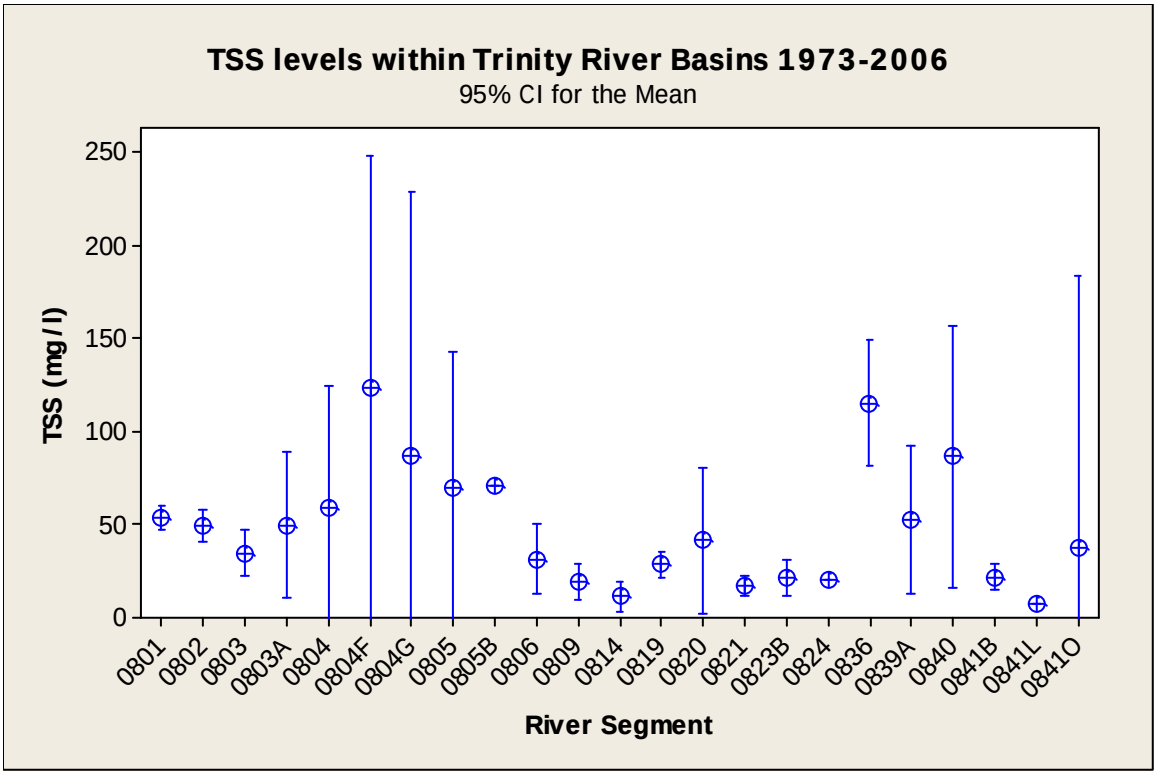


Figure 131. Historical mean and 95% confidence intervals of TSS levels in the Trinity River Basin (source: TCEQ SWQM database; Figure 2).

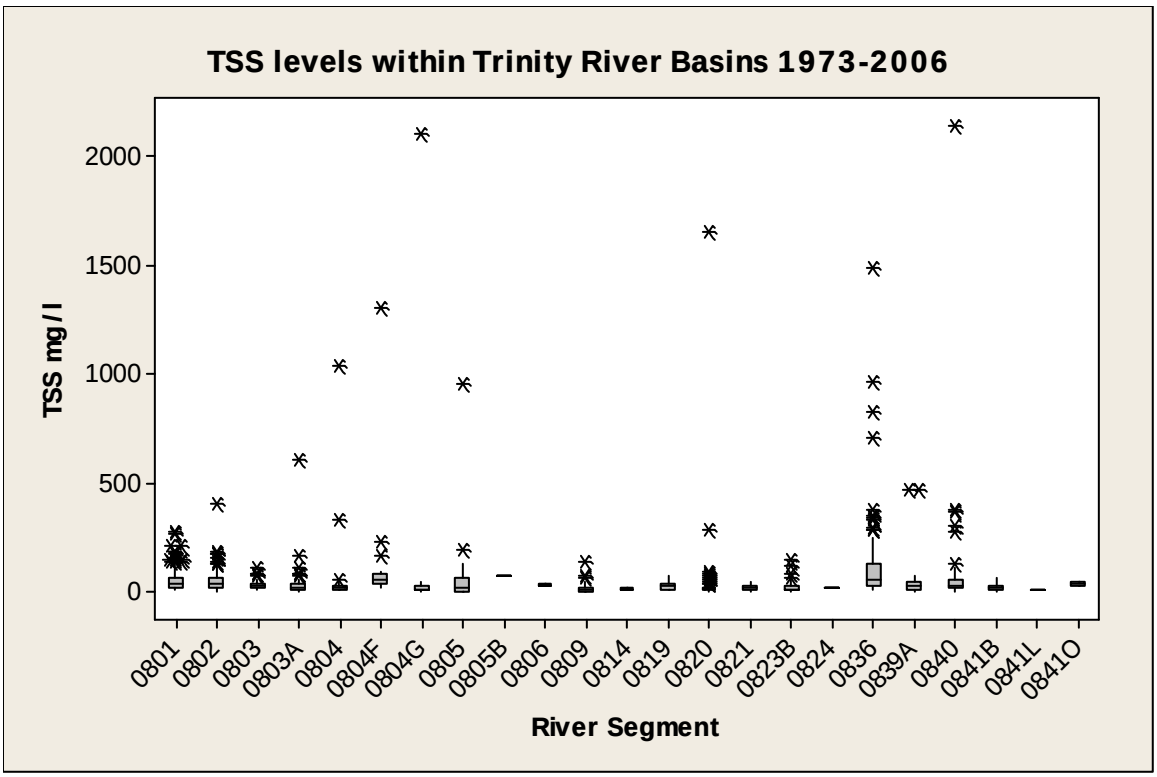


Figure 132. Boxplot depicting historical median and quartiles of TSS levels in the Trinity River Basin (source: TCEQ SWQM database, Map of segments = Figure 2).

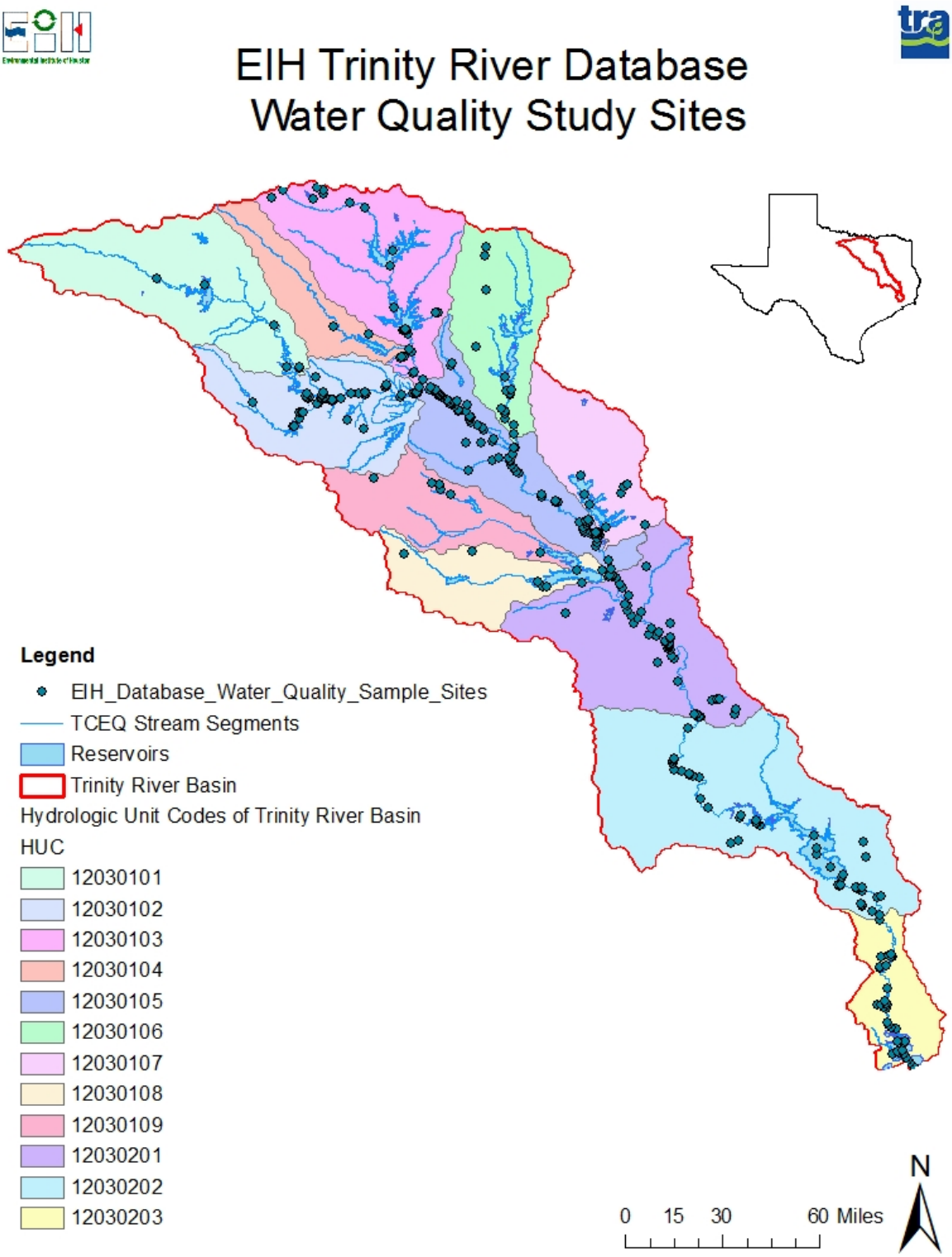


Figure 133. Location of water quality studies historically conducted within the Trinity River basin.

Suspended solids and associated turbidity is quite variable (means levels 125 to <25) within the Trinity Basin but is generally elevated compared to many other streams in the state. The State of Texas does not currently have a numerical turbidity standard for protection of aquatic life. It is highly unlikely though that severe adverse affects would occur to native fish present in the Trinity River under the existing range of turbidity reported. Many warmwater fish species are considered tolerant or adapted to naturally high turbidity levels (Waters 1995). The current species assemblage in the Trinity River has a long evolutionary history in the basin and is probably adapted to the elevated turbidity.

We will first deal with water quality issues affecting instream aquatic communities. The major water quality concern facing aquatic organisms in the mainstem Trinity River and upper tributaries historically has been hypoxia and/or anoxia. In 1925, the Trinity River in the Dallas-Fort Worth area was characterized by the Texas Department of Health as a "mythological river of death."(Browning 1991; Land et al. 1998) With a rapid expansion of industry and population and only primary wastewater treatment beginning in the late 1920s and secondary treatment in the mid-1930s, water-quality conditions in the area were degraded. Conditions did not substantially improve until State and Federal pollution control laws beginning in the early 1970s stimulated efforts to address poor water-quality conditions. For example, The Upper Trinity River Basin Comprehensive Sewage Plan of 1971 resulted in the construction of large, regional wastewater-treatment plants, elimination of many small, industrial and municipal wastewater-treatment plants, and the upgrading of existing wastewater-treatment plants. Advanced wastewater-treatment processes that include nitrification (conversion of ammonia nitrogen to nitrate) were implemented at the new large wastewater-treatment plants that discharge into the Trinity River in the Dallas-Fort Worth area in the late 1980s (Dickson et al. 1991; Land et al. 1998). Large concentrations of ammonia are toxic to fish and other aquatic organisms. Ammonia levels in the Trinity River downstream from Dallas exceeded the TCEQ criterion for dissolved ammonia in freshwater streams and reservoirs (1.0 milligram per liter) consistently until the late 1980s (Land et al. 1998). Since then, the nitrification process used in wastewater-treatment plants has reduced the amount of ammonia nitrogen that is discharged to the river.

During the period between 1970 and 1985, a total of 13 fish kills were documented in the Trinity River from a reach just downstream from Dallas to Lake Livingston in the lower part of the Trinity River Basin (Davis 1987; Dickson et al. 1991; Land et al. 1998). The magnitude and frequency of the fish kills resulted in a depleted fish community, particularly in the reach of the Trinity River immediately downstream from Dallas. An estimated 1.04 million fish died in these 13 kills. Twelve of the 13 fish kills were associated with minor flooding on the Trinity River from rainfall in the Dallas-Fort Worth metropolitan area. According to the Texas Parks and Wildlife Department (TPWD), the probable cause of the kills was the resuspension of bottom sediments and associated organic material during floods that caused an increase in biochemical oxygen demand and a corresponding rapid drop in dissolved oxygen (Davis 1987). Ironically, improvements in water quality during the 1970s set the stage for the fish kills by allowing appreciable fish populations to live in this reach of the Trinity River. Dissolved oxygen, measured as milligrams of oxygen per liter of water, has increased from lows of near zero in the early 1970s to highs of more than 10 milligrams per liter in 1996 (Land et al. 1998) . Notable improvement in dissolved oxygen concentrations in the Trinity River downstream from Dallas began in the mid 1970s and continued through the 1980s and into the 1990s (Schertz et al. 1994). Dissolved oxygen was consistently recorded above the state dissolved oxygen criterion for the support of aquatic life (5.0 milligrams per liter) beginning in the late 1980s. The improvement in dissolved oxygen concentrations is attributable to improvements in wastewater-treatment

practices and the corresponding reduction in the discharge of oxygen-demanding materials from wastewater-treatment plants and industry (Dickson et al. 1991).

As early as 1957, TPWD biologists had documented polluted water in the areas below Fort Worth to Trinidad suffered from pollution (Lamb 1957a; Lamb 1957b). In addition, TPWD biologists were responding to fish kills in the West Fork of the Trinity caused by sewage bypasses (Lamb 1957b). (Lamb 1960) describes fish kills caused by “black-rises”. He describes this as an event that residents below Dallas are very familiar with and occurs when rains scour out the accumulation of organic debris that is deposited in the river during periods of low water. When flow is increased this material is resuspended and moves down the river at high concentrations and kills fish. (Lamb 1961) and (Lamb 1962a) further described numerous sewage bypasses causing fish kills downstream of Fort Worth in the Trinity River during 1960-1961. He noted that the heavier than normal rainfall experienced by the Trinity River watershed in 1961-1962 tended to prevent the usual fish kills on the West Fork of the Trinity in Fort Worth (Lamb 1962b). He further reports that by 1963, “the sewage pollution in the West Fork of the Trinity River, in Fort Wort, has continued, but the fish population has been decimated by previous pollutions and it is believed that few fish remain to be killed”(Lamb and Smith 1964). Water quality surveys conducted by the USGS in 1967 revealed poor water quality in the upper Trinity River associated with sewage discharges (Leifeste and Hughes 1967). They cited a 1958-1960 Texas Department of Health Survey which suggested the poor water quality is due to inadequate collection and treatment of sewage and industrial wastes.

As a result of persistent anoxia and hypoxia, the fish community in the Trinity River immediately downstream from Dallas was almost nonexistent in the early 1970s (Land et al. 1998; TPWD 1974). Only four species of fish were collected by the TPWD during 1972-74. They include smallmouth buffalo, gizzard shad, common carp, and yellow bass. Four of the six surveys yielded no fish from this reach of the river. Two of the species, gizzard shad and common carp, generally are classified as tolerant taxa and could be expected to tolerate the water-quality conditions in this reach in the 1970s. Further downstream beyond the confluence with the East Fork of the Trinity conditions were more favorable in areas with increased dissolved oxygen and numbers of fish species ranged between 4 to 13 species per collection (Smith 1974). Dissolved oxygen levels began to increase in the mid 1970s (Schertz et al. 1994). Segments of the Trinity River in this section which supported only limited numbers of certain fish species had greatly improved by late 1974 (Smith 1974). Further downstream near the headwaters of Lake Livingston during this same time period the number of fish species collected had increased to 16 to 22 (Provine 1974).

Within twenty years, the fish community in a reach of the Trinity River downstream from Dallas had markedly improved. Improvement was most evident in the number of fish caught and the number of species, including those that are not tolerant of polluted water. The TPWD collected 11 species of fish from this reach in 1987 (Kleinsasser and Linam 1989; Land et al. 1998). Although the 1987 survey yielded more species than the 1972-74 surveys, the TPWD still considered the species richness low and attributed the condition to the fishes' exposure to ammonia nitrogen and heavy metal toxicity associated with wastewater-treatment plant effluents (Davis 1991; Kleinsasser and Linam 1989).

The USGS conducted fish-community surveys on the reach at Trinity River downstream from Dallas during 1993-95 (Land et al. 1998). The methods used by the USGS were identical to the methods used by the TPWD in 1987. A cumulative total of 25 species of fish were collected in

this reach during the 3-year period. Several game species were collected including largemouth bass, white crappie, and white bass. None of these game species were collected in the reach during the 1972-74 or 1987 surveys. Two darter species, bigscale logperch and slough darter, also were collected. The presence of these indigenous species suggests a return of this reach to a more natural condition. Other species characteristic of warm-water southeastern streams including alligator, spotted, and longnose gars and flathead, blue, and channel catfish were frequently collected during the 1993-95 survey. None of the gar or catfish species were reported in the reach downstream from Dallas in the 1972-74 or 1987 TPWD surveys. The change since 1972-74 is a likely consequence of improvements in water quality, particularly improvements in the quality of discharges from wastewater-treatment plants in the Dallas-Fort Worth area (Schertz et al. 1994).

Based on USGS surveys nutrient levels remained unchanged in Trinity River Basin streams between 1974 and 1991 (Land et al. 1998; Van Metre and Reutter 1995). Water-quality trends were evaluated for about 4,800 samples from streams. Concentrations of total nitrogen and phosphorous have not changed significantly from 1974 to 1991 at most sites, although there was a decrease in phosphorous concentrations near Dallas. Spatial variations in chemical concentration in streams are related primarily to point sources and reservoirs. The largest nutrient concentrations occur downstream from Dallas, where streamflow is dominated by treated wastewater. The smallest concentrations occur just downstream from reservoirs, which act as sinks for nutrients. The median concentrations for total nitrogen and total phosphorus for most of the Trinity River below Dallas and below Lake Livingston was 6.0 and 1.3 mg/l N, and 1.6 and 0.1 mg/l P, respectively (Van Metre and Reutter 1995). There continued to be a lack of temporal trends during the period from 1993 to 2003 for nitrates as measured at the Crockett 08065350 gage located above Lake Livingston (Sprague et al. 1009). The State of Texas currently does not have nutrient criteria for rivers and streams. Only narrative criteria are provided, which states "Nutrients from permitted discharges or other controllable sources shall not cause excessive growth of aquatic vegetation which impairs an existing, attainable, or designated use"(TNRCC 2000). The EPA has provided technical guidance on development of appropriate numerical criteria based on regional index sites and streams (EPA 2000). The recommended criteria for he variables we have discussed for the Trinity River are 0.067 mg/l NO2+NO3, 0.385-0.507 mg/l TN and 50 ug/l TP. Most of the values we have observed and have been reported in the literature for the Trinity River are above these recommended criteria. It should be noted however that the range of values used to derive these criteria bracket the values observed in the historical record and are quite variable.

Past Studies – Nutrient and Sediment Loading to Galveston Bay

Rivers are major sources of dissolved and suspended nutrients and solids to estuaries in the Gulf of Mexico (Bianchi et al. 1999). Since stream velocity affects the ability to transport sediment, any future management of streamflows could theoretically affect the downstream transport of nutrients and sediments. This has major implications for stream geomorphology and the deltaic environment of the Trinity River. In addition, changes in nutrient inputs into the estuary can change potential primary production within the estuary. Therefore it is necessary to quantify the current and potential loadings associated with changes in streamflow. In addition, since the Trinity River has a major reservoir and dam located (Lake Livingston) near the coast the ability to transport sediments and nutrients has been likely altered based on past studies and data presented in this report. As previously mentioned the median concentrations for total nitrogen and total phosphorus for most of the Trinity River below Dallas and the Trinity River below

Lake Livingston was 6.0 and 1.3 mg/l N, and 1.6 and 0.1 mg/l P, respectively (Van Metre and Reutter 1995). This suggests nutrient levels are reduced as they pass through reservoirs. They specifically estimated loads for three time periods which are presented below in Table 10. The largest reductions occurred in total phosphorus. A focus of their study was to evaluate the influence of Lake Livingston on the downstream transport of phosphorus, nitrogen and suspended solids. They found that all nutrients were generally reduced (Van Metre and Reutter 1995)(Figure 134). The difference in loads observed between these two sites can be attributed to trapping of sediments in Livingston Reservoir. The largest differences in annual suspended sediment loads generally occurred during years of greatest discharge (Figure 134).

Table 10. Mean nutrient loads and mean daily discharge for five priority gage sites in Trinity River Basin estimated by (Van Metre and Reutter 1995).

USGS Gage ID	1974-1979		1984-1989		1974-1989		
	NO2+NO3kg/d	Mean Daily cfs	NO2+NO3kg/d	Mean Daily cfs	Total N kg/d	Total P kg/d	Mean Daily cfs
08049500 West Fork T. River	1,600	565	3,800	777	5,900	2,300	706
08062700 Trinity River @ Trinidad	3,700	2,683	25,100	3,213	32,600	9,800	3,037
08065000 Trinity River near Oakwood	9,000	3,278	Not Estimated	3,213		9,000	3,955
08065350 Trinity River near Crockett	15,800	5,544	24,200	5,579	36,900	10,200	6,038
08066550 Trinity River at Romayor	6,300	8,369	9,700	7,310	24,000	3,600	7,592

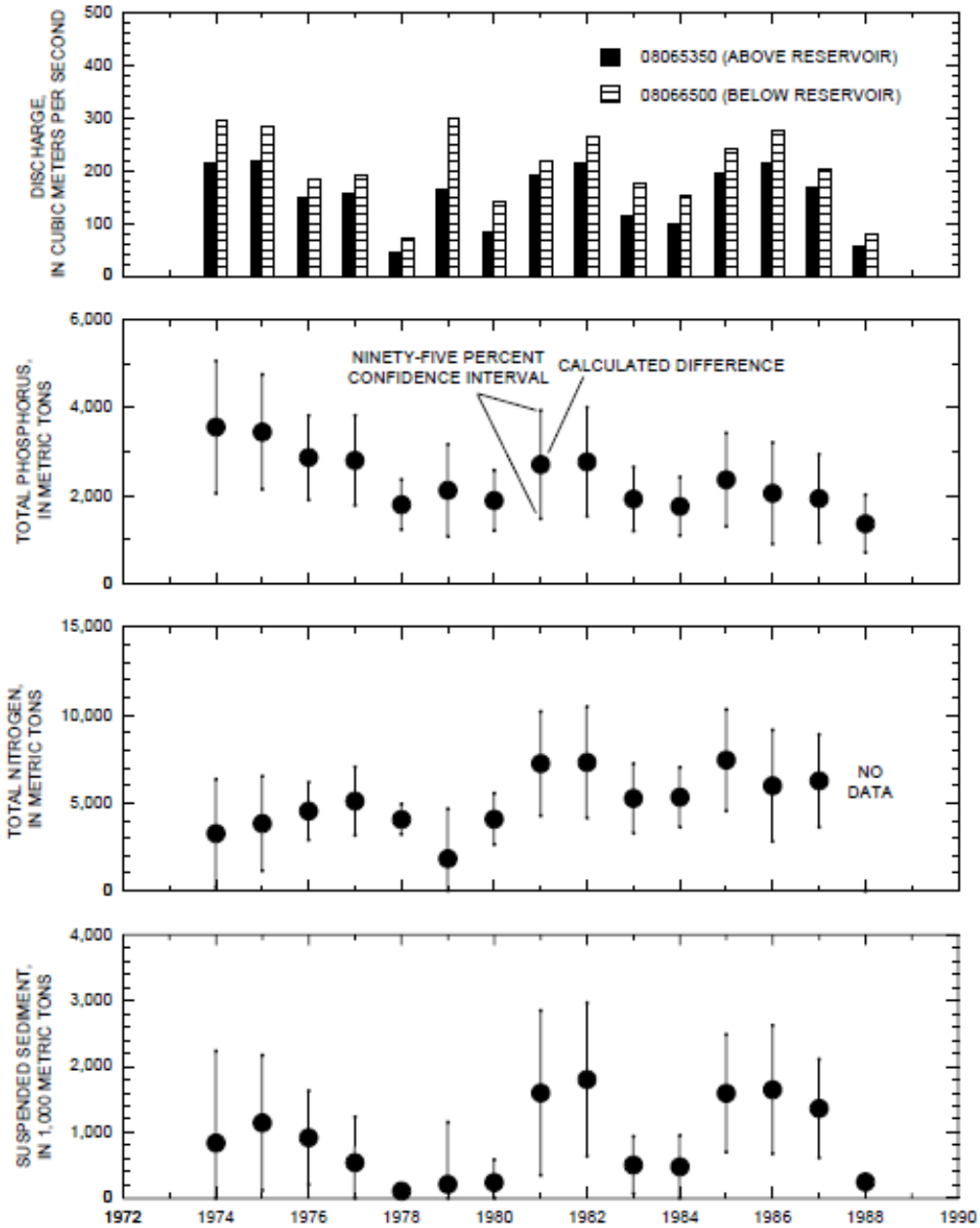


Figure 134. Discharge and difference in nitrogen, phosphorus and sediment loads for sites above and below Livingston Reservoir, 1974-88 (Load differences were calculated by subtracting the loads below Livingston Reservoir from the loads above Livingston Reservoir.) Reprinted from: (Van Metre and Reutter 1995).

(Jensen et al. 2003) reviewed various sources of data on loading into Galveston Bay and summarized pertinent information on the influence of Lake Livingston on nutrient loading (Figures 135-138). He found based on estimates presented in a paper he published in 1991 that the largest point source contribution of nitrogen to Galveston Bay is the Trinity River (Clingenpeel 2002; Jensen et al. 1991) (Figures 135-138). In addition, the construction of Lake Livingston in 1969 had an immediate effect on nitrogen loading to the basin along with enhanced wastewater treatment (Figure 135). He reported that based on Cligenpeel 2002 analysis, loading due to watershed runoff in the Lake separate from the Trinity River had a much greater influence during wet years (Figure 136). He also found, consistent with the TSS trends observed by USGS, that the highest percent reductions in nitrogen and phosphorus occurred during drier years (Jensen et al. 2003; Van Metre and Reutter 1995) (Figure 137). He also concluded that rates of reductions in phosphorus had declined similar to the previous USGS reports but was greatest during wet years suggesting a linkage between reductions in suspended solids and phosphorus (Clingenpeel 2002; Jensen et al. 2003; Van Metre and Reutter 1995)(Figure 138). (Armstrong and Ward Jr. 1993) also provided additional estimates of annual loading of TSS, total nitrogen and total phosphorus as part of an overall contaminants loading study of Galveston Bay (Figures 139-141). They found that Trinity River loads were often up to 10 times greater than any other tributary within the system. The Trinity River during 1968 to 1988 contributed 63, 65 and 58% of the tributary loads of TSS, TN and TP (Armstrong and Ward Jr. 1993). When compared to all sources including other tributaries, point source discharges within the local basin and non-point source runoff estimates in the local watershed, the Trinity River was the most dominant source of total suspended solids and total nitrogen (Armstrong and Ward Jr. 1993).

Past Studies – Sediment and Geomorphology

We had previously conducted a literature review which involved assembling recent and pertinent geomorphology studies within the Trinity River watershed (Figure 142). We examined these publications to evaluate pertinent information on important channel processes including additional studies on suspended sediment transport. From these studies we selected a few key studies that deal with important aspects of hydrology and sediment transport and channel formation.

(Slattery and Phillips 2007) recently conducted a study on the influence of Lake Livingston on the downstream transport and fluvial dynamics of sediment below the dam. Their research study focused on documenting the effects of the Lake Livingston dam on downstream sedimentation processes, in particular the delivery of sediment to the lower Trinity River, Trinity Bay estuary and Galveston bay. Some of the main objectives of that study included identifying the major sediment sources for the Trinity River delta and Trinity Bay, evaluate the effects of various human and natural controls on sediment transport and storage in the lower Trinity River, evaluating the effects of channel slope, flow, and water withdrawals from the Trinity River on sediment transport capacity in the lower River They conducted their study in part because there have been very few studies on the on the effects of the impoundment on the downstream tributaries. These tributaries have been noted for contributing significant inputs of energy (flow) and mass (sediment) to the mainstem system. Based on their analysis of stream discharge data in the lower Trinity basin they ruled out modifications in the discharge regime as a significant cause of change in lower river geomorphology.

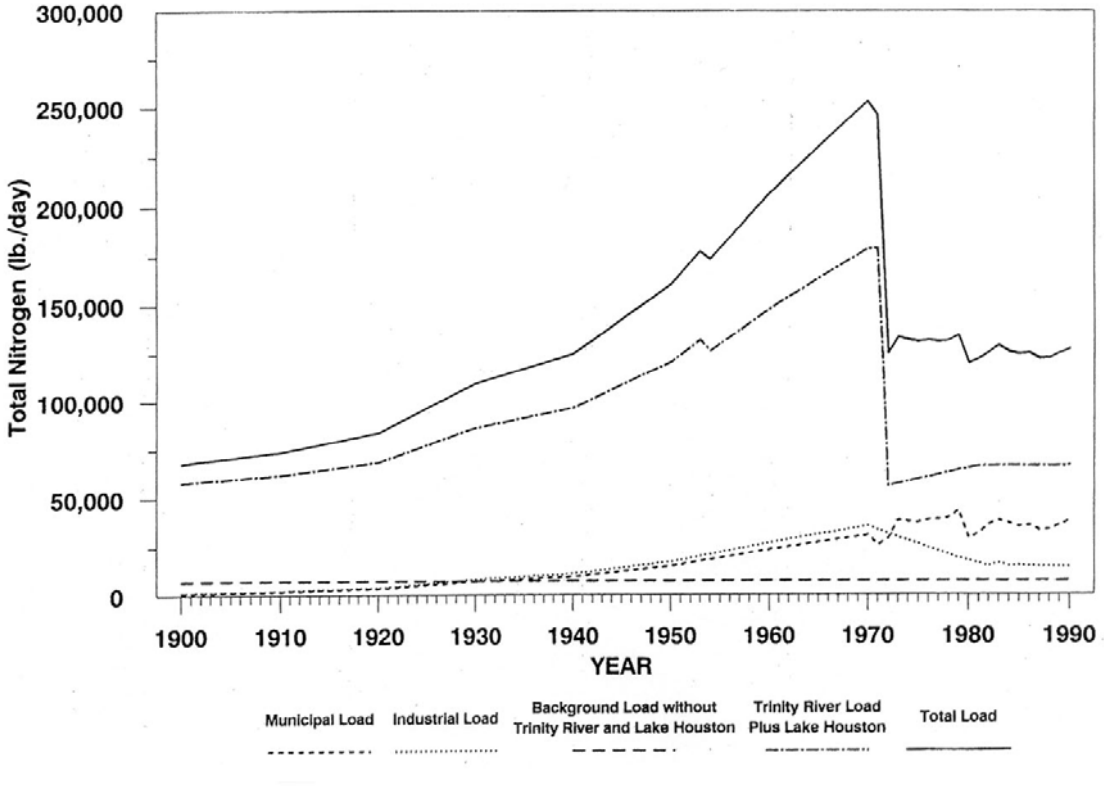


Figure 135. Historical Estimates of nitrogen loads. Source: (Jensen et al. 1991).

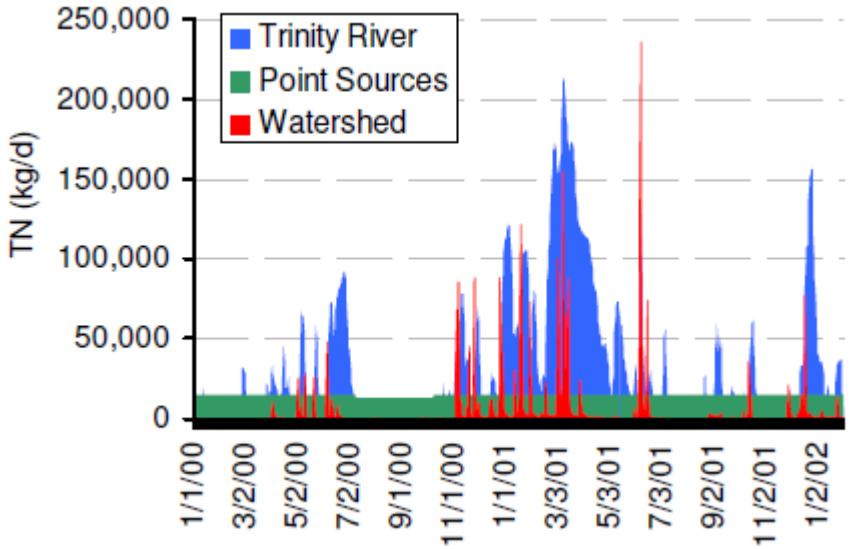


Figure 136. Total nitrogen loads estimated presented and cited by (Jensen et al. 2003). Original source: (Clingenpeel 2002)

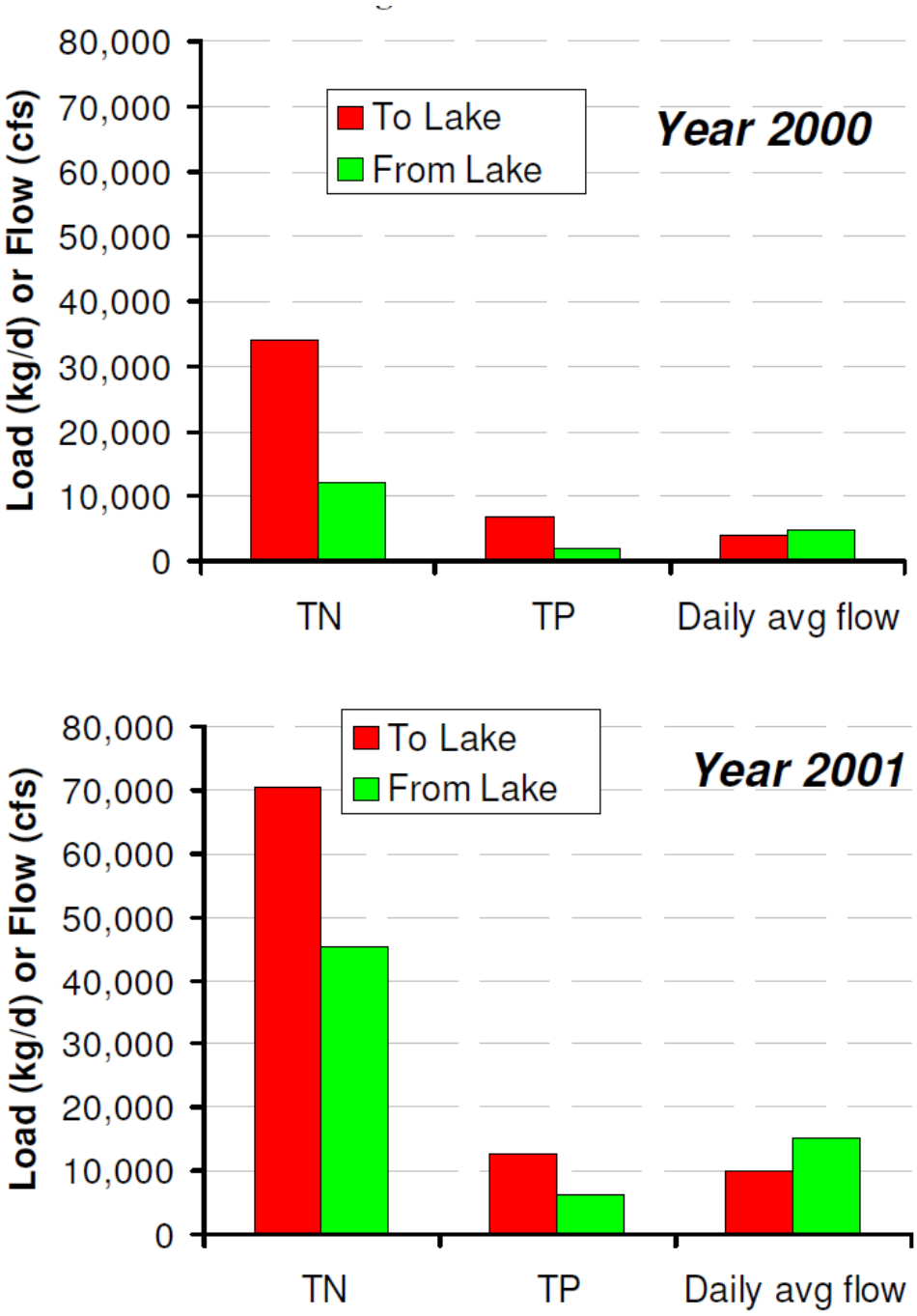


Figure 137. Average Daily Loads of total nitrogen and total phosphorus to and from Lake Livingston. From: (Jensen et al. 2003).

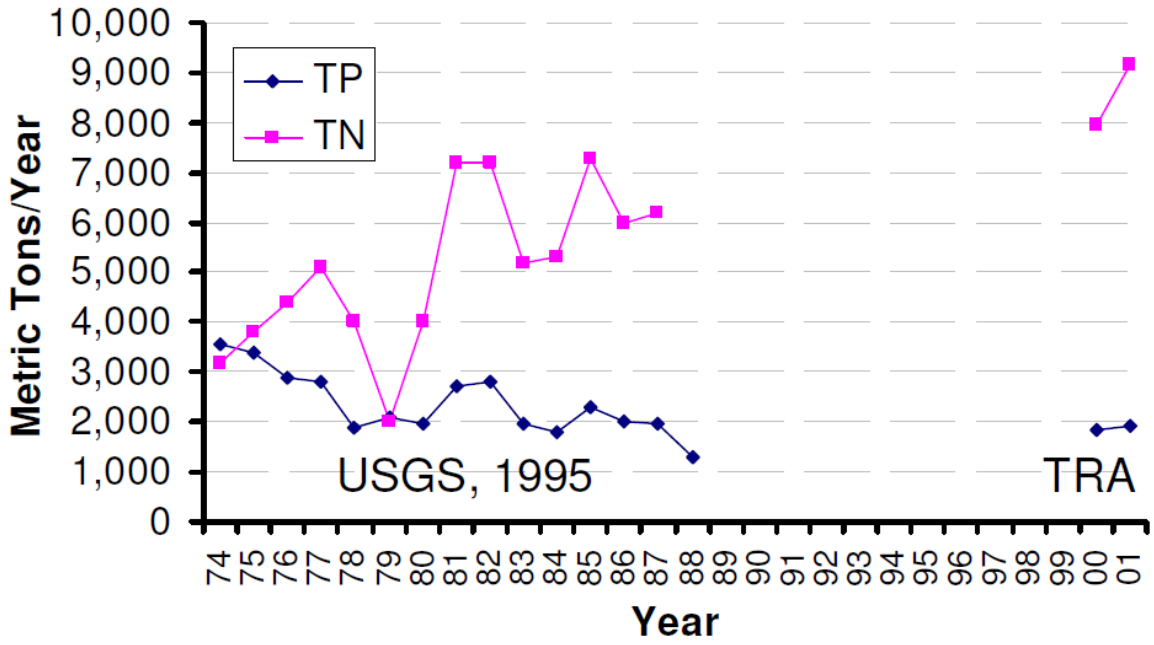


Figure 138. Comparisons between total nitrogen and phosphorus removal. Sources: (Clingenpeel 2002; Jensen et al. 2003)

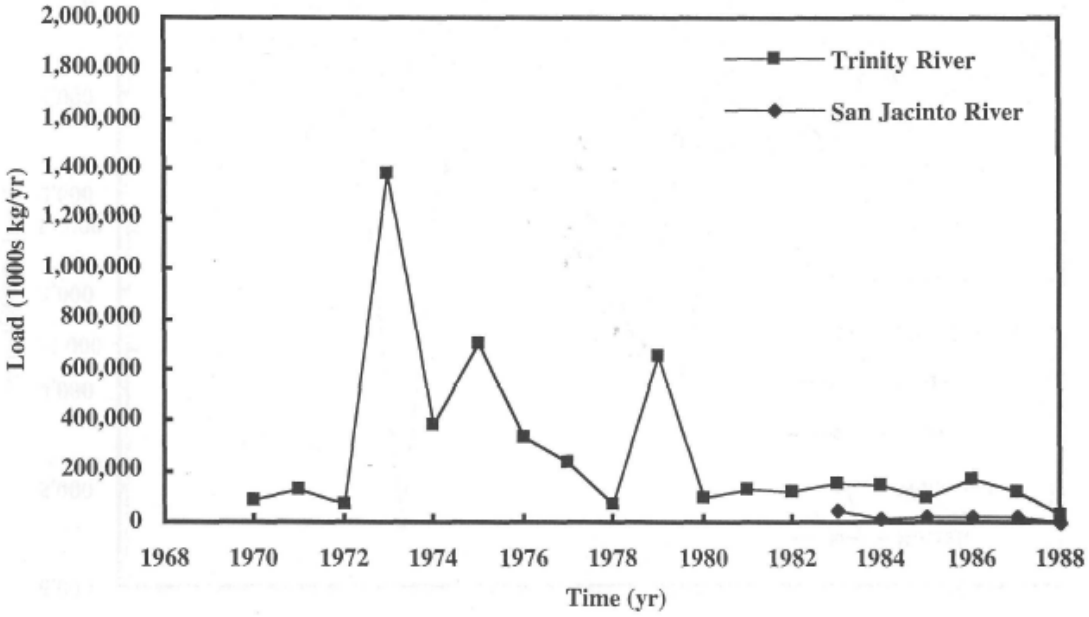


Figure 139. Estimated loads of total suspended solids into Galveston Bay from the Trinity River at Romayor and from the San Jacinto River from 1969 through 1988. Source: (Armstrong and Ward Jr. 1993)

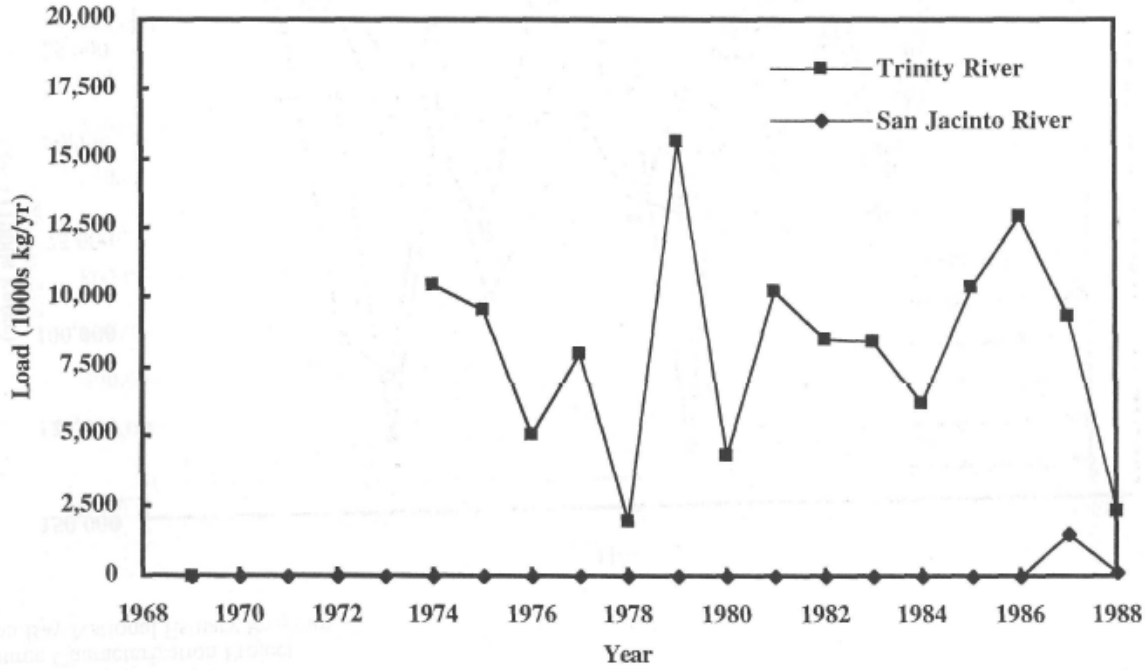


Figure 140. Estimated loads of total nitrogen into Galveston Bay from the Trinity River at Romayor and from the San Jacinto River from 1969 through 1988. Source: (Armstrong and Ward Jr. 1993)

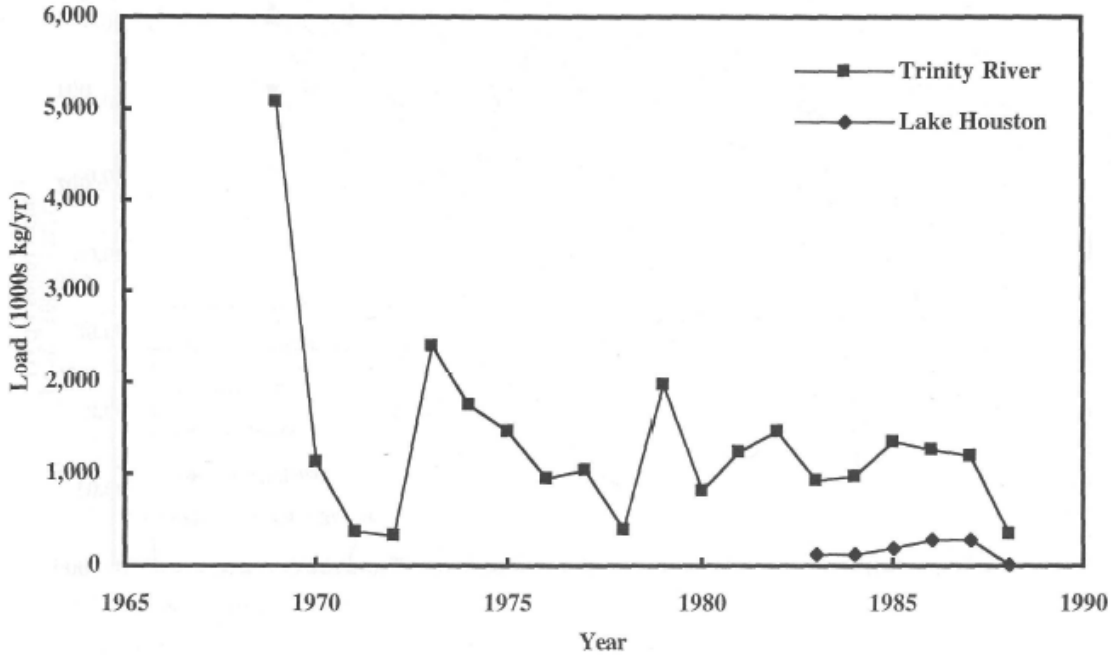


Figure 141. Estimated loads of total phosphorus into Galveston Bay from the Trinity River at Romayor and from the San Jacinto River from 1969 through 1988. Source: (Armstrong and Ward Jr. 1993)

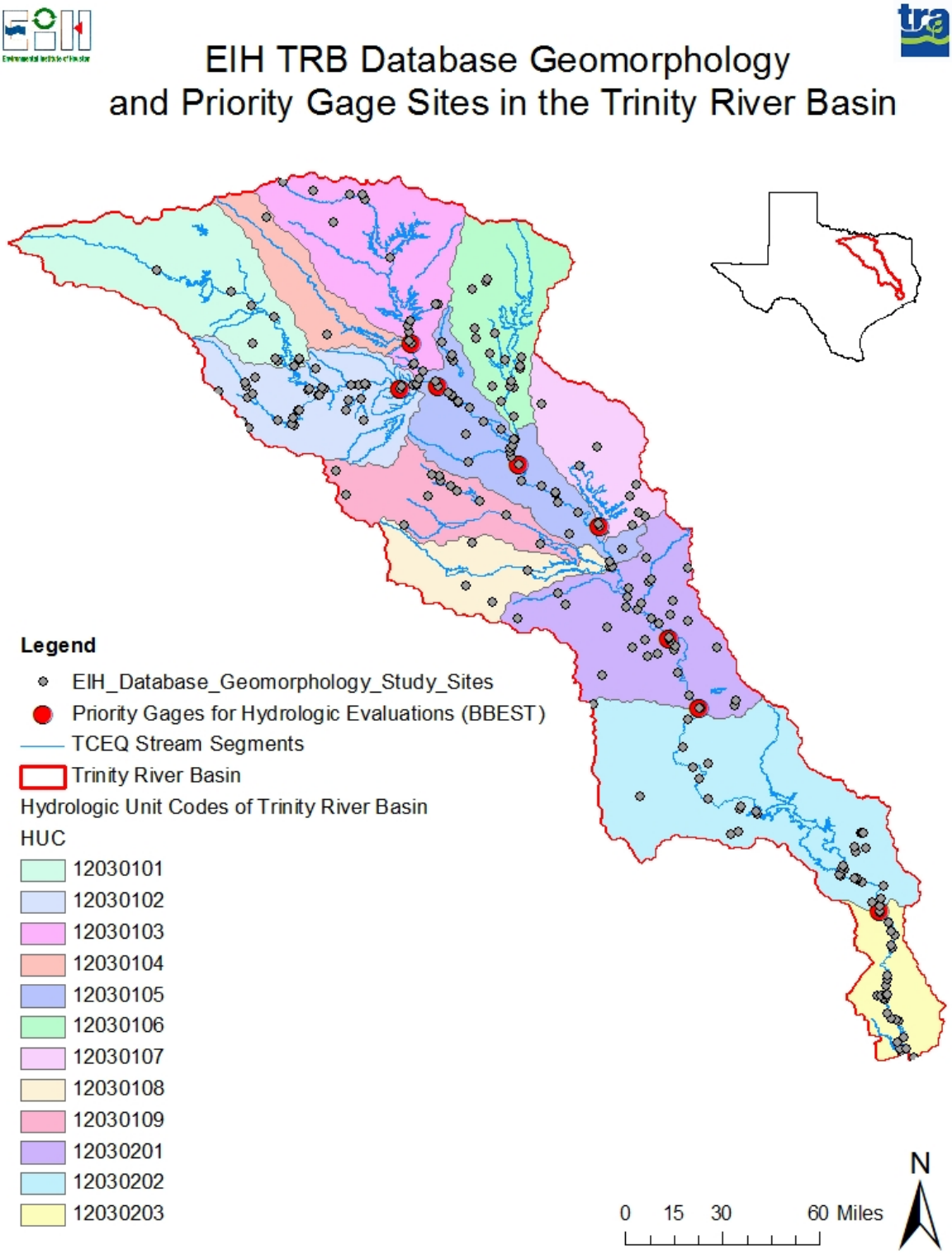


Figure 142. Location of geomorphology study sites based on recent Trinity literature review.

They concluded that the two gauged tributaries below the dam (Long King Creek (LKC) and Menard Creek) along with the three stations on the Trinity River (Goodrich, Romayor and Liberty) do not show any indication of post-dam alterations in flow. On the mainstem, slightly elevated flows in the post-dam period can be attributed to higher than - average precipitation during this corresponding period (Slattery and Phillips 2007). They observed that even though no general change in flow regime is associated with the dam, flood waves are slowed as they pass through Lake Livingston. Thus, tributary flows are out of phase with the Trinity River. Subsequently, the tributaries peak sooner. When the tributaries are carrying their maximum sediment loads to the mainstem, the Trinity has not yet reached its maximum transport potential, and deposition occurs. While changes in the characteristics of the LKC delta have occurred, a delta did exist prior to 1968 and the dam emplacement. As Trinity flows increase, stream power increases, transporting portions of the recently deposited alluvium. While the Trinity flow increases, tributary flows are decreasing, creating backwater flooding. They found evidence of backwater deposits occurs on the delta surfaces at the mouths of LKC and MC (Slattery and Phillips 2007).

(Slattery and Phillips 2007) defined a critical zone as a boundary between different channel responses, channel and valley morphologies, and sediment transport and storage regimes. Earlier studies conducted on the channel morphological responses of the Trinity River to Livingston Dam were reported by (Phillips et al. 2005). Using seven cross-sections from just downstream of the dam to Romayor, about 52 km downstream, they showed morphological evidence of channel scour and/or widening in response to the dam. At the Romayor site, they observed exposed bedrock in the channel, indicating recent scour. This was observed in the channel a short distance downstream of Romayor. However, they did not see any evidence of scour at the cross-sections examined 8 km downstream of Romayor. They also did not see any morphological response to the dam at ten cross-sections between Romayor and Trinity Bay (Phillips et al. 2005). Analysis of suspended sediment transport data from gaging stations at Romayor, located about 8 km upstream of the critical zone, and Liberty, about 45 km downstream, show pronounced differences in sediment transport regimes (Phillips et al. 2004). They estimated that the mean annual sediment yield at Romayor is nearly 3.4 million t yr-1, with a specific yield of 76 t km-2 yr-1. At Liberty, by contrast, the numbers are less than 69,000 t yr-1 and 1.6 t km-2 yr-1. Additionally, while the Romayor station shows a clear reduction in sediment transport following closure of the Livingston Dam, there is no evidence of any change at Liberty (Phillips et al. 2004). They concluded that downstream of Liberty low stream power and ample accommodation space creates a sediment storage bottleneck such that little upstream sediment was reaching the lower reaches of the river even before the dam was constructed. (Phillips et al. 2005) concluded that beyond 60 km downstream of the dam the Trinity River is characterized by extensive sediment storage and reduced conveyance capacity, so that even after dam construction sediment supply still exceeds transport capacity. Downstream of this point sea-level rise and backwater effects from the estuary are more important physical controls. (Phillips et al. 2004) pinpointed the transition in sediment storage regimes at what is called the critical zone in this paper, just downstream of a Deweyville palaeomeander scar, at a point where floodplain elevation generally decreases, width increases, and numerous modern oxbow lakes appear. They found that the reaches up- and downstream of the critical zone also differ significantly in sinuousity, slope, and stream power. Cross-sectional stream power at any given reference flow is 4.5 to 33 times greater at Romayor compared to Liberty, despite the higher discharges downstream, and unit stream power is 20 to 100 times higher upstream of the critical zone (Phillips and Slattery 2006b). The difference is mainly attributable to slope, as channel bed slopes are 25 times steeper upstream of Romayor.

(Phillips and Slattery 2007) concluded that there is no systematic downstream pattern of increases of decreases in the discharge, stream power, or water surface slope of the lower Trinity River. Discharge in the river channel likely decreases downstream due to coastal backwater effects in the lowermost reaches and due to diversion of flow into valley-bottom depressions during high flows. Decreased stream power and slope in the lower reaches is consistent with earlier findings of limited fluvial sediment delivery to the coastal zone (Phillips and Slattery 2007). Their study reinforced the notion that coastal plain rivers may be more complex with sediment transport and flows being controlled by complex topography.

(Phillips 2007) studied the status and various factors influencing geomorphic equilibrium in Southeast Texas rivers. They state that studies directly examining morphological effects downstream of dams in the region have generally found a "hungry water" scour zone downstream of the dam, which extends relatively short distance (< 55 km) downstream, with limited impacts on sediment transport or storage further downstream, due to a combination of sediment supplied by the downstream stream bed and bank erosion in the scour zone, tributary and local sediment inputs downstream of the dams, and the fact that the systems were transport-limited and overloaded with sediment (relative to transport capacity) before dam construction (Phillips and Slattery 2006a; Phillips and Slattery 2007). In the lowermost Trinity and Sabine Rivers the effects of Holocene sea level, antecedent topography, and inherently limited stream power overwhelm the potential effects of any upstream change in sediment supply, including dams (Phillips and Slattery 2007; Phillips and Slattery 2008). They conclude that these factors plus the fact that incision is generally down (or close) to resistant bedrock, suggests that further downstream propagation of dam effects is unlikely and relaxation time equilibrium (RTE) has been achieved. Relaxation time equilibrium (RTE) implies that changes in response to a disturbance or to new boundary conditions have run their course, or at least slowed to negligible rates.

Recent studies of the upper Trinity River Basin suggest that the Trinity River is highly fragmented in comparison to other Texas Rivers (Chin et al. 2008). The authors used a stream fragmentation metric (km of river per number of dams) as one measure of hydrological modification. In addition, they utilized reservoir storage as another metric. They argue that the amount of reservoir storage represents the amount of water held behind a dam instead of being allowed to flow downstream naturally , thus serving as a primary indicator of the potential disruption to the hydrologic cycle. Dams on the other hand pose physical barriers to the flow of water and sediment where they occur. So that dammed river networks are composed of disconnected channel segments between dams. They argue that these two factors contribute to river habitat degradation by altering microhabitat quality and changing aquatic community composition (Chin et al. 2008). When they applied these metrics they found that the Trinity River exhibits the highest degree of river fragmentation and hence has a high degree of hydrological alteration within the State of Texas. The majority of these dams were however smaller dams located on average about every 44 km of river length. The author recommends therefore that smaller dams should be emphasized in mitigating environmental impacts associated with the fragmentation of river landscapes including the degradation of aquatic habitat and movement of sediment as well as aquatic species (Chin et al. 2008).

Based on these studies it is very evident that the construction of Lake Livingston has had an influence on the downstream transport of sediments and nutrients. Reductions in nitrogen, phosphorus and suspended solids have occurred since the impoundment in 1969. However,

since nutrient loading from urban sources have increased during this period it is difficult to evaluate the overall impacts on the estuary in terms of primary productivity. However, based on the studies of (Phillips and Slattery 2007) the impacts on downstream sediment transport on the estuary are probably minimal due to the upstream placement of the dam far upstream of the estuary and the natural reduced sediment transport capacity of the river at a point below the dam, but still far above the estuary. The capacity of the river to transport sediment is diminished due to low stream gradients, increased distribution to back water areas, meandering and natural attenuation due to tidal action. The loss sediment load near the dam represents a quantity that under natural conditions would have seldom reached the estuary. The river however reaches a new equilibrium and replenishes this lost load from the lower river before entering the estuary.

Focal Species Matrix and Potential Flow Relationships

Our literature survey identified numerous fish collections and taxa spanning the entire watershed and all sub-watersheds and ecoregions (Figures 143-145). The location of these collections spans numerous land use types including urban areas near Dallas Fort Worth, forested areas, and prairies and pastures (Figure 146). There was a clear gradient in number of species collected with highest numbers on the mainstem river and major tributaries being collected above and below the Dallas Fort Worth area (Figure 145). Fish collections started in the mid-1950s and continued through 2000s (Figure 147 and 148) However, fish collecting activity appeared to be largely absent during the mid-1970's through mid-1980's. (Figure 147 and 148). We have no immediate explanation for this pattern. However, it does appear that earlier collections were associated with fisheries studies conducted primarily in reservoirs (Figure 148). The period during the early 1970s was marked by such poor water quality that few fish survived in the upper portions of the Trinity River. As water quality improved fish would move into areas but would soon perish when oxygen levels dropped due to additional "black rises". The transition to more river studies occurred during the period of time when agencies and cities began to aggressively assess and deal with impacts caused by organic pollution in the Trinity River. The source of much of this pollution was believed to come from faulty sanitary sewer collection systems and improperly designed wastewater plants. During this time numerous "black-rises" were reported downstream of the Dallas-Fort Worth area. It was believed that this was largely due to resuspended untreated organic waste with high biological oxygen demand that was released after heavy spring rains and rising river levels (Dickson et al. 1991). By the late 1980's water quality had begun to improve due to improvements in wastewater treatment and new regional treatment capacity (Wells 1991). However, (Anderson et al. 1995) described major shifts in fish communities in the Trinity Basin between 1953 and 1986, with reductions in catfish, darter species and increases in tolerant silversides and *Gambusia affinis.* They indicated that one of the major causes of these declines were the construction of dams and exotic species introductions.

Based on the results of our cluster analysis we generated a dendrogram depicting species with similar life history attributes (Figure 149). Fish species with similar traits were placed into one of six community guilds (Table 11). We then checked to see if at least one candidate "focal" species occurred in each of the community guilds and could therefore theoretically serve as indicator species as well. We did find at least one focal species in each guild (Table 4). Fish guild 1 consisted of water quality tolerant invertivores and piscivores consisting of open substratum and nest spawners. The focal species found in this group was the alligator gar. Species in guild 2 consisted mainly of moderately water quality tolerant invertivores who are exclusively open substratum spawners. The focal species found in this group was the blackspot shiner.

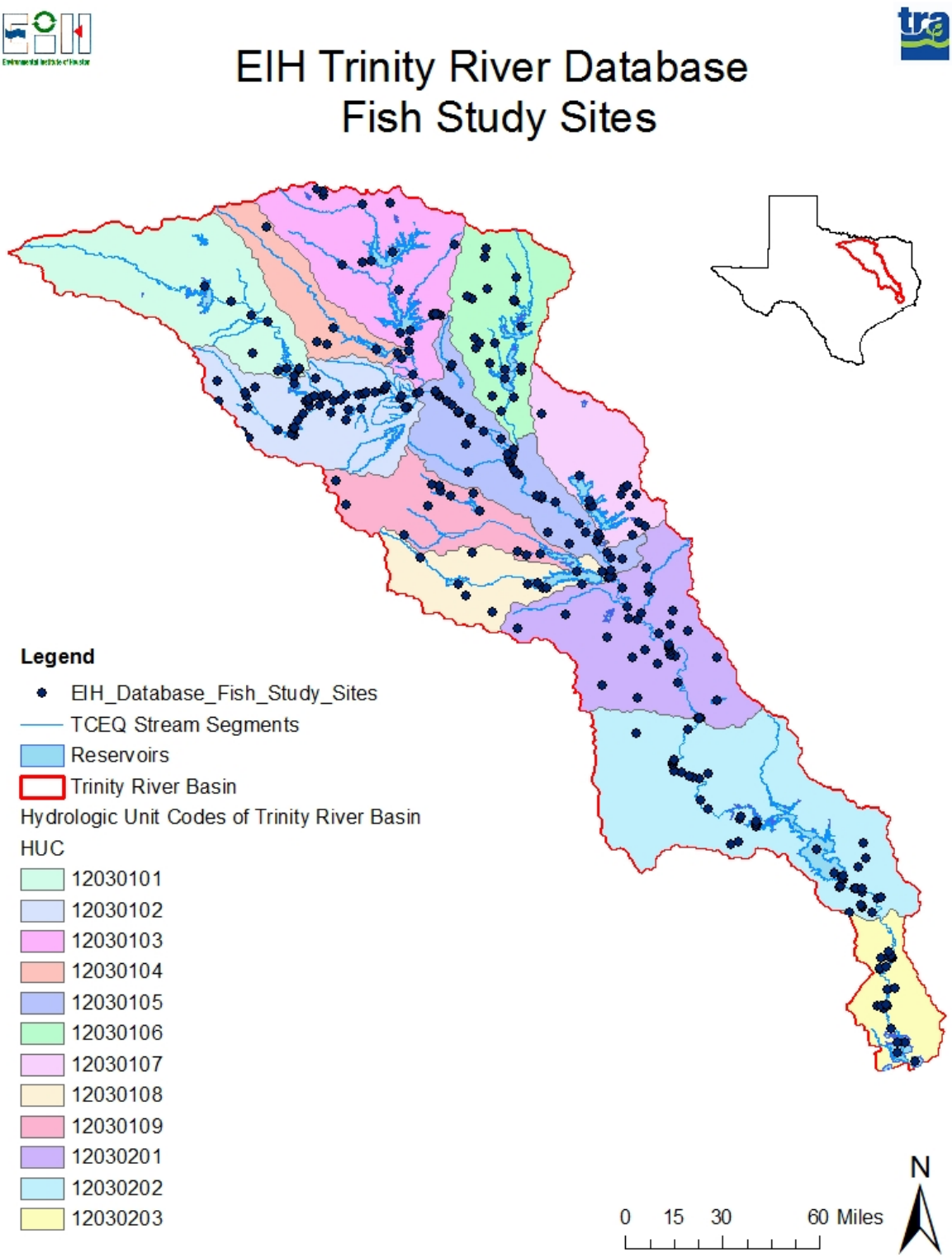


Figure 143. Location of published and unpublished fish studies archived in the EIH Trinity River database that were used to document the historical distribution of fish species in the Trinity River basin.

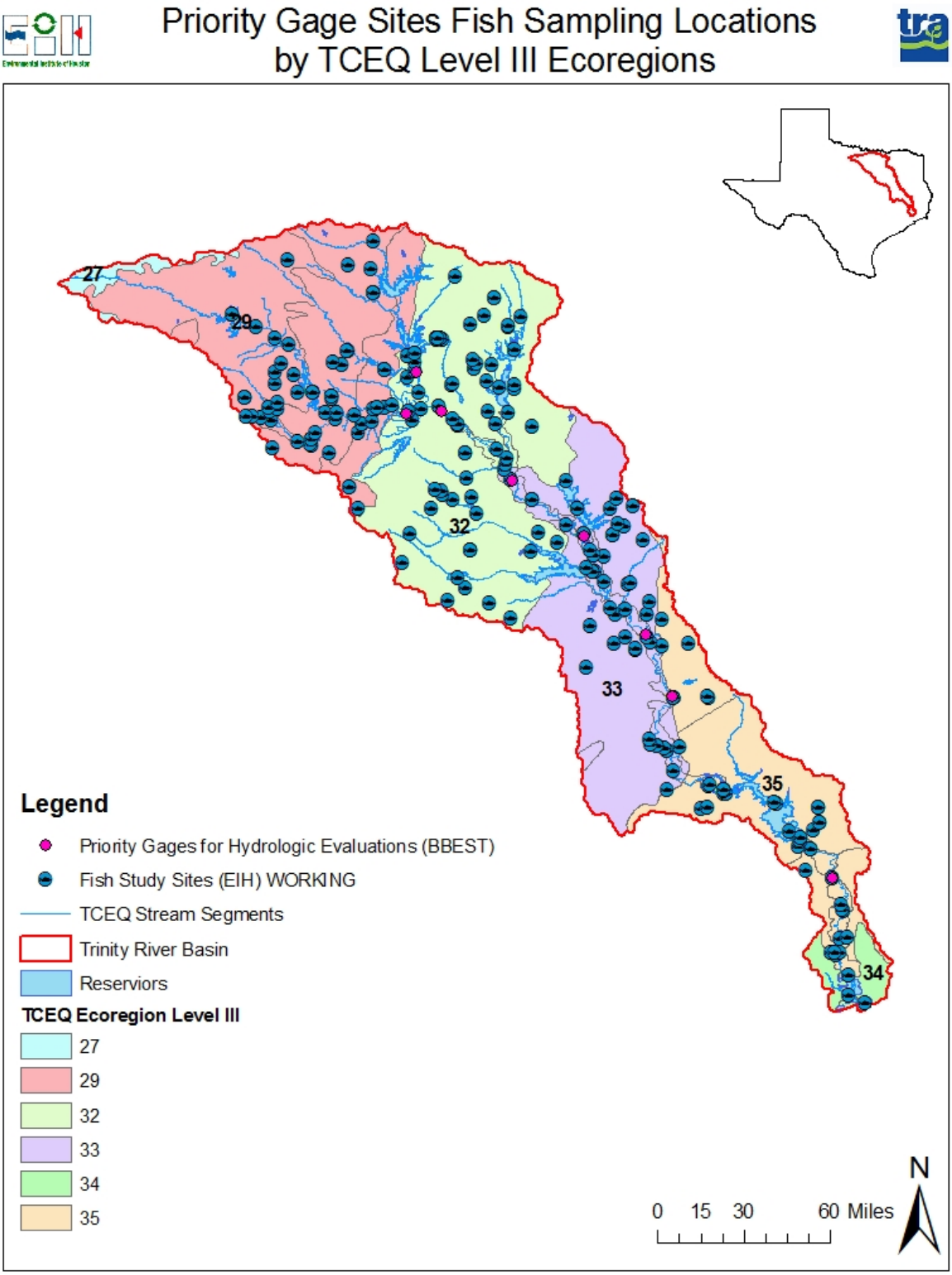


Figure 144. Fish collections by Ecoregion.

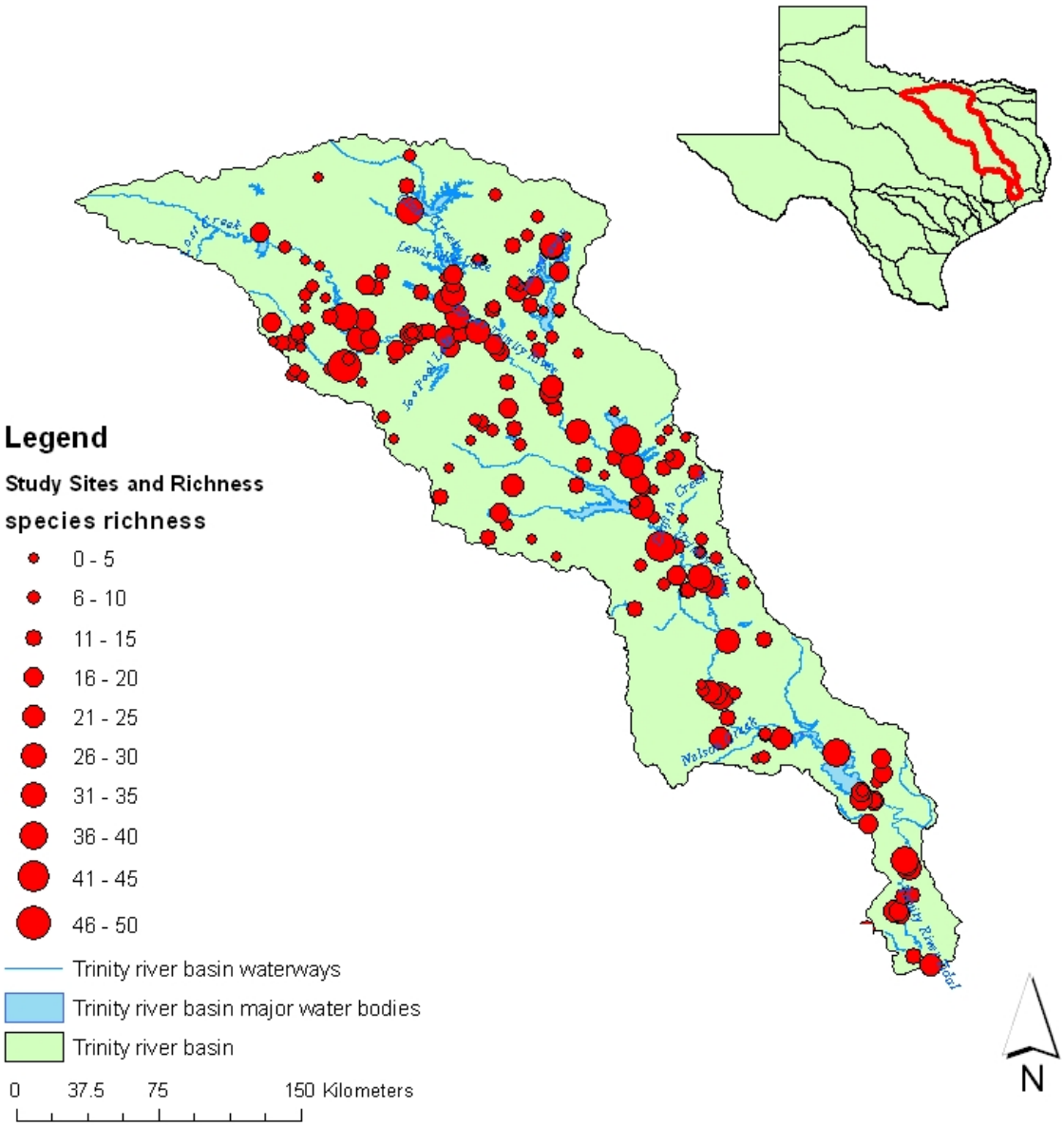


Figure 145. Numbers of fish taxa reported during each study within the Trinity River basin.

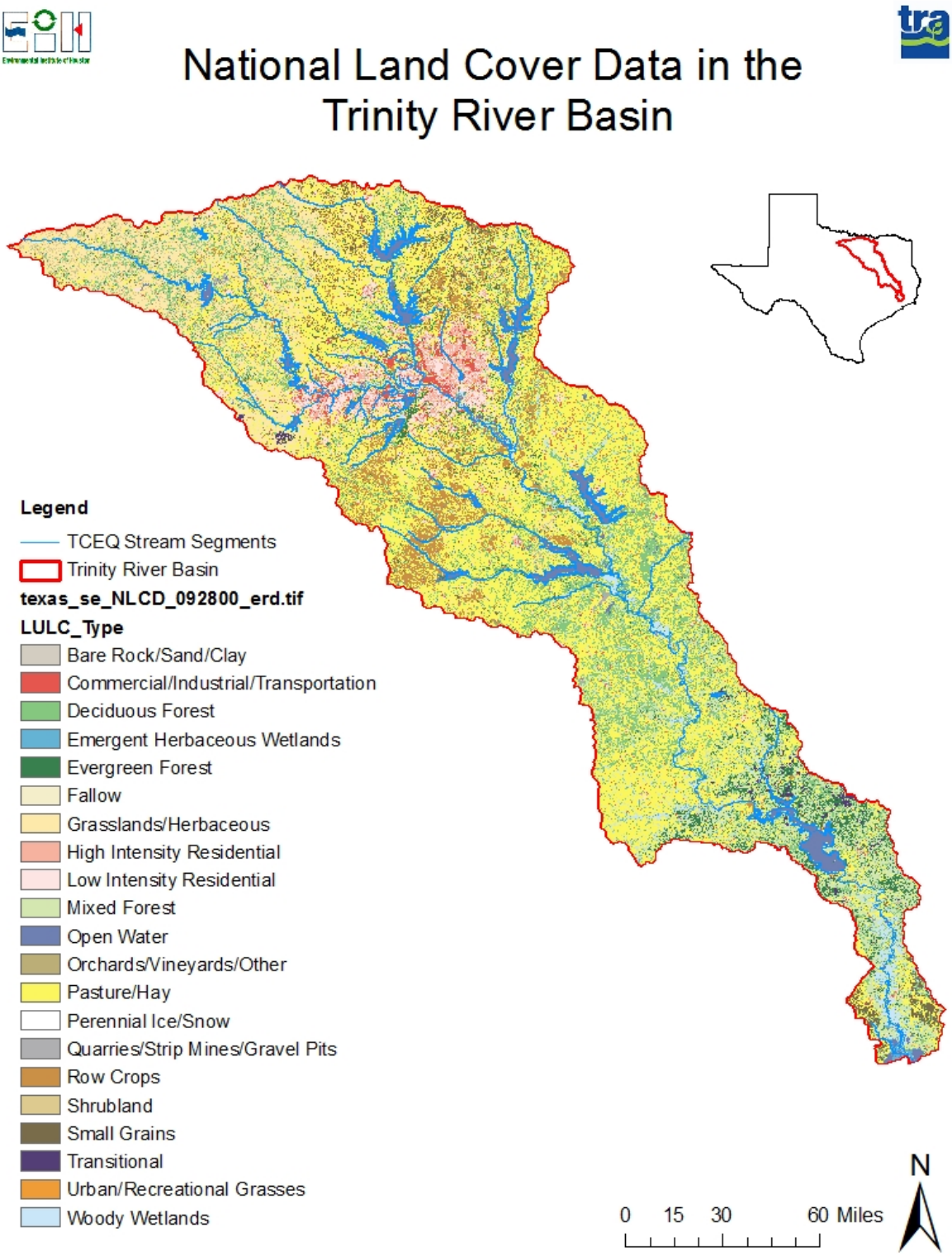


Figure 146. Major land use categories present in the Trinity River basin.

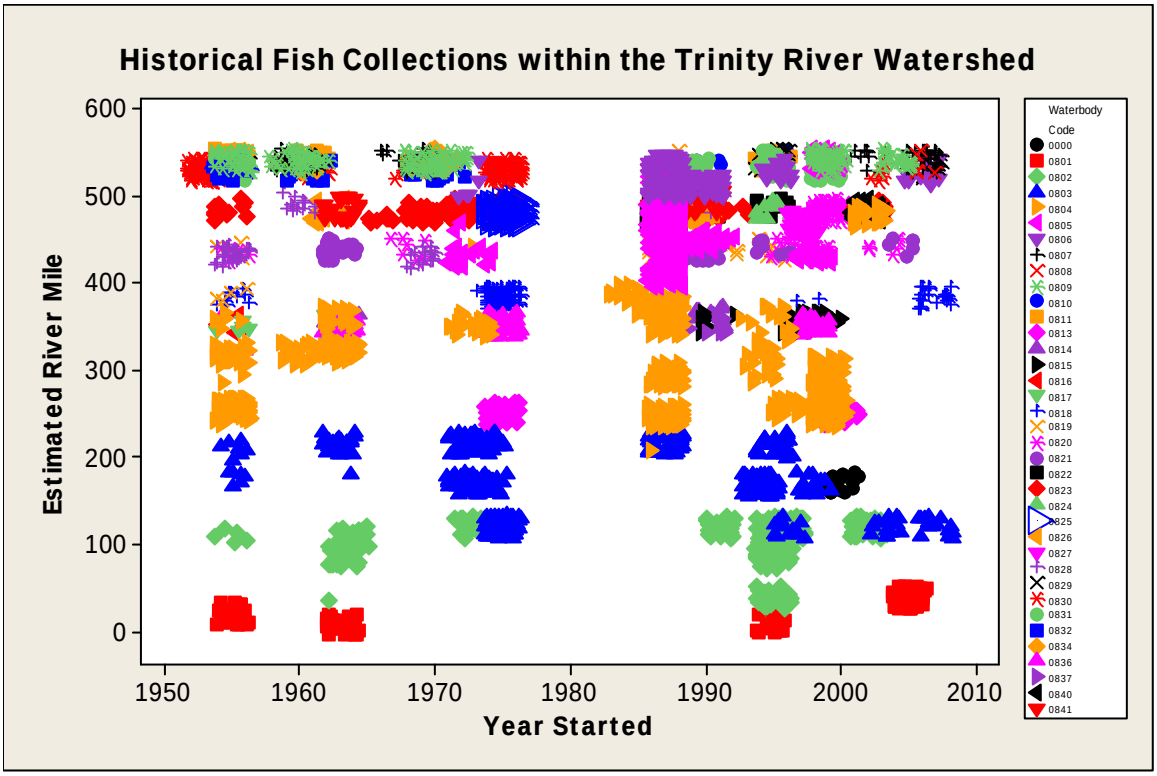


Figure 147. Location of fish collections obtained from literature review. Waterbody code is the TCEQ segment number (see Table 2). Code 0000 denotes collections from uncertain locations or tributaries without a TCEQ segment number. Data includes collections from fish kills and reservoirs.

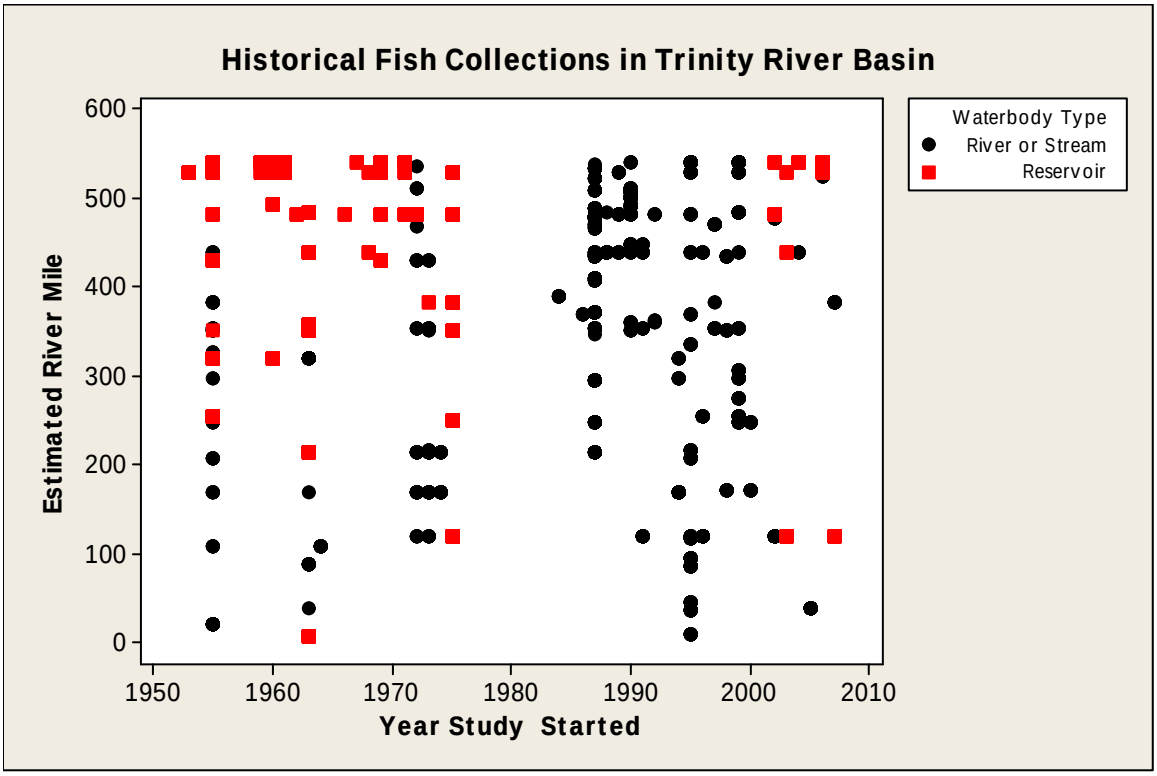


Figure 148. Location of fish collections obtained from literature review. Data from reservoirs and fish kills included.

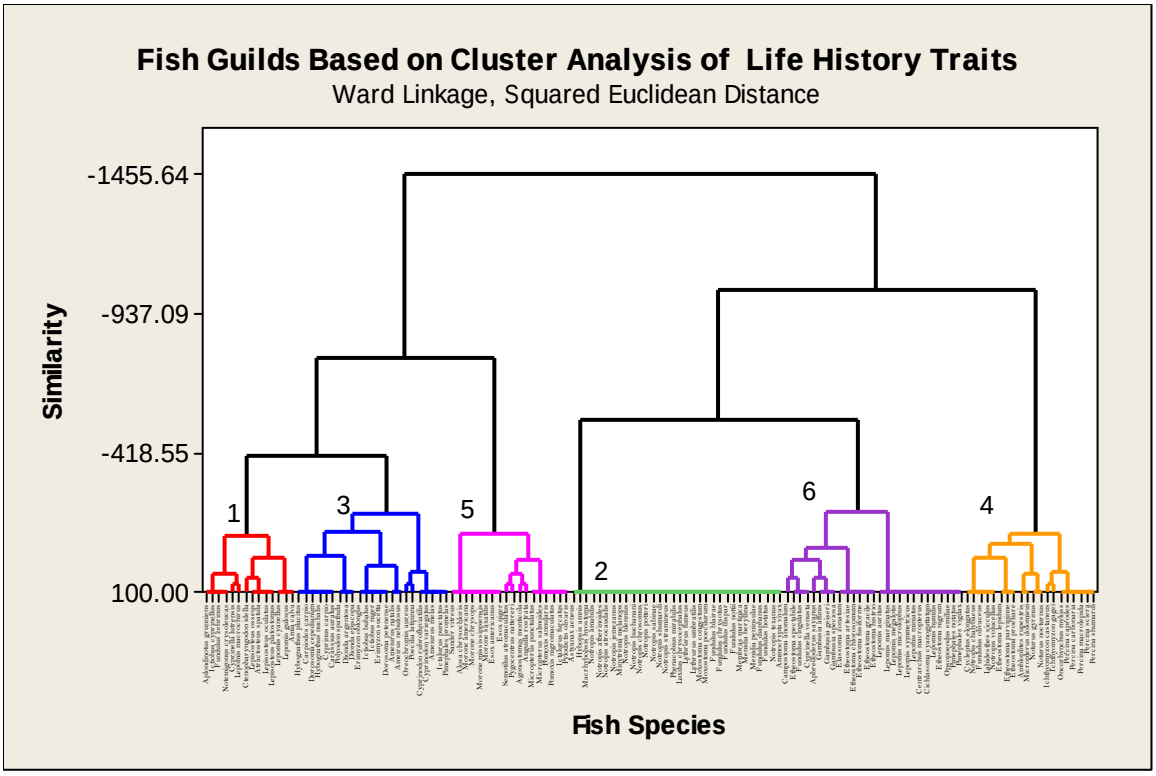


Figure 149. Fish guilds estimated from cluster analysis of life history characteristics including trophic level, water quality tolerance and reproductive behavior. (Balon level 1).

Table 11. Fish community guilds identified using cluster analysis.

SPECIES	COMMON NAME	FAMILY	Trophic	Tolerance	Balon Level 1	TPWD Focal Species	Cluster
Aplondinotus grunniens	**freshwater drum**	**Sciaenidae**	**IF**	**T**	**A1**	**TR**	**1**
Ctenopharyngodon idella	grass carp	Cyprinidae	H	T	A1	no	1
Ictiobus cyprinellus	bigmouth buffalo	Catostomidae	IF	T	A1	no	1
Fundulus zebrinus	plains killifish	Fundulidae	IF	T	A1	no	1
Lepisosteus osseus	longnose gar	Lepisosteidae	P	T	A1	**SJR**	1
Atractosteus spatula	**alligator gar**	**Lepisosteidae**	**P**	**T**	**A1**	**TR**	**1**
Lepisosteus oculatus	spotted gar	Lepisosteidae	P	T	A1	no	1
Lepisosteus platostomus	shortnose gar	Lepisosteidae	P	T	A1	no	1
Notemigonus crysoleucas	golden shiner	Cyprinidae	IF	T	A1	no	1
Cyprinella lutrensis	red shiner	Cyprinidae	IF	T	A2	no	1
Lepomis cyanellus	green sunfish	Centrarchidae	P	T	B2	no	1
Lepomis macrochirus	bluegill	Centrarchidae	IF	T	B2	no	1
Lepomis gulosus	warmouth	Centrarchidae	P	T	B2	no	1
Amia calva	bowfin	Amiidae	P	T	B2	no	1
Astyanax aeneus	Mexican tetra	Characidae	IF	N	A1	no	2
Hybopsis amnis	pallid shiner	Cyprinidae	IF	N	A1	**SJR**	2
Macrhybopsis hyostoma	shoal chub	Cyprinidae	IF	N	A1	no	2
Notropis amabilis	Texas shiner	Cyprinidae	IF	N	A1	no	2
Notropis atherinoides	emerald shiner	Cyprinidae	IF	N	A1	no	2
Notropis atrocaudalis	**blackspot shiner**	**Cyprinidae**	**IF**	**N**	**A1**	**TR&SJR**	**2**
Notropis jemezanus	Rio Grande shiner	Cyprinidae	IF	N	A1	no	2
Minytrema melanops	spotted sucker	Catostomidae	IF	N	A1	no	2
Notropis blennius	ghost shiner	Cyprinidae	IF	N	A1	no	2
Notropis buchanani	ghost shiner	Cyprinidae	IF	N	A1	no	2
Notropis chrosomus	rainbow shiner	Cyprinidae	IF	N	A1	no	2
Notropis potteri	chub shiner	Cyprinidae	IF	N	A1	no	2
Notropis sabinae	Sabine shiner	Cyprinidae	IF	N	A1	no	2
Notropis shumardi	**silverband shiner**	**Cyprinidae**	**IF**	**N**	**A1**	**TR**	2
Notropis stramineus	sand shiner	Cyprinidae	IF	N	A1	no	2
Phenacobius mirabilis	suckermouth minnow	Cyprinidae	IF	N	A1	no	2
Luxilus chrysocephalus	striped shiner	Cyprinidae	IF	N	A1	no	2
Lythrurus fumeus	ribbon shiner	Cyprinidae	IF	N	A1	**SJR**	2
Lythrurus umbratilis	redfin shiner	Cyprinidae	IF	N	A1	no	2
Moxostoma congestum	gray redhorse	Catostomidae	IF	N	A1	no	2
Moxostoma poecilurum	blacktail redhorse	Catostomidae	IF	N	A1	**SJR**	2
Fundulus blairae	western starhead topminnow	Fundulidae	IF	N	A1	no	2
Fundulus chrysotus	golden topminnow	Fundulidae	IF	N	A1	no	2
Fundulus dispar	starhead topminnow	Fundulidae	IF	N	A1	no	2
Fundulus nottii	bayou topminnow	Fundulidae	IF	N	A1	no	2
Membras martinica	rough silverside	Atherinopsidae	IF	N	A1	no	2
Menidia beryllina	inland silverside	Atherinopsidae	IF	N	A1	no	2
Menidia peninsulae	tidewater silverside	Atherinopsidae	IF	N	A1	no	2
Fundulus diaphanus	banded killifish	Fundulidae	IF	N	A1	no	2
Fundulus notatus	blackstripe topminnow	Fundulidae	IF	N	A1	no	2
Notropis texanus	weed shiner	Cyprinidae	IF	N	A1	no	2
Ammocrypta vivax	scaly sand darter	Percidae	IF	N	A1	no	2
Hybognathus placitus	plains minnow	Cyprinidae	O	T	A1	no	3
Carpiodes carpio	river carpsucker	Catostomidae	O	T	A1	no	3
Dorosoma cepedianum	gizzard shad	Clupeidae	O	T	A1	no	3
Erimyzon oblongus	creek chubsucker	Catostomidae	O	N	A1	**SJR**	3
Hybognathus nuchalis	Mississippi silvery minnow	Cyprinidae	O	T	A1	no	3
Ictiobus bubalus	smallmouth buffalo	Catostomidae	O	N	A1	no	3
Ictiobus niger	black buffalo	Catostomidae	O	N	A1	no	3
Polyodon spathula	**paddlefish**	**Polyodontidae**	**O**	**I**	**A1**	**TR**	**3**
Dionda argentosa	Manatial roundnose minnow	Cyprinidae	O	I	A1	no	3
Dionda episcopa	roundnose minnow	Cyprinidae	O	I	A1	no	3
Cyprinus carpio	common carp	Cyprinidae	O	T	A1	no	3
Erimyzon sucetta	lake chubsucker	Catostomidae	O	N	A1	no	3
Carassius auratus	goldfish	Cyprinidae	O	T	A1	no	3
Dorosoma petenense	threadfin shad	Clupeidae	O	N	A1	no	3
Oreochromis aureus	blue tilapia	Cichlidae	O	T	B1	no	3
Cyprinodon rubrofluviatilis	Red River pupfish	Cyprinodontidae	O	T	B2	no	3
Cyprinodon variegatus	sheepshead minnow	Cyprinodontidae	O	T	B2	no	3
Ameiurus melas	black bullhead	Ictaluridae	O	T	B2	no	3
Ameiurus natalis	yellow bullhead	Ictaluridae	O	N	B2	no	3
Ameirus nebulosus	brown bullhead	Ictaluridae	O	N	B2	no	3
Ictalurus punctatus	channel catfish	Ictaluridae	O	T	B2	no	3
Pimephales promelas	fathead minnow	Cyprinidae	O	T	B2	no	3
Poecilia latipinna	sailfin molly	Poeciliidae	O	T	C2	no	3

Table 11. Continued.

SPECIES	COMMON NAME	FAMILY	Trophic	Tolerance	Balon Level 1	TPWD Focal Species	Cluster
Cycleptus elongatus	blue sucker	Catostomidae	IF	I	A1	no	4
Notropis chalybaeus	ironcolor shiner	Cyprinidae	IF	I	A1	no	4
Fundulus olivaceus	blackspotted topminnow	Fundulidae	IF	I	A1	no	4
Labidesthes sicculus	brook silverside	Atherinopsidae	IF	I	A1	no	4
Notropis volucellus	mimic shiner	Cyprinidae	IF	I	A1	no	4
Ichthyomyzon castaneus	chestnut lamprey	Petromyzontidae	P	I	A2	no	4
Ichthyomyzon gagei	southern brook lamprey	Petromyzontidae	None	I	A2	no	4
Oncorhynchus mykiss	rainbow trout	Salmonidae	IF	I	A2	no	4
Percina caprodes	logperch	Percidae	IF	I	A2	no	4
Percina carbonaria	Texas logperch	Percidae	IF	I	A2	no	4
Percina macrolepida	bigscale logperch	Percidae	IF	I	A2	no	4
Percina sciera	**dusky darter**	**Percidae**	**IF**	**I**	**A2**	**TR**	**4**
Percina shumardi	river darter	Percidae	IF	I	A2	no	4
Etheostoma lepidum	greenthroat darter	Percidae	IF	I	B1	no	4
Etheostoma parvipinne	goldstripe darter	Percidae	IF	I	B1	no	4
Etheostoma proeliare	cypress darter	Percidae	IF	I	B1	no	4
Ambloplites rupestris	rock bass	Centrarchidae	P	I	B2	no	4
Micropterus dolomieui	smallmouth bass	Centrarchidae	P	I	B2	no	4
Noturus gyrinus	tadpole madtom	Ictaluridae	IF	I	B2	no	4
Noturus nocturnus	freckled madtom	Ictaluridae	IF	I	B2	**SJR**	4
Sander vitreus	walleye	Percidae	P	N	A1	no	5
Alosa chrysochloris	skipjack herring	Clupeidae	P	N	A1	no	5
Morone americana	white perch	Moronidae	P	N	A1	no	5
Morone chrysops	**white bass**	**Moronidae**	**P**	**N**	**A1**	**TR**	**5**
Morone mississippiensis	yellow bass	Moronidae	P	N	A1	no	5
Morone saxatilis	striped bass	Moronidae	P	N	A1	no	5
Esox americanus	redfin pickerel	Esocidae	P	N	A1	no	5
Esox niger	chain pickerel	Esocidae	P	N	A1	no	5
Semotilus atromaculatus	creek chub	Cyprinidae	P	N	A2	no	5
Pygocentrus nattereri	red piranha	Characidae	P	N	B1	no	5
Micropterus punctulatus	spotted bass	Centrarchidae	P	N	B2	no	5
Micropterus salmoides	**largemouth bass**	**Centrarchidae**	**P**	**N**	**B2**	**TR**	**5**
Pomoxis annularis	white crappie	Centrarchidae	P	N	B2	no	5
Pomoxis nigromaculatus	black crappie	Centrarchidae	P	N	B2	no	5
Ictalurus furcatus	**blue catfish**	**Ictaluridae**	**P**	**N**	**B2**	**TR**	5
Pylodictis olivaris	flathead catfish	Ictaluridae	P	N	B2	SJR	5
Agonostomus monticola	mountain mullet	Mugilidae	O	N	CAT	no	5
Anguilla rostrata	American eel	Anguillidae	P	N	CAT	no	5
Campostoma anomalum	central stoneroller	Cyprinidae	H	N	A2	no	6
Etheostoma spectabile	orangethroat darter	Percidae	IF	N	A2	no	6
Fundulus cingulatus	Banded topminnow	Fundulidae	IF	N	A2	no	6
Cyprinella venusta	blacktail shiner	Cyprinidae	IF	N	A2	no	6
Elassoma zonatum	banded pygmy sunfish	Elassomatidae	IF	N	B1	no	6
Etheostoma artesiae	redspot darter	Percidae	IF	N	B1	no	6
Etheostoma chlorosomum	bluntnose darter	Percidae	IF	N	B1	no	6
Etheostoma fusiforme	swamp darter	Percidae	IF	N	B1	no	6
Etheostoma gracile	slough darter	Percidae	IF	N	B1	no	6
Etheostoma histrio	harlequin darter	Percidae	IF	N	B1	no	6
Lepomis auritus	redbreast sunfish	Centrarchidae	IF	N	B2	no	6
Lepomis marginatus	dollar sunfish	Centrarchidae	IF	N	B2	no	6
Lepomis megalotis	**longear sunfish**	**Centrarchidae**	**IF**	**N**	**B2**	**TR**	**6**
Lepomis microlophus	redear sunfish	Centrarchidae	IF	N	B2	no	6
Lepomis symmetricus	bantam sunfish	Centrarchidae	IF	N	B2	no	6
Lepomis miniatus	redspotted sunfish.	Centrarchidae	IF	N	B2	no	6
Centrarchus macropterus	flier	Centrarchidae	IF	N	B2	no	6
Cichlasoma cyanoguttatum	Rio Grande cichlid	Cichlidae	IF	N	B2	no	6
Lepomis humilis	orangespotted sunfish	Centrarchidae	IF	N	B2	no	6
Etheostoma nigrum	johny darter	Percidae	IF	N	B2	no	6
Opsopoeodus emiliae	pugnose minnow	Cyprinidae	IF	N	B2	no	6
Pimephales notatus	bluntnose minnow	Cyprinidae	IF	N	B2	no	6
Pimephales vigilax	bullhead minnow	Cyprinidae	IF	N	B2	no	6
Aphredoderus sayanus	pirate perch	Aphredoderidae	IF	N	C1	no	6
Gambusia affinis	western mosquitofish	Poeciliidae	IF	N	C2	no	6
Gambusia geiseri	largespring gambusia	Poeciliidae	IF	N	C2	no	6
Gambusia speciosa	Tex-Mex gambusia	Poeciliidae	IF	N	C2	no	6

Explanation for various codes used in Table 11 provided in Table 4. Focal species nominated by TPWD and presented at BBEST meeting in August 2009 are in bold.

Species in guild 3 were all omnivores who exhibited a wide range of tolerances to poor water quality and exhibited a variety of spawning behavior including open substrate spawning, nest spawning and internal fertilization. The focal species located in this group was the paddlefish, which is classified as an omnivore, intolerant to poor water quality, and an open substratum spawner over gravel and rocks.

Guild 4 mainly consisted of invertivores which were intolerant and exhibited a range of reproductive traits including open substrate spawning, brood hiding, substrate choosers and nest spawning. Dusky darter was the only focal species found in this group.

Fishes in guild 5 consisted of predatory species with neutral water quality tolerance which exhibited open substrate and nest spawning. Two focal species were found in this group including the white bass (an open substrate spawner) and largemouth bass (a nest spawner). The final group 6 consisted mainly of invertivores with intermediate tolerance to water quality, who largely exhibited nest spawning. The longear sunfish was the only focal species in this group.

Focal species distributions, including data independently summarized by Dr. Hendrickson were plotted against river mile, HUC codes and TCEQ segments by year (Figures 150, 151, 152 and 153). Based on our compiled data most records of focal fish species occurred between river mile 200 and 400 in TCEQ waterbody segments 0802 through 0805 (Figures 150 and 151). However, some species ranged from river mile 84 to 550 (Figure 152).

Focal species distributions were also plotted against reported stream flows and years when both variables were measured (1987-2007). Focal fish species were primarily observed between flows ranging from 0 to 20 cfs. These recorded occurrences were not associated with an instream flow study and are not meant to imply any preferred flow regime (Figure 150). However, at a minimum it does provide a baseline to compare conditions under which fish have been collected. In addition, many of these species distribution overlapped the location of priority gage sites that will be used for hydrological analysis (Figure 150 and 151). Data compiled by the Fishes of Texas Project documented in some cases extensive temporal and spatial distributions of some species (e.g. largemouth bass and longear sunfish)(Figure 153)(Hendrickson 2009). Distributions of fish documented during our literature survey are similar to their findings (Figures 152 and 153). However some species such as paddlefish were not encountered in their study. His data also suggests that most accounts of blue catfish were restricted to the lower river while freshwater drum were encountered in the upper river (Figure 153

Individual Species Accounts and Hydrological Relationships

Aplodinotus grunniens (Freshwater drum)

Aplodinotus grunniens (freshwater drum) were generally collected throughout the basin during lower recorded flows (Figures 150-156). Many collections occurred very close to the priority gage sites. Freshwater drum is considered a large river fish species which serves as a host for at least six species of mussel glochidia including one species of concern, the Rock Pocketbook (Table 5). The primary literature on the ecology of freshwater drum in Texas has been summarized by (Bonner 2009).

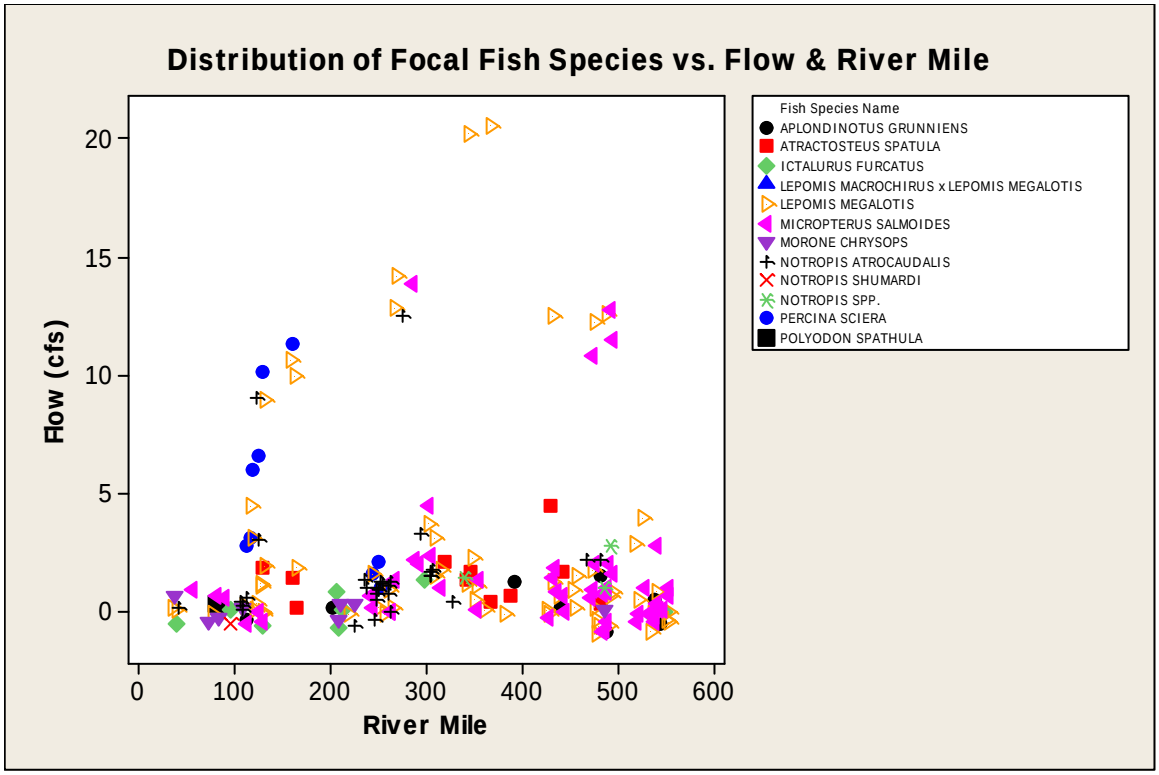


Figure 150 . Occurrence of focal fish species and associated flow measurements. Excludes fish kill and reeservoir data. Period of record 1989 to 2007. (jitter added to data display)

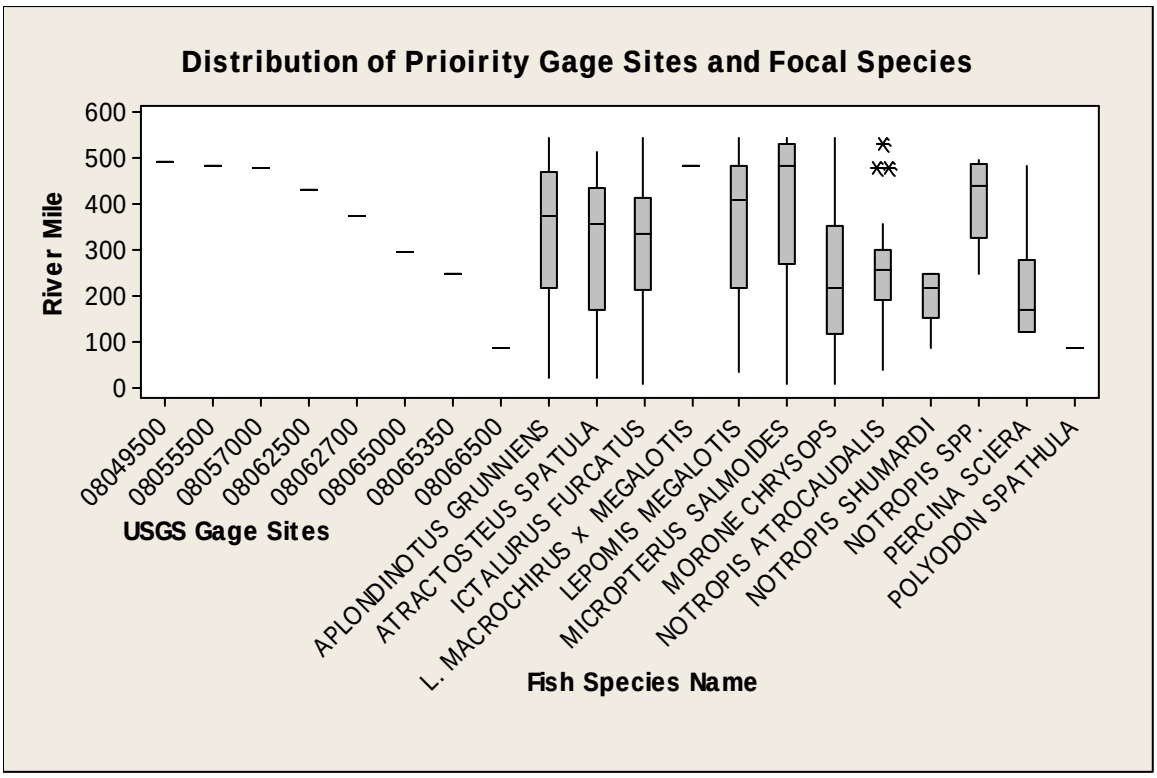


Figure 151 . Distribution of focal fish species based on literature review within the Trinity River Basin. Period of record 1953-2007 (excluding reservoir sites).

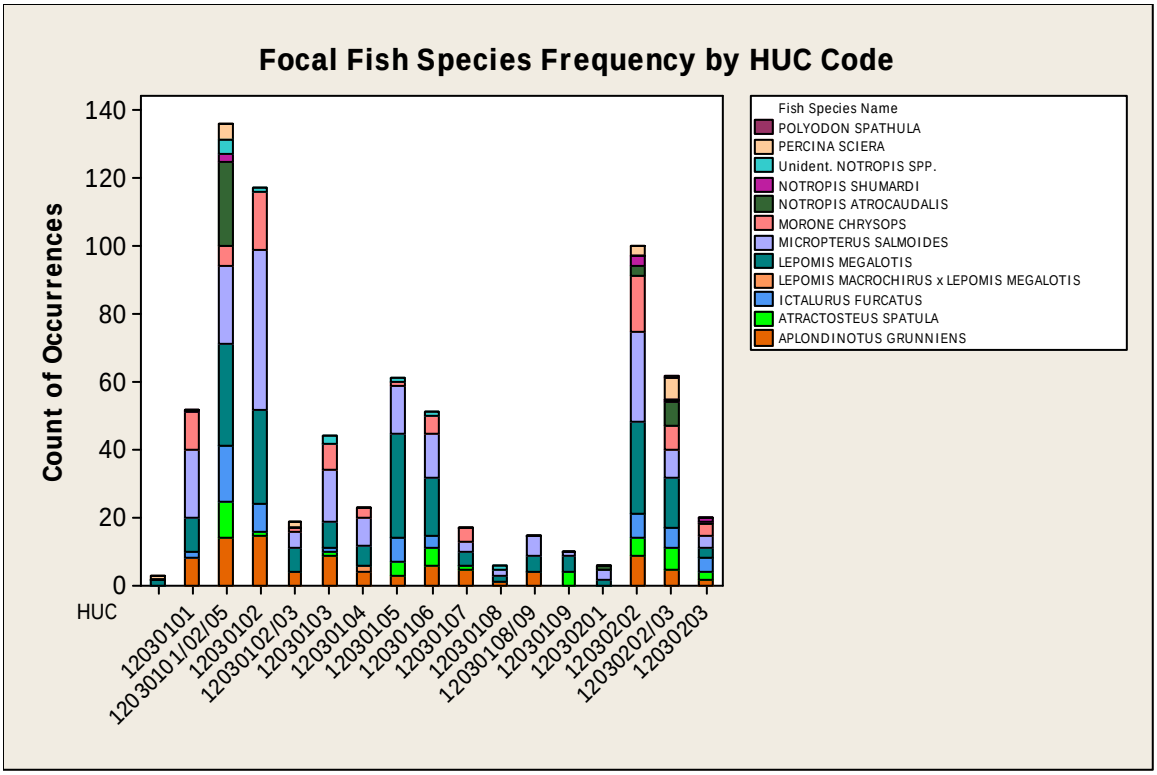


Figure 152. Distribution of focal fish species within the Trinity River Basin by year and HUC codes. Period of record 1953-2007. Includes data from fish kill investigations and reservoirs. Multiple HUC listing due to transcription from TCEQ codes.

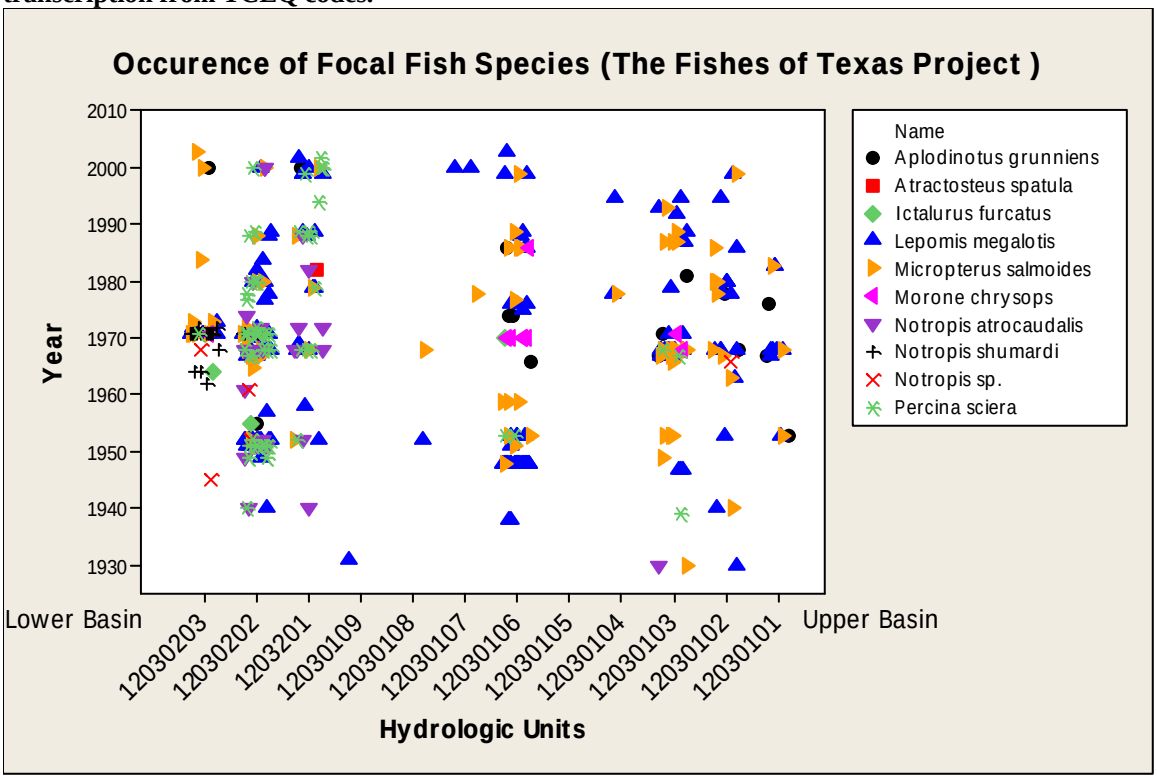


Figure 153. Distribution of focal fish species within the Trinity River Basin by year and HUC codes. Based on data provided by D. Henrickson "Fish of Texas Project". Period of record 1930 to 2004.

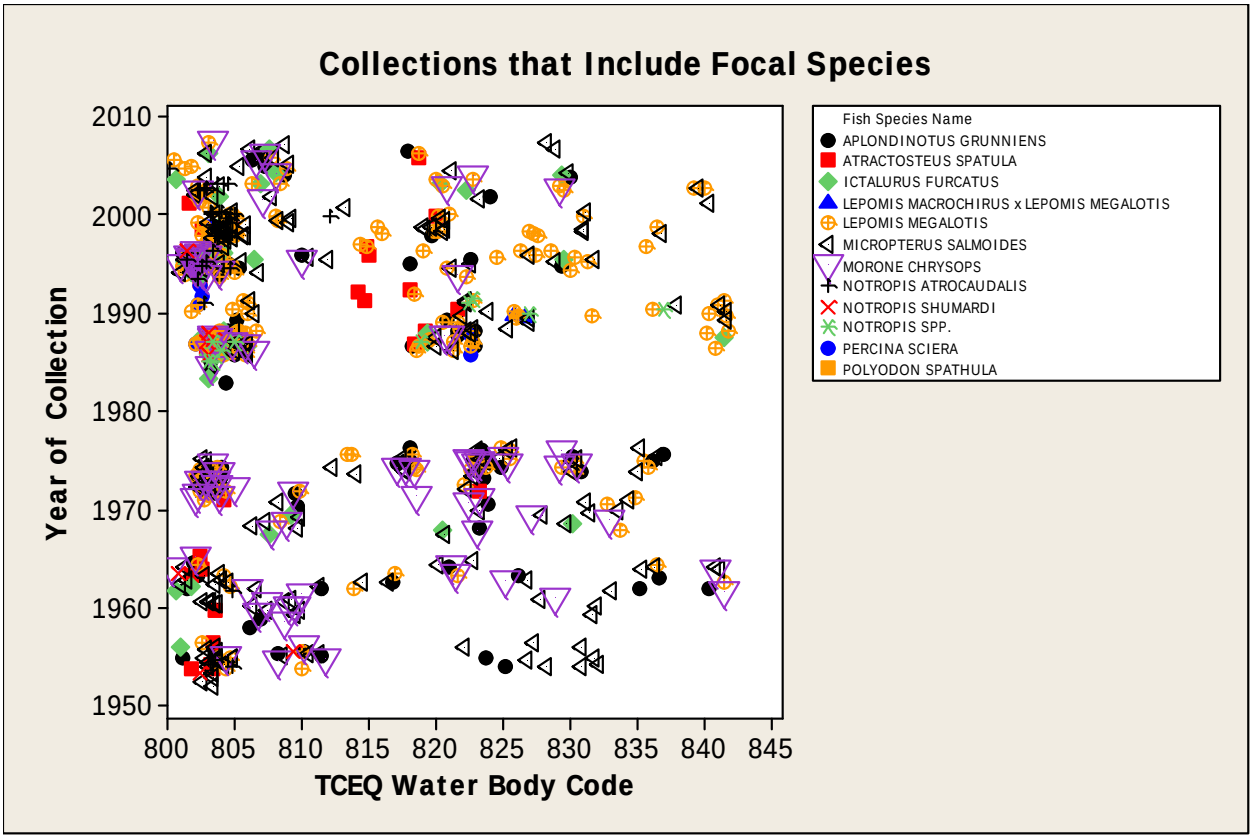


Figure 154. Distribution of focal fish species within the Trinity River Basin by year and TCEQ waterbody code. Period of record 1953-2007. Includes data from fish kill investigations and reservoirs. (jitter added to data display).

Much of the following data below was extracted from this study. Freshwater drum are typically found in a range of habitats ranging from turbid to clear lakes and rivers (Bonner 2009). It is usually found associated with benthic habitats of large, shallow bodies of water up to 40-60 feet deep. In large rivers, fish may move distances of at least 161 km. Individual freshwater drum have been observed to become distressed when water temperatures exceed 25.6°C, and when dissolved oxygen concentrations remain low over an extended period. Spawning season for freshwater drum occurs in May and June, usually when water temperatures range between 18-26°C (Bonner 2009). Spawning apparently occurs in open water. This species is considered a non-guarders, open substratum spawners or pelagophils which produces numerous buoyant eggs (Tables 3 and 4) (Simon 1999a). Hatching occurs in 1-2 days and the larvae drift for 1-2 days before settling to the bottom and begin feeding (Winemiller et al. 2005). This species is considered a riverine (flow) dependent species and a generalist (Herbert and Gelwick 2003a; Schramm Jr. 2005; Winemiller et al. 2005). Species may not be that dependent on access to aquatic habitats in the floodplain. The species probably benefit from extended periods of low flow during the summer to promote benthic secondary production. The freshwater drum has flow requirements for spawning and dispersal of early life stages very similar to paddlefish (Winemiller et al. 2005).

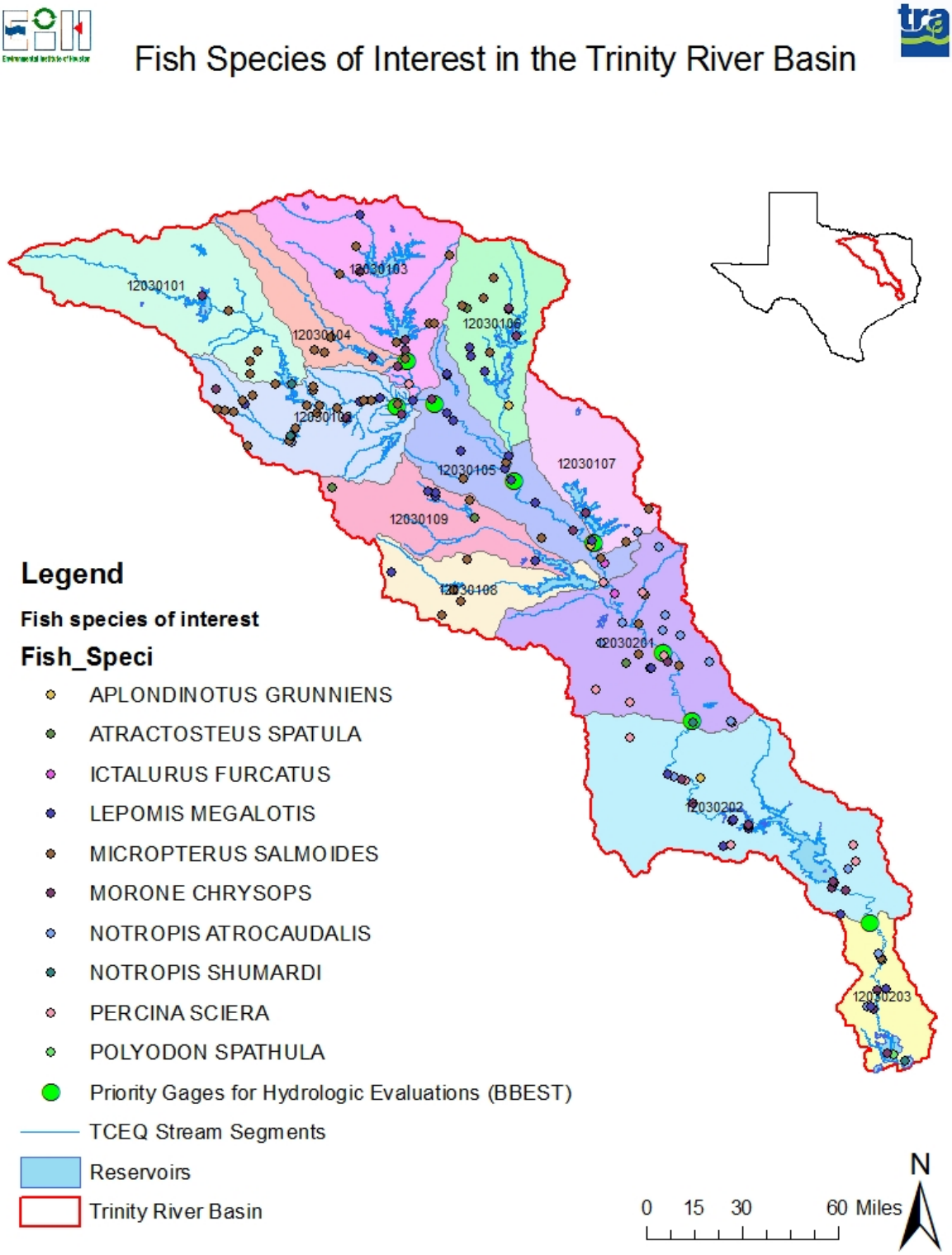


Figure 155. Spatial distribution of focal fish species in relation to priority gage sites within Trinity River basin. Period of record 1953-2007.

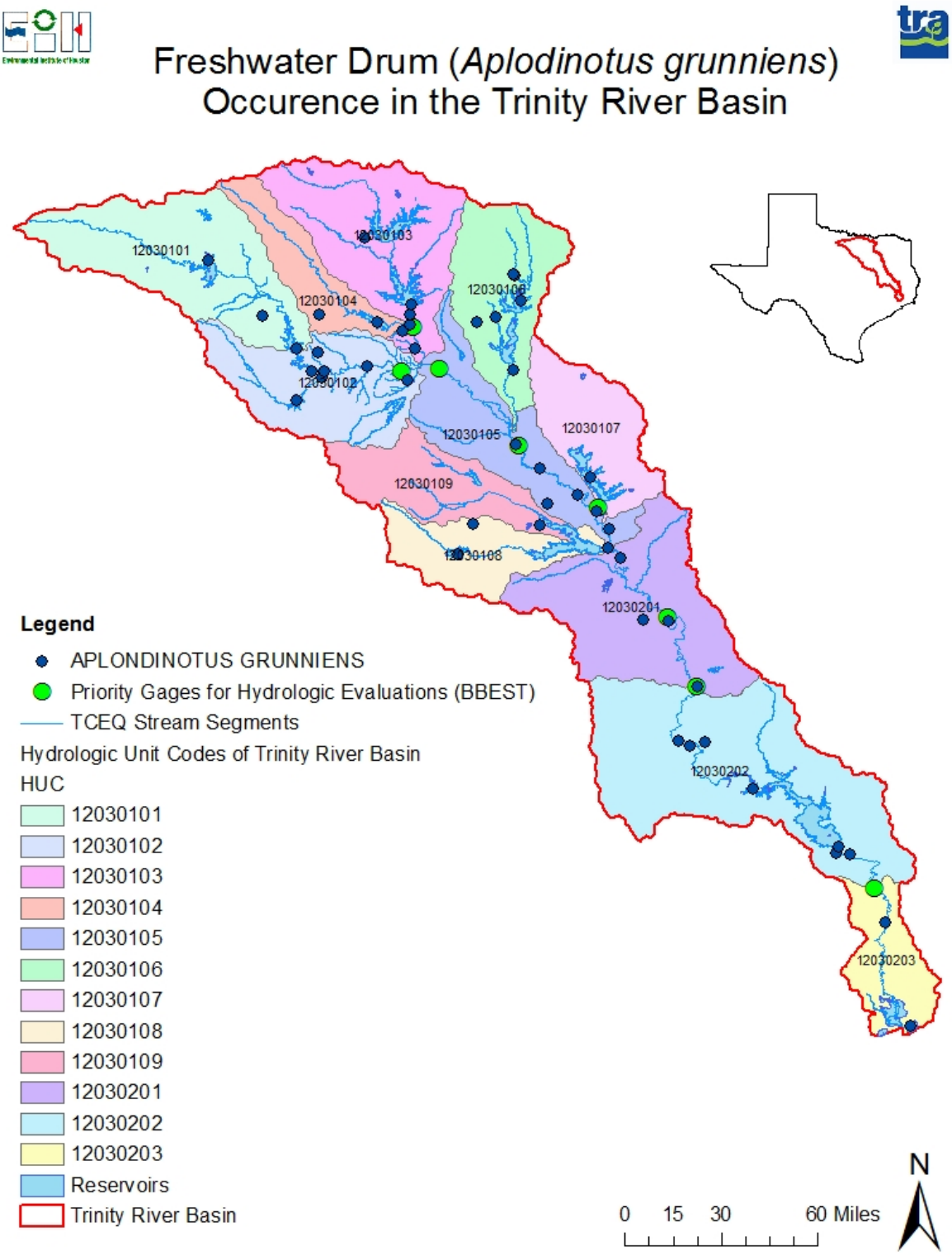


Figure 156. Spatial distribution of freshwater drum in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

Atractosteus spatula (alligator gar)

Alligator gars were found throughout the watershed at lower flows (Figures 150-155, 157). In some cases they were also collected in the vicinity of priority gages. The primary literature on the ecology of alligator gar in Texas has been summarized by (Bonner 2009). Much of the data below was extracted from his web site. Alligator gar is considered a species of concern in Texas (Table 3)(Hubbs et al. 2008). It inhabits large river systems and is dependent upon backwater and floodplain habitats for reproduction. It is a top level piscivore (Table 3) (Linam and Kleinsasser 1998). It is generally associated with near surface habitats in slack water and backwater habitats of rivers (Bonner 2009). It prefers pool, pool-bank snag, pool-channel snag, pool-snag complex, pool-edge, and pool-vegetation habitat. It has been collected from deep, frequently connected oxbow lakes; and has significantly higher abundance in oxbow habitats during wet years (Bonner 2009). Typically specimens collected from oxbows are juveniles (409- 810 mm), while only adults (1474-1850 mm) are captured in the river channel (Bonner 2009). However, this may be due in part to large individuals escaping capture in oxbow sampling. Adults may move into oxbows during flooding to exploit abundant prey, returning to the river channel later. Factors including enhanced foraging, growth and survival may influence juveniles to remain in oxbows for extended periods (Bonner 2009). The spawning season most likely extends from April to June in Texas based on observed activity in Louisiana and Oklahoma (Bonner 2009). Alligator gar are considered phytophils, specifically plant material nesters that have adhesive eggs and free embryos that attach to plants by cement glands (Bonner 2009; Simon 1999a). Furthermore they are classified as nonguarders; open substratum spawners. They are long lived species living up to 50 years. No other specific data on instream flow requirements for Texas populations or elsewhere were encountered. No data was found on possible host relationships with mussel species of concern.

Ictalurus furcatus (blue catfish)

Blue catfish were found throughout the watershed at lower flows (Figures 150-155, 158). Blue catfish are large river species with adults inhabiting the main river and juveniles being found in tributaries. It is considered a sportfish in Texas. Blue catfish are migratory and prefer open waters of large reservoirs and main channels, backwaters, and flowing rivers with strong current where water is normally turbid (Graham 1999). Declines in blue catfish have been documented and appear to be associated with stream channelization, snag removal and depressed oxygen (Graham 1999). They appear to be more sensitive to hypoxia than channel catfish. The primary literature on the ecology of blue catfish in Texas has been summarized by (Bonner 2009). In Texas, blue catfish usually inhabit larger rivers and streams (Bonner 2009). It is typically found in rivers and streams containing swift chutes and pools of noticeable current, and over bottom areas that contain silt-free sand, gravel and rubble substrates (Bonner 2009). Based on published literature and TPWD coastal fisheries data it will also enter estuaries and upper Galveston Bay during freshets. It has been found in salinities between 3.7 to 15 ppt (Bonner 2009; Graham 1999). Blue catfish is considered an indicator species for lower salinity regimes in Galveston Bay. Blue catfish spawn between April and June at water temperatures of 21-25 degrees C (Bonner 2009). Males construct nests in cavities often in pools and backwaters (Simon 1999a). It is classified as a guarder, nest spawners or speleophils or hole nester (Table 3) (Simon 1999). A nest is constructed and cared for by the parents until the young hatch. Blue catfish can live at least 14 years but their life expectancy is likely over 20 (Bonner 2009). No other specific data on instream flow requirements for Texas populations or elsewhere were encountered.

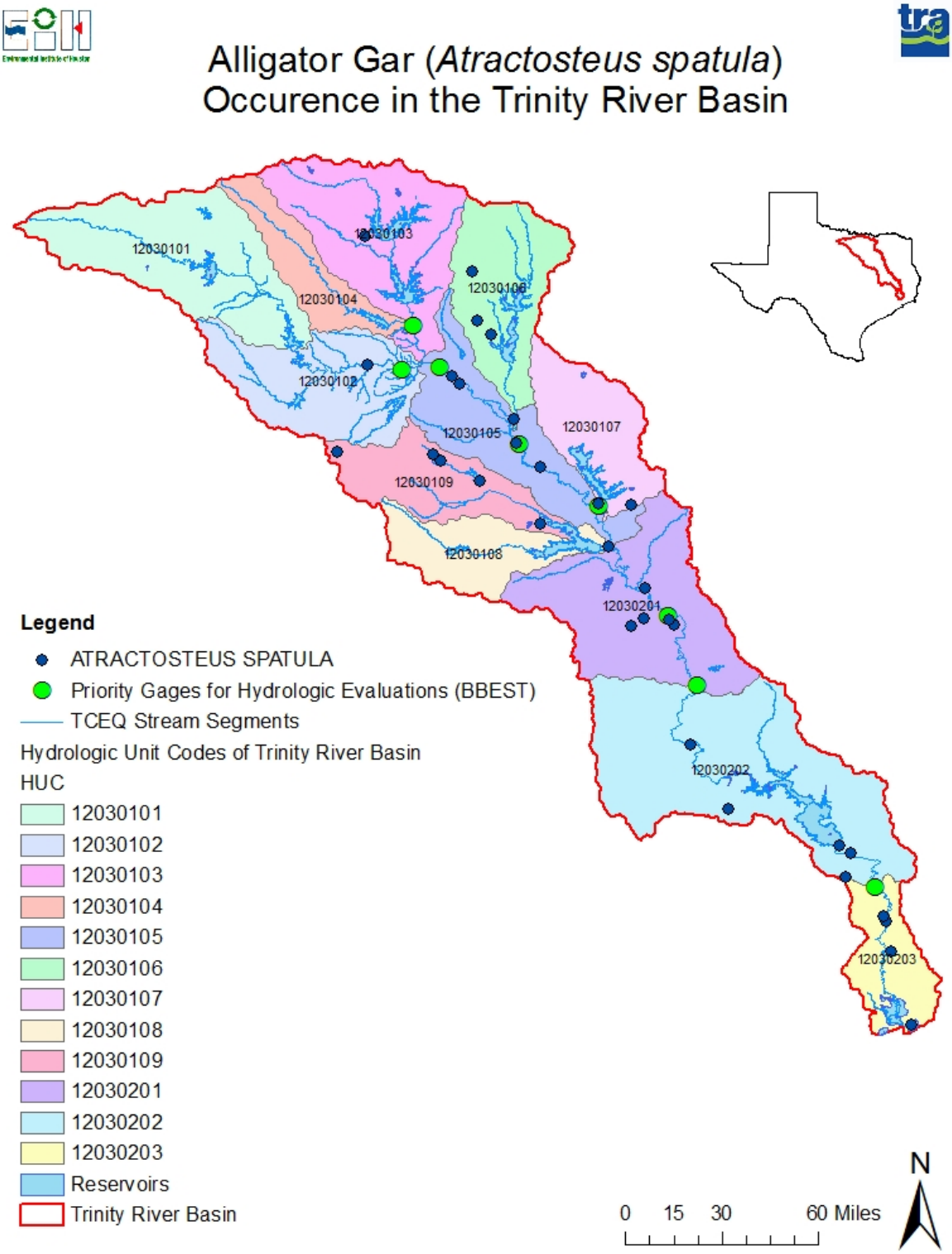


Figure 157. Spatial distribution of alligator gar in relation to priority gage sites within the Trinity River Basin. Period of Record 1953-2007.

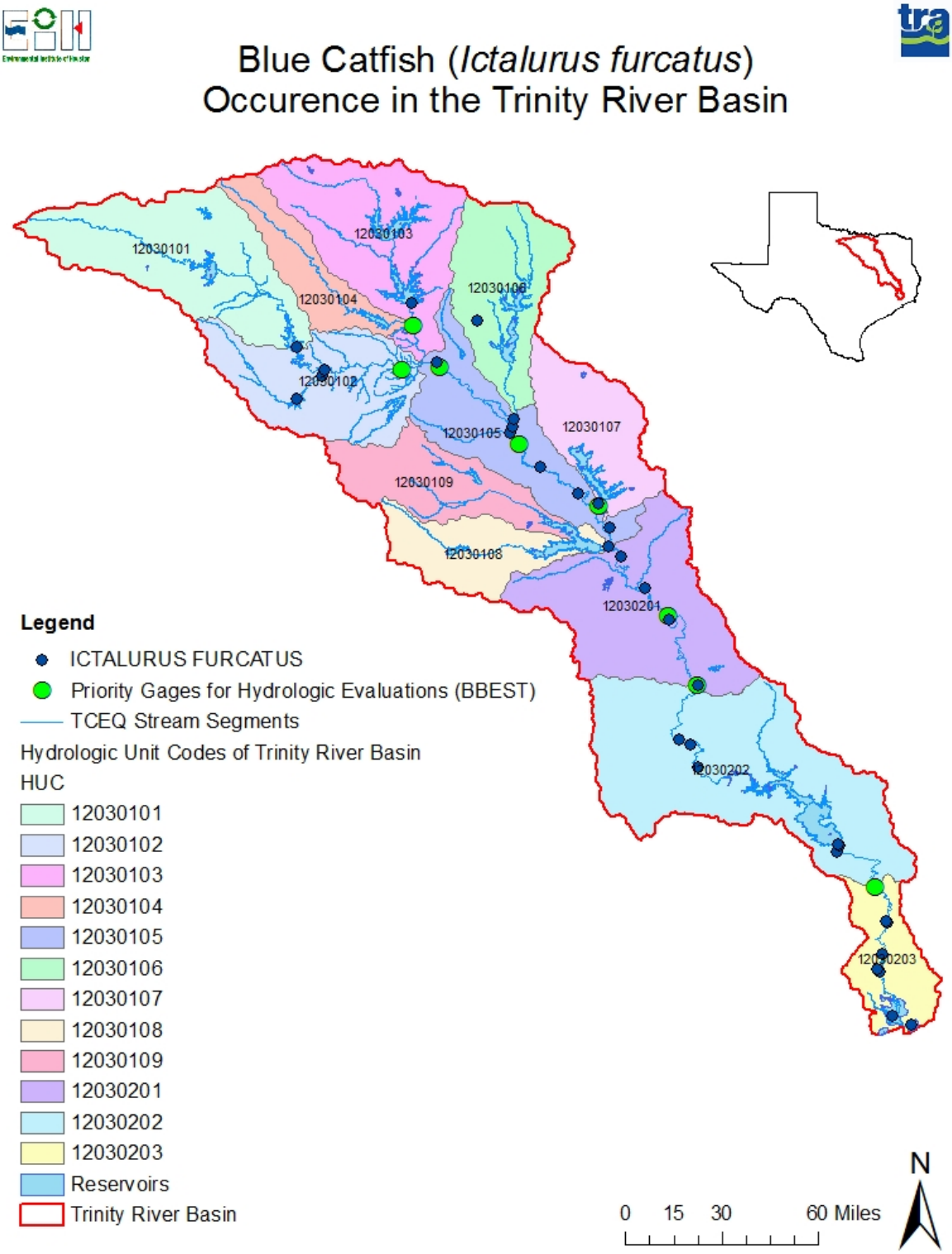


Figure 158. Spatial distribution of blue catfish in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

Lepomis megalotis (longear sunfish)

Longear sunfish was one of the most common species collected throughout the watershed based on historical records (Figures 150-155, 159). They were captured over a larger range of flows and were generally the one of the few species collected above 10 cfs. In addition, this species was generally more abundant in the upper portion of the watershed. Many collections occurred very close to the priority gage sites (Figures 154). A comprehensive synthesis of the ecology of the species is provided by (Warren 2009). The primary literature on the ecology of longear sunfish in Texas has been summarized by (Bonner 2009). Longear sunfish inhabits both main stem rivers and tributaries in pools and backwater areas. It is an invertivore (Simon 1999a)(Table 1). They are reported to serve as potential hosts for at least two species of mussel glochidia (Table 5). Longear sunfish are typically found in reservoirs and small streams (Bonner 2009). They are abundant in clear, small upland streams with rocky or sandy bottoms and permanent or semi-permanent flows with pools ((Warren 2009). In previous studies in Mississippi, longear sunfish habitat averaged 61 cm deep and had slow current flow (5.2 cm/s) and possessed a silt, mud or sand substratum (Bonner 2009). This species generally shows little movement in streams; however, when movements do occur they are more often downstream than upstream and average approximately 17 km. Longear sunfish spawning occurs during the late spring and early summer (Bonner 2009). Spawning may occur at discrete intervals from late May to August between 22 and 31 C (Warren 2009). This species is considered a polyphil, that is utilizing miscellaneous substrate and material for nest building and producing adhesive eggs that are either attached or occur in clusters (Table 3)(Simon 1999a). Spawning has been reported in shallow water with gravel bottom, shallow water and little current (Bonner 2009). Flood events and potentially associated lowered water temperatures can delay initiation of spawning and result in high nest abandonment and decreased brood survival (Warren 2009). It is believed that longear sunfish can live up to 6 years in southern areas (Bonner 2009). Longear sunfish were most often found in pools (velocity 0.07 to 0.29 m/s) (Edwards 1997). (Schramm Jr. 2005) classified longear as a backwater dependent species. (Bio-West Inc 2008) grouped this species into the shallow pool/backwater guild. No other specific data on instream flow requirements for Texas populations or elsewhere were encountered.

Micropterus salmoides (largemouth bass)

Largemouth bass was one of the most common species collected throughout the watershed based on historical records (Figures 150-155, 160). It inhabits both the main stem Trinity River and tributaries in pool and backwater areas. It is considered a nest builder and piscivore (Table 3). Furthermore it is considered on the most popular freshwater sportfish in Texas. Largemouth bass were one of the most common species collected in the Trinity River. They were captured over a large range of flows and were generally one of the few species encountered above 10 cfs. Largemouth bass were encountered more frequently in the upper portion of the watershed (Figure 160). Many collections occurred very close to the priority gage sites. Largemouth bass are reported to serve as a host for at least 4 species of mussel glochidia (Table 5) The primary literature on the ecology of largemouth bass in Texas has been summarized by (Bonner 2009). A comprehensive synthesis of the ecology of the species is provided by (Warren 2009).

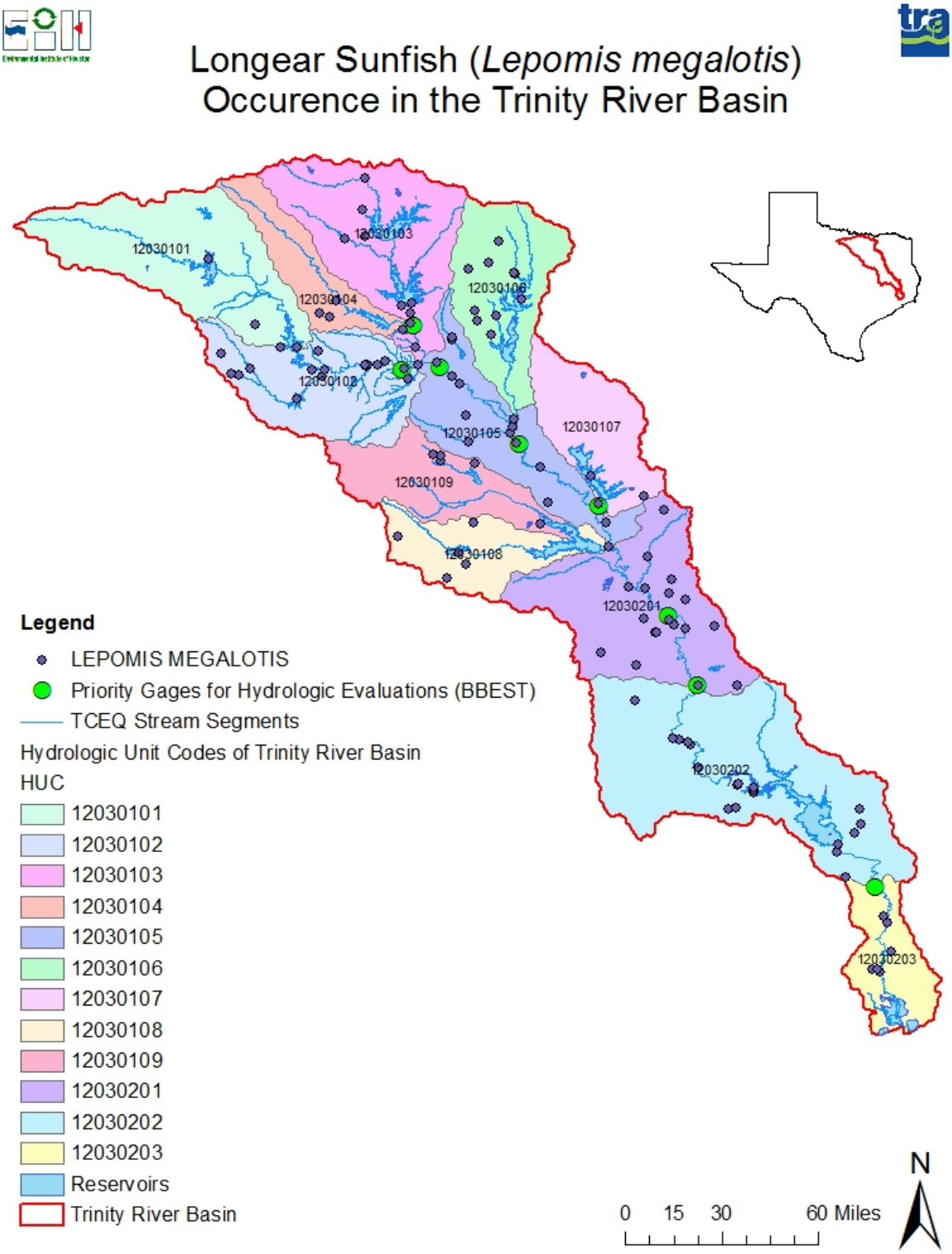


Figure 159. Spatial distribution of longear sunfish in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

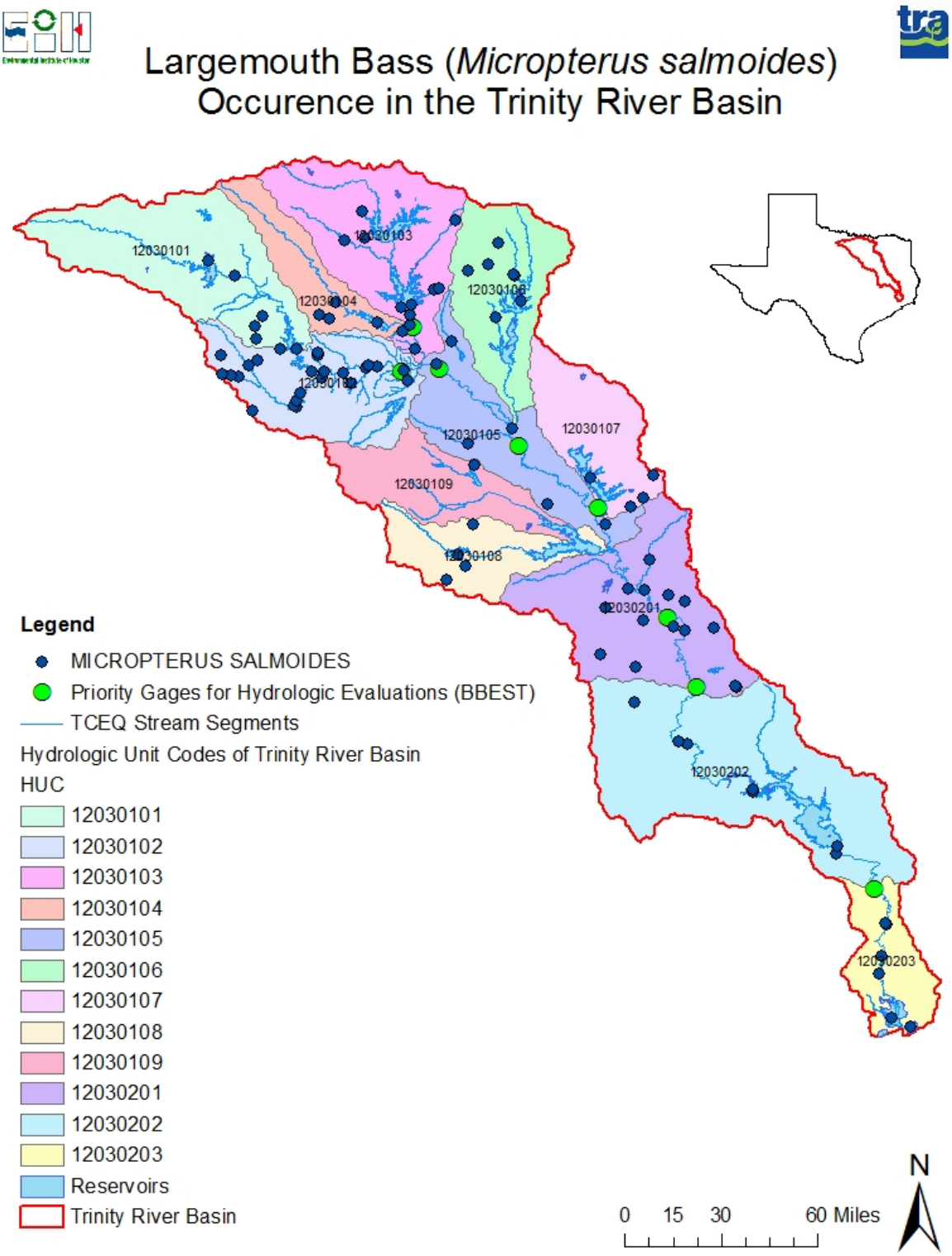


Figure 160. Spatial distribution of largemouth bass in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

Largemouth bass are found in lakes, ponds, reservoirs, backwaters, and slow-moving rivers and streams. They appear to prefer clear, quiet waters with aquatic vegetation but can survive in a wide variety of mesohabitats. In riverine habitats young and adults are most common in deep pools or low-velocity habitats near undercut banks, instream wood, overhanging and aquatic vegetation, or other cover (Warren 2009). The spawning season for largemouth bass occurs in late winter or early spring (mid March to May), when water temperatures rise to about 15.5 degrees C and continuing over a temperature range of 15-24 degrees C (Bonner 2009; Warren 2009). Largemouth bass often next in backwater areas lacking current, either stream margins, oxbows or floodplain lakes (Winemiller et al. 2005). Largemouth bass are considered polyphils utilizing miscellaneous substrate and material to create nests that receive adhesive eggs that are either attached or occur in clusters (Simon 1999a) Largemouth bass guard their nests. The male guards nest for several weeks after spawning. Largemouth bass can tolerate warm (<= 38.5 C) temperatures, but are limited by colder water (<10C), and can tolerate low dissolved oxygen > 3.0 mg/l (Warren 2009).

A habitat suitability index (HSI) model that addresses instream flow needs for riverine largemouth bass has been published by USFWS (Stuber et al. 1982)(Figure 161). According to the authors, the models are applicable throughout the natural range of largemouth bass in lower 48 states of North America with its greatest applicability in southern states. Several riverine habitat variables were identified as useful metrics for defining suitable habitat for largemouth bass including percent pool and backwater area, percent bottom cover, water level fluctuation, dissolved oxygen, pH range, temperature, turbidity, salinity, and substrate, current velocity and stream gradient (Stuber et al. 1982). Suitable levels of these variables that would support and/or provide critical life functions including food, cover, water quality and reproduction were defined. Several of these including percent pool and backwater area, water level fluctuation and current velocity are directly affected by hydrology (Stuber et al. 1982). For example rivers possessing greater than 55% pool and backwater areas during average summer flows are considered the best conditions for providing food. Minimum dissolved oxygen levels in pools that are frequently above 8.0 mg/l are considered ideal water quality conditions. Ideal average water level fluctuations during the growing season for adults and juveniles should be less than 3 meters (Stuber et al. 1982). The ideal maximum water level fluctuation during spawning should be close to zero for embryos. The average water level fluctuation during growing season for fry should be no more than 1 meter (Stuber et al. 1982). Average current velocities at 0.6 depths during summer should be less than 6 cm/sec for adult and juveniles. Maximum current stream velocities at 0.8 depths within pools and backwater during spawning should be less than 3.0 cm/sec during the spawning period. Average current velocity at 0.6 depths during the summer for fry rearing should be 0.8 cm/sec during the summer to optimize survival and growth. These metrics, along with the other less flow dependent variables, are used in the construction of a total HSI that can used in the Habitat Evaluation Procedure (HEP) and/or Instream Flow Incremental Approach (IFIM) physical habitat simulation model (PHABSIM), or similar approaches, to define and describe how overall habitat and quality vary with flow. A copy of this document with associated suitability index curves is provided with this report. In order to appropriately apply these HIS metrics, all of the metrics should be evaluated simultaneously in order to properly evaluate how habitat fluctuates with flow regime.

(Schramm Jr. 2005) classified largemouth bass as a backwater dependent species. (Bio-West Inc 2008) grouped this species into the shallow pool/backwater guild. (Winemiller et al. 2005) evaluated this species for use in setting instream flow targets in the Big Cypress Caddo Lake system (Figure 162).

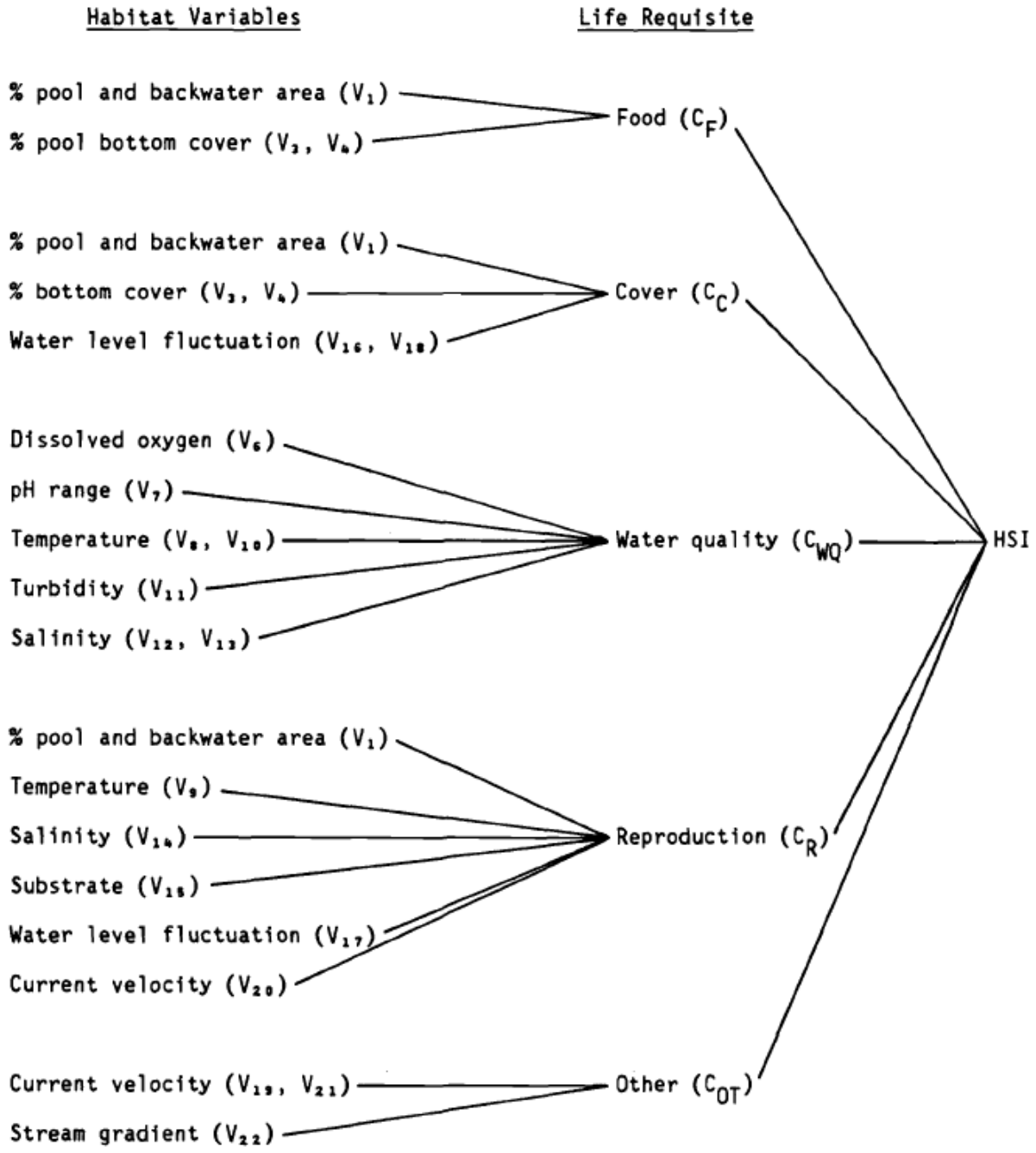


Figure 161. Conceptual structure for riverine model for largemouth bass (Stuber et al. 1982).

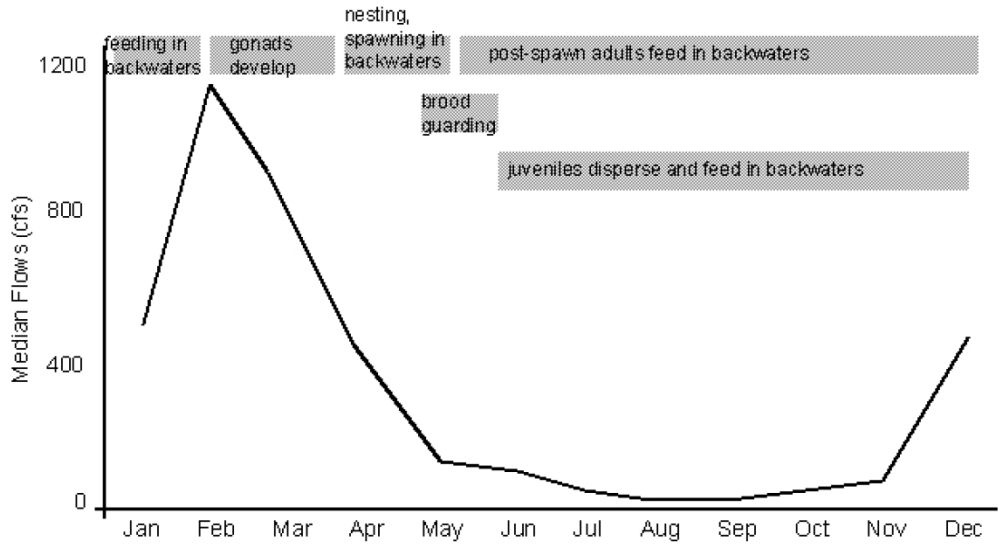


Figure 162. Largemouth bass (backwater dependent species) life cycle in relation to seasonal flow (portrayed relative to pre-1957 median flows in Big Cypress Bayou). Source: (Winemiller et al. 2005)

Morone chrysops (white bass)

White bass was collected throughout the watershed based on historical records (Figures 150-155, 163). It inhabits both the main stem Trinity River and reservoirs. Many collections occurred very close to the priority gage sites. White bass typically inhabits main stem rivers and are considered migratory. They are considered sportfish within Texas and many states. White bass are also reported to serve as a host for at least three species of mussel glochidia (Table 5). The primary literature on the ecology of white bass in Texas has been summarized by (Bonner 2009). This species is abundant in lakes and reservoirs, being more common in clear versus turbid waters (Bonner 2009). The spawning season extends from mid-March to late May at water temperatures of 12-20 degrees C (Bonner 2009). White bass are open substratum spawners and phytolithophils (nonobligatory plant spawner that deposit eggs on submerged items) which have late hatching larvae with cement glands (Table 3). The larvae have moderately developed respiratory structures, and are photophobic (Bonner 2009). Most phytolithophils reproduce in clear water on submerged plants or, if not available, on other submerged items such as logs, gravel, and rocks in shallow (< 3m) water (Balon 1975; Balon 1981; Simon 1999a). Spawning usually occurs in small tributary streams or wave-swept points or shoals within reservoirs (Bonn 1952; Riggs 1955). The species is a nonguarders (Simon 1999a). The species forms spawning groups consisting of several males following a ripe female. The female then rises to the surface releasing her eggs which may be fertilized by several males that have remained in close proximity to her. The demersal adhesive eggs then sink to the bottom, attaching to rocks, boulders, plants, or other surfaces. The species is considered a potamodromus species that homes, often forming unisexual schools that migrates to spawning sites on shoals and in streams in the spring(Bonner 2009). Fish move upstream in early spring, when water temperatures are above 7-13°C, with males preceding females onto spawning grounds by at times at least a month. The net movement during these spawning runs occurs from either large rivers or reservoirs into small streams for spawning.

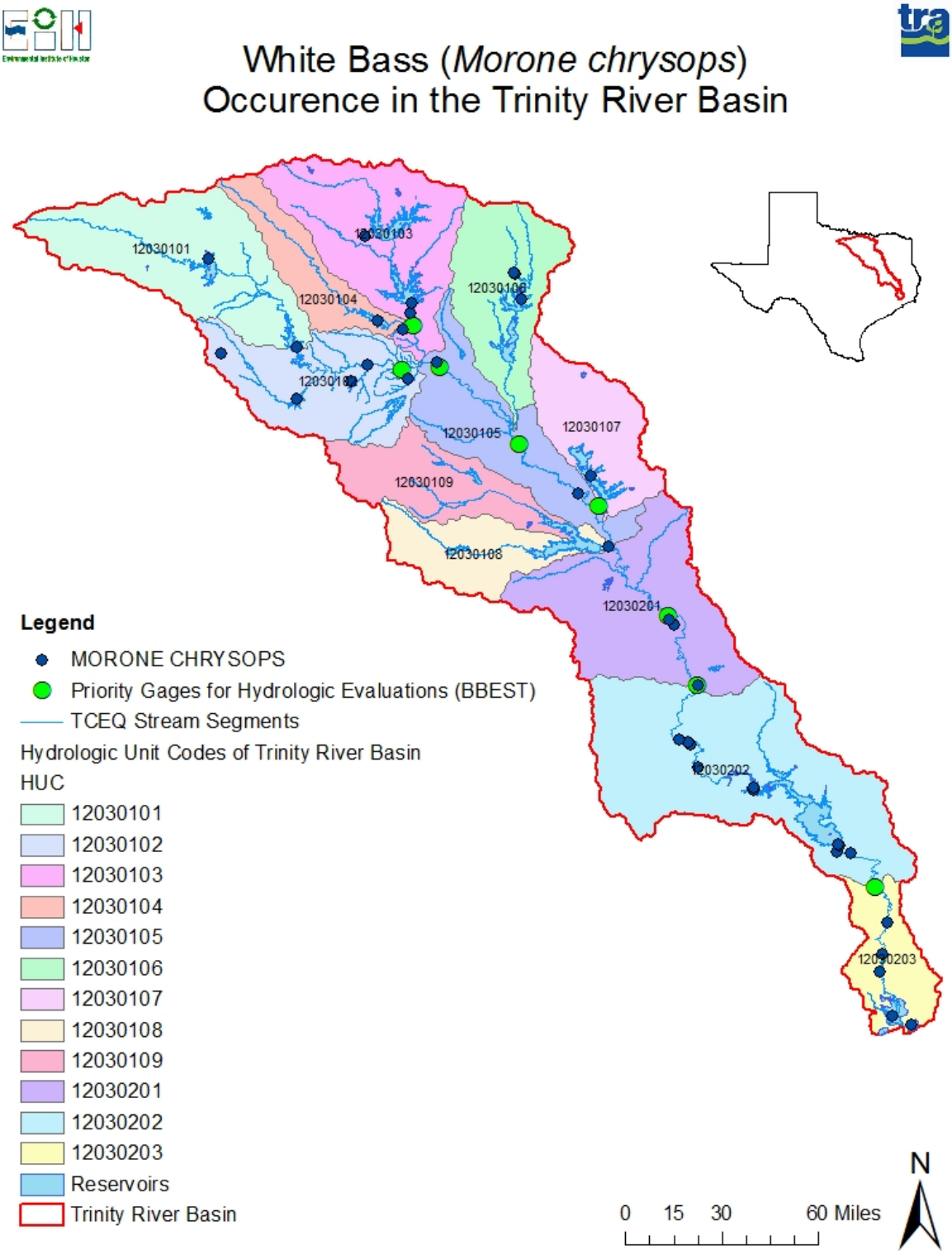


Figure 163. Spatial distribution of white bass in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

A habitat suitability index (HSI) model that addresses instream flow needs for white bass has been published by USFWS (Hamilton and Nelson 1984)(Figure 164). According to the authors, the models are applicable throughout the natural range of white bass in lower 48 states of North America with its greatest applicability in southern states. Several riverine habitat variables were identified as useful metrics for defining suitable habitat for white bass including forage fish, water level change, temperature, length: depth ratio, stream order, percent low velocity area, day-degrees and substrate index. Suitable levels of these variables that would support and/or provide critical life functions including food and reproduction were defined. Several of these including water level change, percent low velocity area and temperature are directly affected by hydrology. For example rivers possessing between 25 and 75% surface area with a surface current velocity $\leq$ 0.4 m/sec provide the best habitat for this species. This can include deep pools, behind structure or off channel pools. Another metric is the maximum water level change from the onset of white bass spawning to the hatching of fry. The ideal value is zero which declines linearly to -4.0 meters. Another metric is average weekly water temperature during spawning and incubation. The ideal range is 15 to 17 C (Hamilton and Nelson 1984). These metrics, along with the other less flow dependent variables, are used in the construction of a total HSI that can used in the Habitat Evaluation Procedure (HEP) and/or Instream Flow Incremental Approach (IFIM) physical habitat simulation model (PHABSIM), or similar approaches, to define and describe how overall habitat and quality vary with flow. A copy of this document with associated suitability index curves is provided with this report.

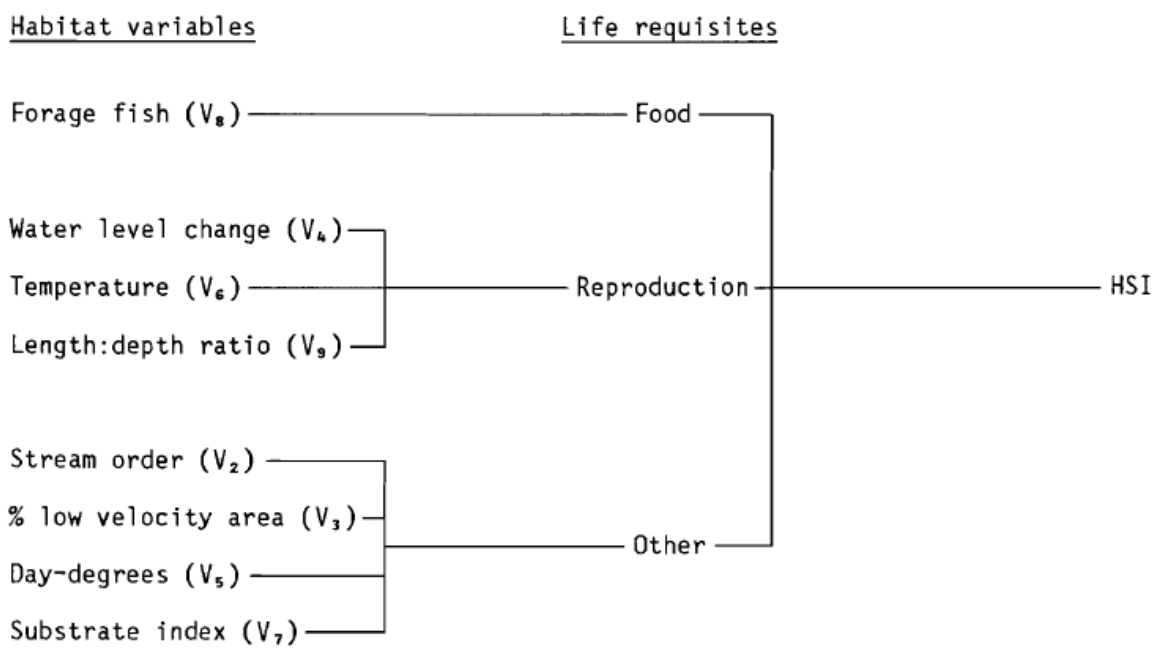


Figure 164. Conceptual structure for riverine model for white bass.

Notropis atrocaudalis (blackspot shiner)

Blackspot shiner was collected primarily in the middle and lower portion of the watershed based on historical records (Figures 150-155, 165). Only three of the priority gage sites in the middle and lower Trinity River were located near historical collections. Based on historical records Blackspot shiner was collected at various flows less than 12 cfs in the Trinity River (Figure 150). Blackspot shiner was recommended as a focal species by TPWD because it is a species of concern (Table 3) (Hubbs et al. 2008). The primary literature on the ecology of blackspot shiner in Texas has been summarized by (Bonner 2009). Blackspot shiner inhabits small to moderate size tributary streams. It is usually more abundant near headwaters. The species classified as a fluvial specialist (Bonner 2009). It is found in runs and pools over all types of substrates, generally avoiding areas of backwater and swiftest currents. In Banita Creek, TX, blackspot shiner were found at mean depths ranging from 0.19 to 0.29 m, and mean current velocities ranging from 0.13 to 0.30 m/s (Bonner 2009). The species most commonly occurs in small seepage-fed hill streams with sandy bottoms, where it is closely associated. The blackspot shiner spawning season occurs from April through June in open water, most likely producing multiple batches of eggs throughout the season. This species is most likely a pelagophils (broadcast spawner)(Balon 1981; Bonner 2009). Juveniles of this species may undergo movement between downstream sites to upstream sites up to 15 km (Bonner 2009). The species is believed to live up to 2 years. (Herbert and Gelwick 2003a)classified this species as a fluvial specialist. No other specific data on instream flow requirements for Texas populations or elsewhere were encountered.

Notropis shumardi (silverband shiner)

Silverband shiner has been collected infrequently throughout the watershed based on historical records (Figures 150-155, 166). It was collected primarily in the lower and upper portions of the watershed at lower flow (< 5 cfs) (Figures 150 and 166). It occurred only near two of the priority gage sites. According to TPWD silverband shiner is considered a species of concern and sensitive to alterations in stream flow and is a species of concern (Table 3) (Hubbs et al. 2008). The primary literature on the ecology of silverband shiner in Texas has been summarized by (Bonner 2009). Silverband shiner is found large rivers as well as smaller tributaries and oxbows. Past research in Brazos River indicates that it is common in oxbow lakes that frequently reconnect to the mainstem river (Balon 1981). It is founds in the main channel of rivers with moderate to swift current velocities and moderate to deep depths. It is often found in turbid water over silt, sand, and gravel substrate. The species is tolerant of high turbidities. The spawning season occurs from May through mid August at least and possibly mid-fall.(Bonner 2009). Spawning occurs in the main channels of rivers. Breeding aggregations have been observed over hard sand to fine gravel substrates in water 1-2 m deep in strong current (Bonner 2009). The species is likely a broadcast spawner. This species may migrate into tributaries for spawning, especially during high flows. The reported maximum lifespan of approximately 2 years. No other specific data on instream flow requirements for Texas populations or elsewhere were encountered.

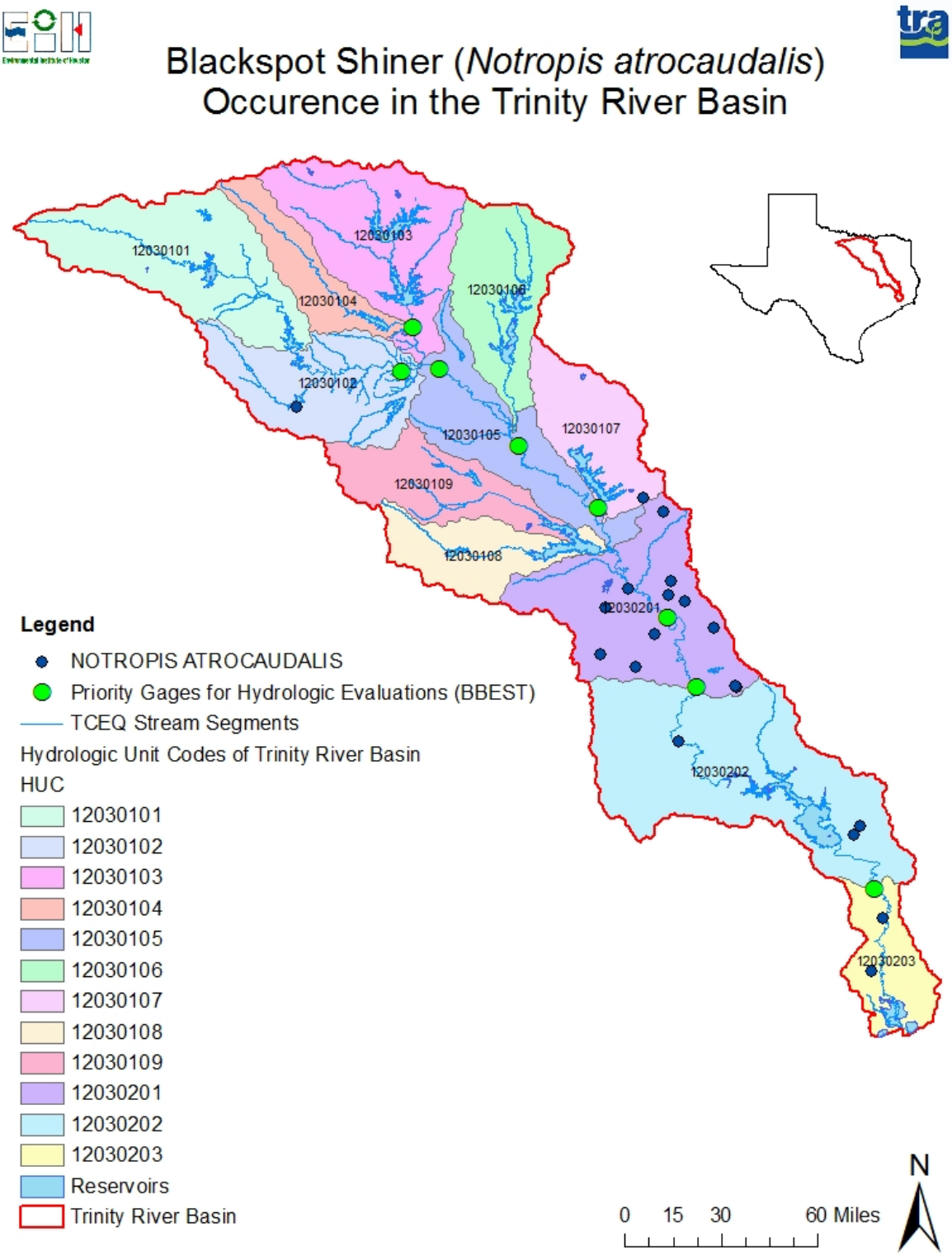


Figure 165. Spatial distribution of blackspot shiner in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

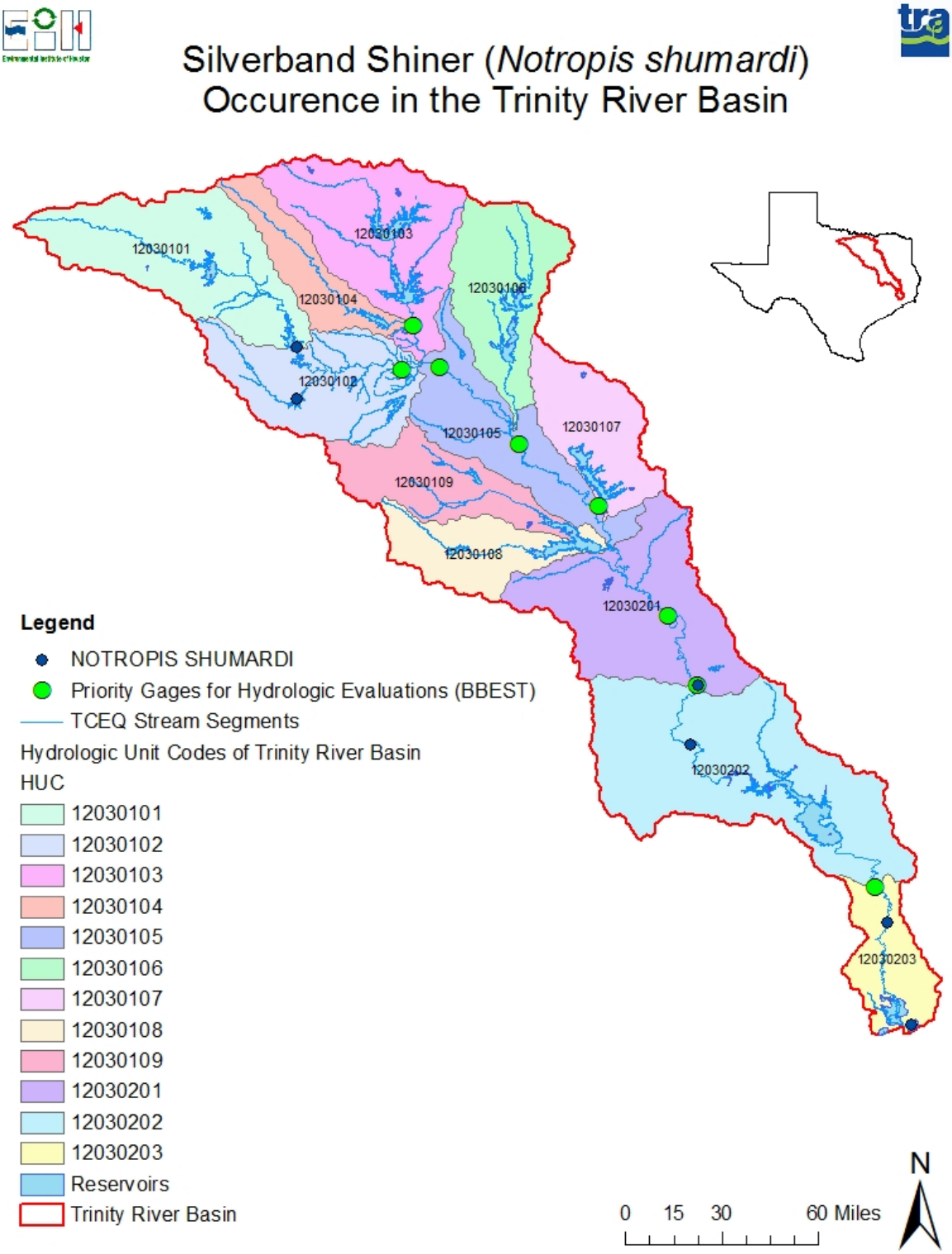


Figure 166. Spatial distribution of silverband shiner in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

Percina sciera (dusky darter)

Based on historical records dusky darter was collected primarily in the middle and lower portions of the watershed at various flows up to approximately 12 cfs. (Figures 150-155, 167). It was collected in numerous tributaries as well. It is considered and invertivore and considered intolerant of poor water quality (Table 3)(Linam and Kleinsasser 1998). Dusky darter inhabits main stem and tributaries in run and riffle areas and is considered flow sensitive by TPWD biologists. The primary literature on the ecology of dusky darter in Texas has been summarized by (Bonner 2009). The species is found in medium to large streams of moderate to low gradients which are not highly turbid. (Herbert and Gelwick 2003a) found this fluvial specialist to be associated with the free-flowing East Fork of the San Jacinto River, Texas. Prior to impoundment, this species was common in the West Fork of the San Jacinto River, Texas, but no specimens were collected during the study at West Fork sites where the species had been present before impoundment. This species is most common over gravel or gravel and sand raceways and often occupy midwater stratum in moving current within accumulations of branches and leaves (Bonner 2009). The young, in contrast to adults are often found along the shallow gravel edges of pools with moderate currents and at times may enter tributaries not visited by adults (Bonner 2009). Throughout its range this species is often forms species associations with other fishes including *Percina caprodes* and *Etheostoma* (including *E. spectabile, E. lepidum and E. fonticola*, *E. gracile*, and *E. histrio* (Bonner 2009). Many of species were categorized into the same guild based on our cluster analysis (Figure 144 and Table 11). Spawning most likely occurs in Texas from February - June (Bonner 2009). Dusky darters are considered lithophils spawning over rock and gravel substrate (Simon 1999a). Spawning has occurred over gravel riffles at depths of 30-90 cm. During the winter dusky darter may shallower upstream locations and smaller tributaries and move to deeper downstream habitats. Males typically live up to 4+ years while females tend to live to 3+ years (Bonner 2009). (Edwards 1997) described the mean and range of velocities at which dusky darter typically occur including habitat they were usually found in. He found that this species most often (68%) in riffles most often at 0.5 to 0.74 m/s. (Herbert and Gelwick 2003a) considered this species a fluvial specialist. (Bio-West Inc 2008) classified this species into riffle guild and proposed HSC criteria for the guild (Figure 168).

Polyodon spathula (paddlefish)

Based on our historical review paddlefish have only been collected in the mainstem Trinity River below Lake Livingston at low flows (Figures 155-160, 169). However, at least 130,503 juveniles were stocked in Lake Livingston during 4 years (1990-1993) (Henson and Webb 2004). Paddlefish is considered threatened in Texas (Table 3)(Hubbs et al. 2008). They are riverine dependent and inhabit medium to large rivers usually in pool and backwater areas (Schramm Jr. 2005; Wilson and McKinley 2004). The primary literature on the ecology of paddlefish in Texas has been summarized by (Bonner 2009). The are usually found in low-gradient areas of moderate to large-sized rivers, sluggish pools, backwaters, bayous, and oxbows with abundant zooplankton (Bonner 2009; Wilson and McKinley 2004). Large reservoirs provide good feeding areas, with paddlefish moving from reservoirs into flowing streams in the spring for spawning (Bonner 2009). In altered reaches of large rivers, fish occur in areas where they may find protection from strong currents, such as near dikes, or bridges (Bonner 2009). In the winter, paddlefish usually move into deep water, as in the Nueces River system, Texas, where spring to fall capture depths averaged 3.9-5.0 m, increasing to 7.6 m in the winter (Bonner 2009).

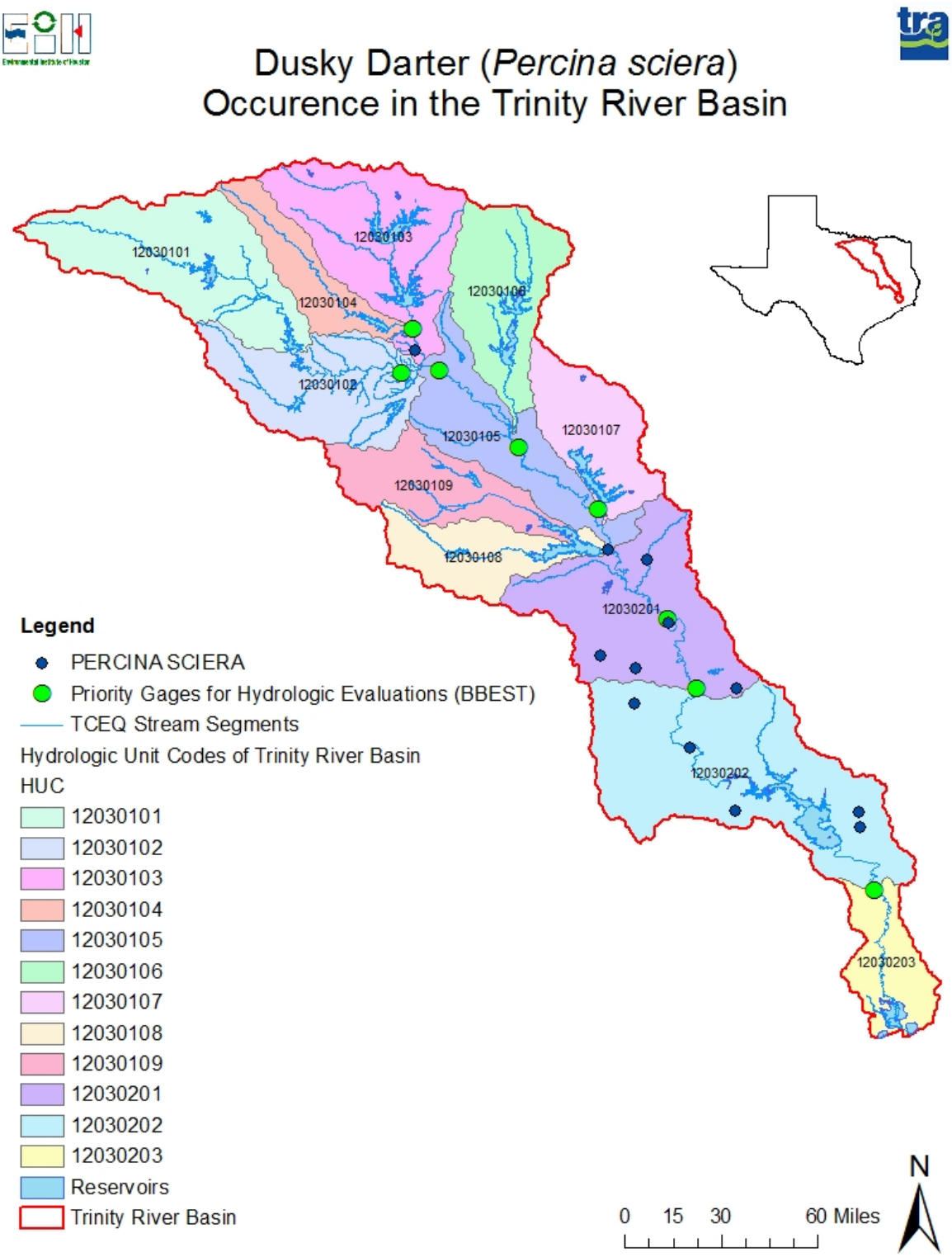


Figure 167. Spatial distribution of dusky darter in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

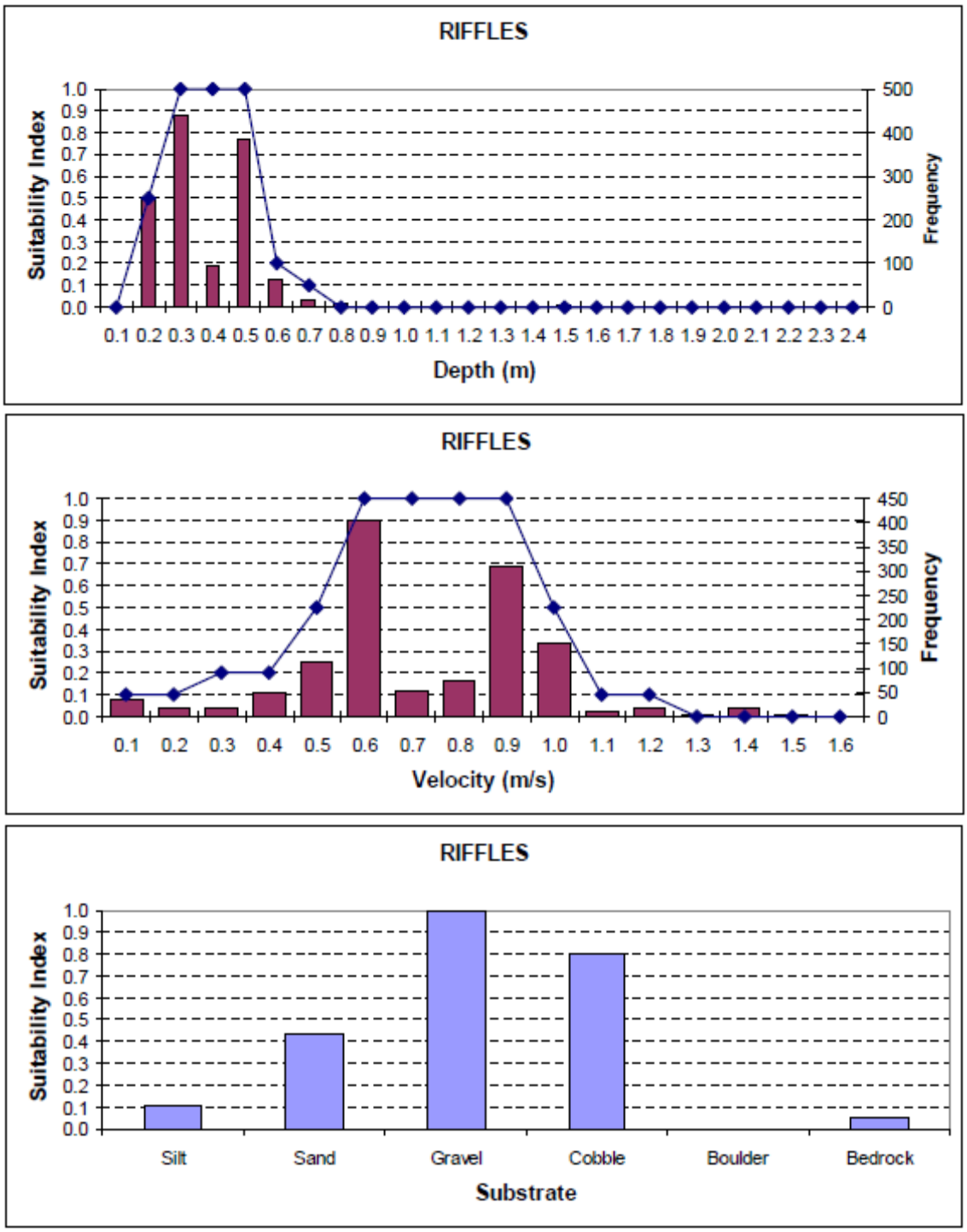


Figure 168. Frequency distribution and HSC values for riffles habitat guild for depth, velocity and substrate in the lower Colorado River. Note: Dusky Darter part of this guild. Source: (Bio-West Inc 2008)

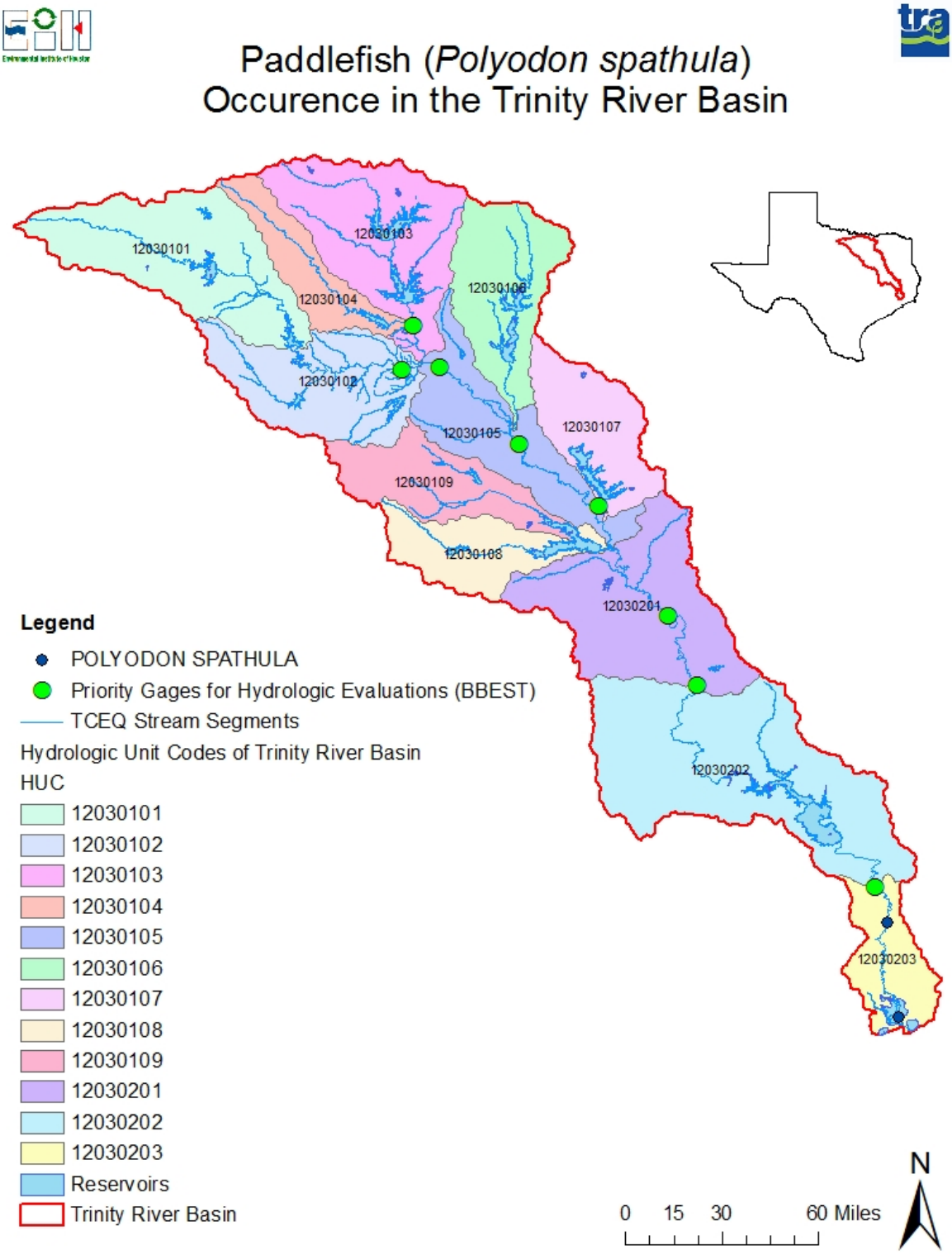


Figure 169. Spatial distribution of paddlefish in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

Large river populations make extensive spawning migrations in the spring associated with pools during high water, and with tailwater (where dams exist) and turbulent main-channel border habitats. Optimum temperatures for this species have been shown to range from about 12-24 C (Bonner 2009). Paddlefish spawning occurs between late February and late June when water temperatures are 10-17°C(Bonner 2009). Even at optimum temperatures, only increased and prolonged river flow will attract fish onto the gravel beds. Flow must be able to maintain a 3-5 m rise in the river for about 10-14 days (Bonner 2009; Wilson and McKinley 2004). Paddlefish typically spawn over gravel beds in swift water. Paddlefish are non-guarding open substratum spawners or lithopelagophils with pelagic embryos (Simon 1999a). Velocity, depth, or substrate may be used as cover, either singly or in combination (Bonner 2009). In the Cumberland River, Tennessee, paddlefish were observed spawning over gravel-rubble substrate in waters 2-12 m deep (Pasch et al. 1980).

Two habitat suitability index models have been developed for paddlefish, one for spawning habitat and one for adult summer and winter habitat (Hubert et al. 1984)(Figure 170). According to the authors, the models are applicable throughout the natural range of paddlefish in North America in riverine and associated reservoir habitat. Various levels of habitat variable that support reproduction and adult habitat were defined. The authors defined appropriate levels of spawning temperature, access to riverine habitat, spawning substrate, spring water level rise, spring current velocity and dissolved oxygen that would support reproduction in paddlefish. The authors also defined appropriate levels of ratios of area of summer/winter habitat, stream/reservoir width, percent backwaters and instream eddy that would provide sufficient adult habitat. Specific variables that are directly related to flow include spawning water temperature, spring water rise and spring current velocity (Hubert et al. 1984). To support reproduction it is recommended that a 21 day period of rising water temperatures between 10 and 17 C should occur annually (Hubert et al. 1984). Furthermore the authors recommended that average magnitude of spring water rise in the river over average midwinter flow for a period exceeding 10 days while temperatures are 10 to 17 C should be at a minimum 3 meters. The also recommended that the average current velocity measured at a point 0.3 meters above the substrate over potential spawning substrates during the spring water rise should be equal to or greater than 0.4 m/sec. These metrics, along with the other less flow dependent variables, are used in the construction of a total HSI that can used in the Habitat Evaluation Procedure (HEP) and/or the Instream Flow Incremental Approach (IFIM) physical habitat simulation model (PHABSIM), or similar approaches, to define and describe how overall habitat and quality vary with flow. A copy of this document with associated suitability index curves is provided with this report. (Winemiller et al. 2005) constructed a life history table relative to median flow values in the Big Cypress Bayou system where it has been extirpated. (Figure 171). He noted that because so little is known about the spawning and ecology of paddlefish, it may prove difficult to make a recommendation regarding instream flows to restore a self sustaining population under existing constraints.

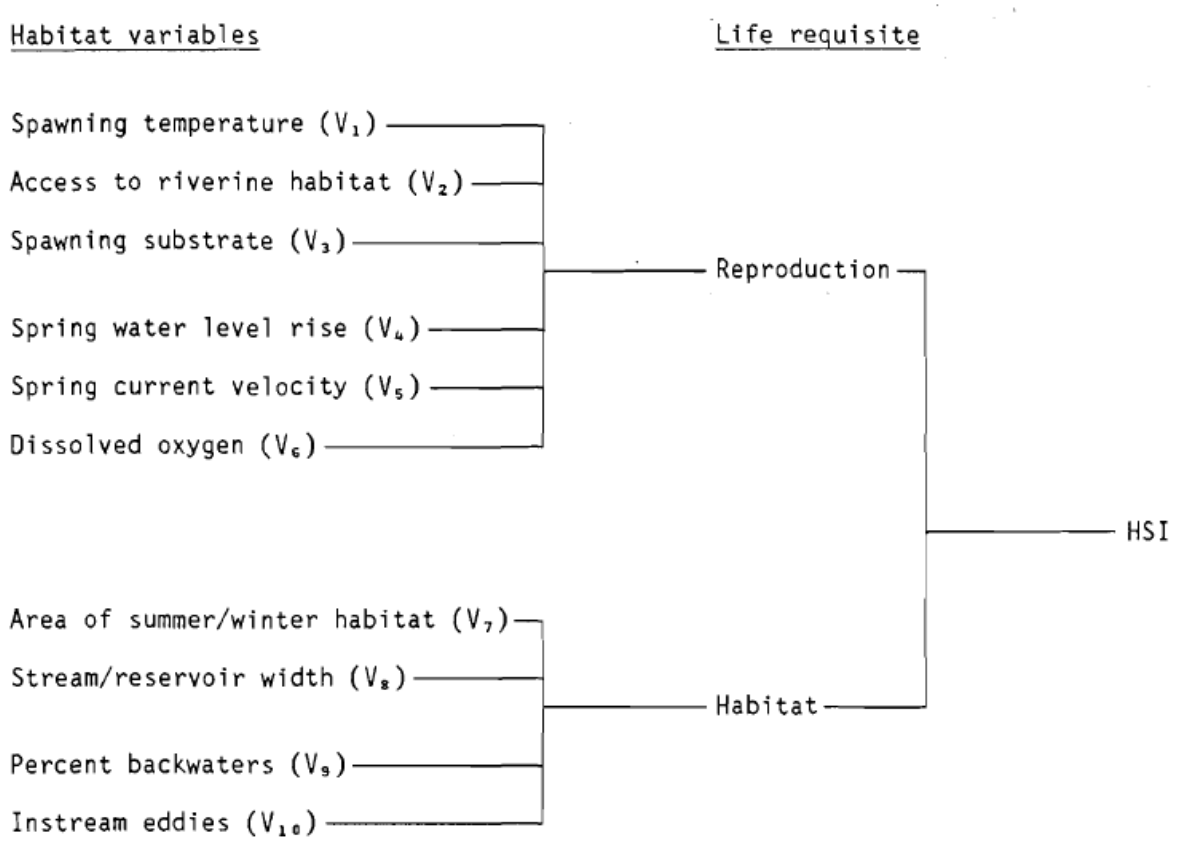


Figure 170. Conceptual structure for riverine model for paddlefish.

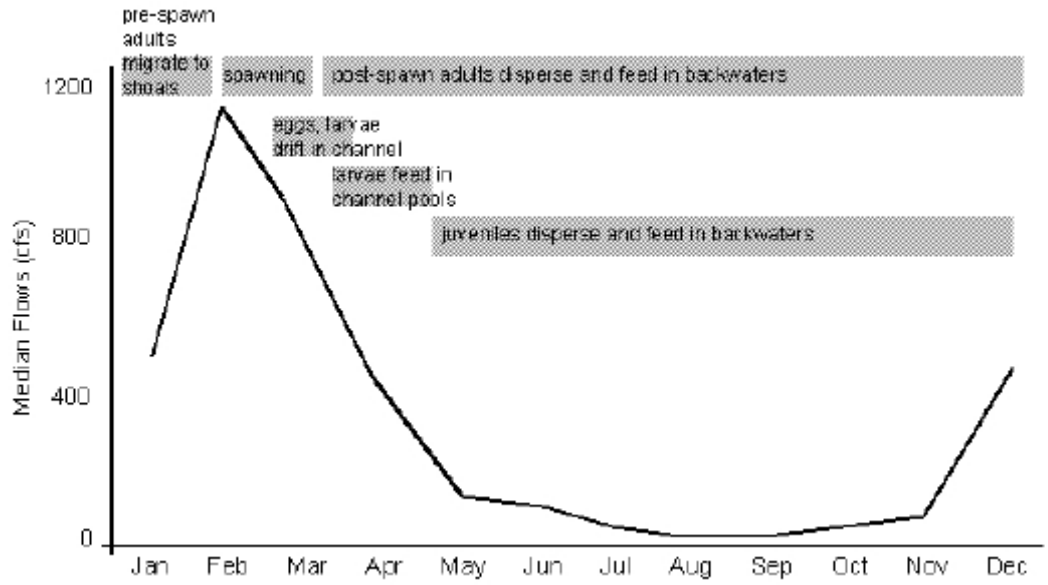


Figure 171. Paddlefish (flow dependent riverine species) life cycle in relations to seasonal flow (relative to per-1957 median flows in Big Cypress Bayou). Source: (Winemiller et al. 2005)

Guidance on Development of Recommended Hydrological Regime

Based on our literature survey targeted instream flow studies which document biological responses to flow and associated variables are lacking in the Trinity River. However, based on literature summarized in this report, most notably published habitat suitability models, and current studies in Texas, fish distribution data within the Trinity River, online literature syntheses and additional published literature we can provide generic and in some cases specific recommendations and guidance on development of instream flow requirements for focal species and by extension similar species within the trophic-reproductive guilds identified by cluster analysis. Based on our review of the ecology of the focal species several patterns emerge. Spawning of many of these fish species occurs in the spring and early summer (Table 12). This corresponds with the period of increasing overall median flows and increased daily fluctuation in flows (e.g. Figures 11,13,15,17,19,21). Invertebrates however had in many cases extended spawning periods. Many of the focal mussel species are also dependent on focal species and other species within the fish guild as hosts for their larvae. Therefore maintenance of flow sufficient to support these species, maintain sufficient dissolved oxygen and prevent dewatering should support most mussel populations. Several species of mussel were however noted in their ability to tolerate poor water quality and/or drought conditions. Several species including largemouth bass, white bass and paddlefish had more specific habitat requirements delineated in accompanying habitat suitability index documents. However, the majority of species did not. Some discussion of paddlefish habitat needs is warranted. Based on our literature review and lists compiled by Drs. Bonner and Hendrickson it is unclear how extensive the historical distribution of paddlefish may have been in the Trinity River. Currently, all recent historical records of paddlefish have been constrained to areas below Lake Livingston dam although they were stocked in Lake Livingston during the early 1990s (Henson and Webb 2004). Paddlefish occur in every major river drainage from the Trinity Basin eastward, but its numbers and range had been substantially reduced by the 1950's (Hubbs et al. 2008). Therefore it may not be appropriate to develop instream flow recommendations for this species above Lake Livingston.

The only instream recommendations that can be made are either going to be generic or specific depending on the availability of existing habitat suitability criteria that can be linked to easily measurable hydrological features (e.g. flow, gage height etc), availability of HEP and previous IFIM/PHABSIM studies in the basin or similar rivers. Examples of generic recommendations include maintaining flows and associated velocities and depths (e.g. maintain connectivity of backwater and oxbows to promote survival and growth of alligator gar and other species utilizing these areas). Another example is managing flows to reduce flooding events during the nesting period for longear sunfish and largemouth bass (Table 12). Examples of specific criteria include paddlefish. For example a recommendation may be to maintain the average magnitude of spring water rise in the river over average midwinter flow at a minimum of 3 meters, for a period exceeding 10 days while temperatures range from 10 to 17 C. Another example is promoting management that would reduce the probability of water levels increases during the months of April and May to maximize the spawning potential of white bass. A final example is managing flows to maintain minimum water temperatures between 17 and 22 C to promote largemouth spawning during the months of March through May. These recommendations are described in detail in the HEP documents provided.

Table 12. Summary of life history requirements for focal species of fish and invertebrates.

	Spawning Season													
Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Key Instream Flow Needs	HS Index?
Freshwater Drum													It is usually found associated with benthic habitats of large, shallow bodies of water up to 40-60 feet deep. In large rivers, fish may move distances of at least 161 km. Individuals have been observed to become distressed when water temperatures exceed 25.6°C, and when dissolved oxygen concentrations remain low over an extended period. Spawning season for freshwater drum occurs in May and June, usually when water temperatures range between 18-26°C	
Alligator Gar													It has been collected from deep, frequently connected oxbow lakes; and has significantly higher abundance in oxbow habitats during wet years. Typically specimens collected from oxbows are juveniles (409- 810 mm), while only adults (1474-1850 mm) are captured in the river channel. However, this may be due in part to large individuals escaping capture in oxbow sampling. Adults may move into oxbows during flooding to exploit abundant prey, returning to the river channel later. Factors including enhanced foraging, growth and survival may influence juveniles to remain in oxbows for extended periods	
Blue Catfish													Blue catfish spawn between April and June at water temperatures of 21-25 degrees C	
Longear Sunfish													They are abundant in clear, small upland streams with rocky or sandy bottoms and permanent or semi-permanent flows with pools. In previous studies in Mississippi, longear sunfish habitat averaged 61 cm deep and had slow current flow (5.2 cm/s) and possessed a silt, mud or sand substratum Found in channels and slow pools in Texas between 0.08 and 0.29 m/s. Spawning has been reported in shallow water with gravel bottom, shallow water and little current. Flood events and potentially associated lowered water temperatures can delay initiation of spawning and result in high nest abandonment and decreased brood survival	
Largemouth Bass													Cover needs (percent pool and backwater), (percent cover, water level fluctuation), water quality (d.o., temp, turbidity), reproduction (percent pool&backwater, temp, water level fluctuation, current velocity), other (current velocity)	Yes
White Bass													Reproduction (Water level change, temperature), Other (percent low velocity, day-degrees).	Yes
Blackspot shiner													The species classified as a fluvial specialist. It is found in runs and pools over all types of substrates, generally avoiding areas of backwater and swiftest currents. Found at mean depths ranging from 0.19 to 0.29 m, and mean current velocities ranging from 0.13 to 0.30 m/s	
Silverband shiner													Past research in Brazos River indicates that it is common in oxbow lakes that frequently reconnect to the mainstem river. It is founds in the main channel of rivers with moderate to swift current velocities and moderate to deep depths. It is often found in turbid water over silt, sand, and gravel substrate. The species is tolerant of high turbidities. The spawning season occurs from May through mid August at least and possibly mid-fall. Spawning occurs in the main channels of rivers. Breeding aggregations have been observed over hard sand to fine gravel substrates in water 1-2 m deep in strong current. The species is likely a broadcast spawner. This species may migrate into tributaries for spawning, especially during high flows.	
Dusky darter													Spawning has occurred over gravel riffles at depths of 30-90 cm. (20-60 cm) in Colorado River. Fluvial specialist, intolerant to poor water quality and dam construction, requires flowing water; mean current velocities: 0.5 to 0.74-1.00 m/s. Prefers gravel and cobble.	
Paddlefish													Spawning season: Spawning occurs between late February and late June when water temperatures are 10-17°C. Even at optimum temperatures, only increased and prolonged river flow will attract fish onto the gravel beds; flow must be able to maintain a 3-5 m rise in the river for about 10-14 days. HS Index =:reproduction(spawn temp, access to riverine habitat, spawn ubstrate, spring water level rise, spring current velocity, d.o.) habitat(instream eddies, percent backwaters, stream/reservoir widt, area of summer/winter habitat)	Yes
Invertebrates													Maintain flows to prevent dessication and provide suitable habitat for host fishes	

Another option is to substitute or supplement some of the proposed priority focal species (e.g. paddlefish) with another species within the guild for which we may have habitat suitability criteria that can be coupled with flow regimes. Also, using habitat suitability criteria developed in adjacent watersheds for fish species or specific guilds may be another option. For example, in our classification scheme guild 3 includes the paddlefish. In addition, the channel catfish is found in this group. The channel catfish does in fact have a HSI Model (McMahon and Terrell 1982) Channel catfish habitat variables are illustrated in Figure 171 and a copy of the document is provided. Another example is the bigmouth buffalo, *Ictiobus cyprinellus*, which is found in guild 1 along with freshwater drum and alligator gar, which lack published criteria (Edwards 1983)(Figure 172). Another example is smallmouth buffalo *Ictiobus bulbalus*, which has HSI criteria, is found in guild 3 along with paddlefish(Edwards and Twomey 1982b)(Figure 173). Smallmouth buffalo is currently a candidate species being used to develop instream flow criteria on Big Cypress Bayou (Winemiller et al. 2005).

Other candidate species which possess HSI models that can be used to substitute or supplement other species in their guilds include bluegill sunfish, redear sunfish, slough darter, common carp, black bullhead, flathead catfish, smallmouth buffalo (Edwards et al. 1982; Edwards and Twomey 1982a; Edwards and Twomey 1982b; Lee and Terrell 1987; Stuber 1982; Stuber and Gebhart 1982; Twomey et al. 1984). Guidance is also available on the application of individual riverine and lacustrine HSI models with Habitat Evaluation Procedures (Terrell et al. 1982) (Figure 173). It should be noted however that many of the HSI models presented here are for habitat generalists, that is species that are not extremely sensitive to changes in streamflow (Herbert and Gelwick 2003b). The only fluvial specialist species present in our focal species list was Blackspot Shiner and Dusky darter. These habitat generalists however in some cases have preferred and required needs during their development (Schramm Jr. 2005)

Another potential approach would be to attempt to adopt criteria developed for other Texas Rivers. For example Bio-West, Inc. working for the LCRA has proposed several guilds and has been developing habitat suitability criteria (HSC) for selected guilds of fishes (Bio-West Inc 2008). Examples of their guilds and associated HSC are provided in Table 13 and Figures 168. Three of the Trinity Rivers focal species, dusky darter *Percina sciera*, largemouth bass *Micropterus salmoides* and longear sunfish *Lepomis megalotis* are found within two guilds 1) riffles and 2) shallow pools/edge/backwaters (Figure 168). Therefore to the extent the guilds identified in the Colorado River and those proposed for the Trinity can be consolidated into a meaningful group that can be validated at a later date it may be possible to construct some HSC using the combination of the site specific criteria developed for the Colorado River and published literature values (HSI model). Published HSI models and/or HSC developed in other watersheds may be necessary because several focal species identified in the Trinity River are not found or were not selected for the Colorado River analysis.

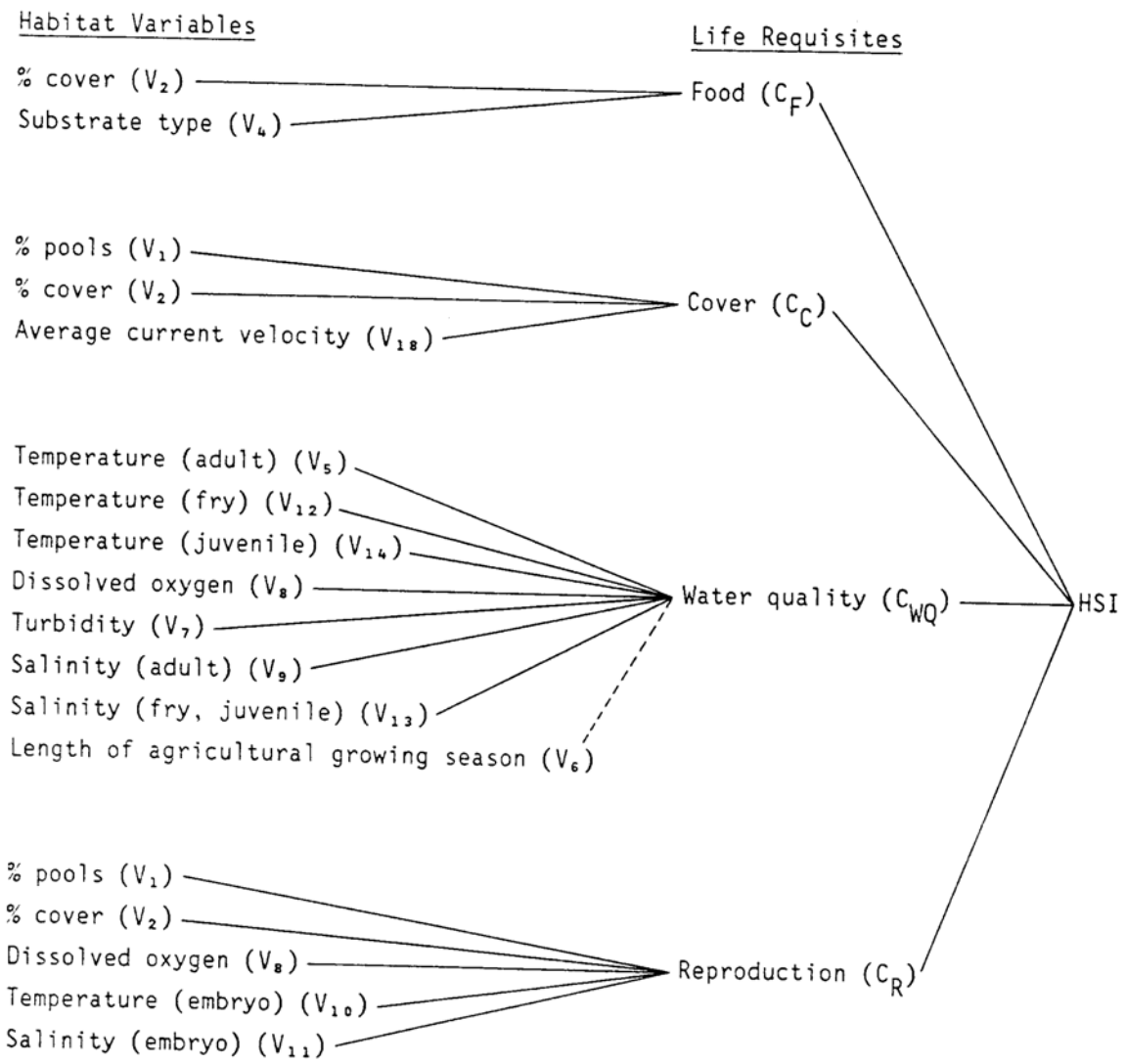


Figure 171. Conceptual structure for riverine model for channel catfish.

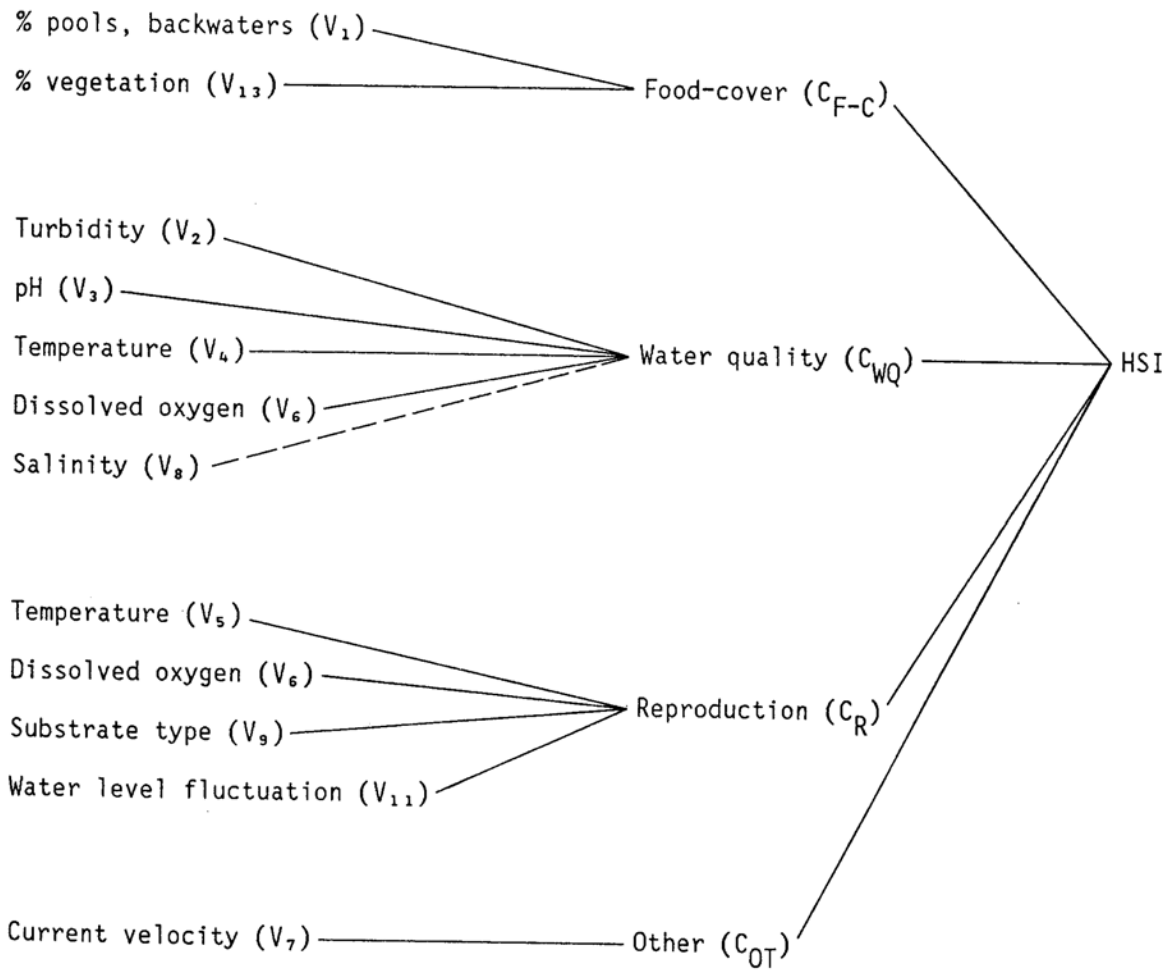


Figure 172. Conceptual structure for riverine model for bigmouth buffalo.

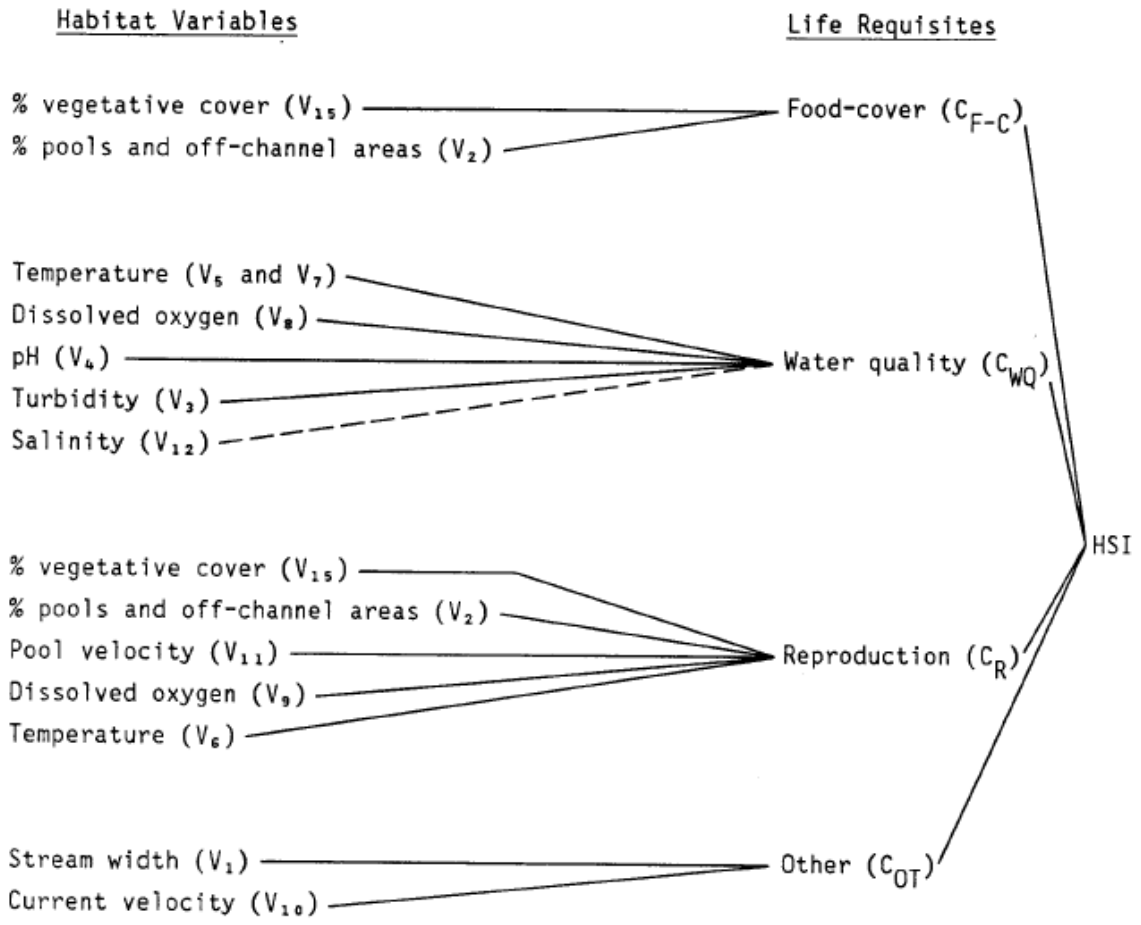


Figure 173. Conceptual structure for riverine model for smallmouth buffalo.

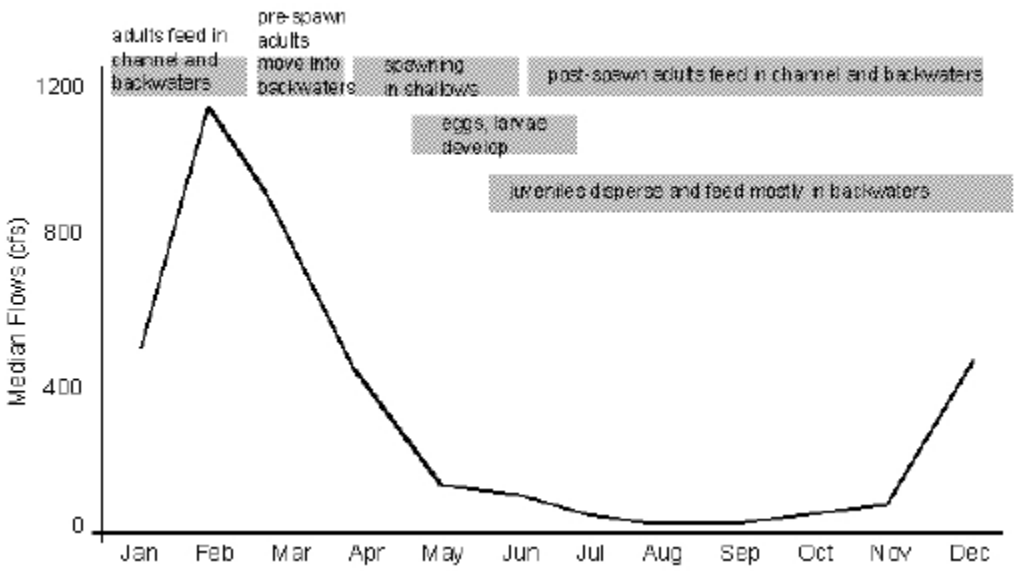


Figure 174. Smallmouth buffalo (flow-responsive species) life cycle in relation to seasonal flow (relative to pre-1957 median flows in Big Cypress Bayou. Source: (Winemiller et al. 2005)

	Riverine						Lacustrine																						
	Habitat			Stream size			Habitat					Cover					Temperature[a]			Spawning[b]							Turbidity tolerance		
							Near-shore		Open-water																				
Species[c]	Riffles, runs	Pools, eddies	Backwaters, bayous, oxbow lakes	Small (< 5 m); order: 1-3	Medium (5-30 m); order: 2-6	Large (> 30 m); order: 5+	Shallow (≤ 5 m)	Deep (> 5 m)	Surface (< 5 m)	Mid-water (5-15 m)	Deep (> 15 m)	Rocky substrate	Aquatic vegetation	Cut-banks	Logs, brush, debris piles	No special cover needs	Cold (< 20°C)	Cool (20-28°C)	Warm (> 28°C)	Free-drifting eggs, no substrate req.	Eggs deposited in or on rocky substrates; current required	Eggs deposited in or on rocky substrates; no current required	Eggs deposited on plants	Eggs deposited in holes, cavities	Eggs deposited in nests of mud, sand, or plant debris	Eggs deposited over a variety of substrates	Low (< 25 JTU)	Moderate (25-100 JTU)	High (> 100 JTU)
Largemouth bass			x		x	x	x						x		x				x						x			x	
Spotted bass		x			x	x		x		x		x			x				x						x			x	
Black crappie		x	x		x	x	x		x				x		x				x						x			x	
White crappie		x	x		x	x	x		x				x		x				x						x				x
Bluegill		x	x		x	x	x			x			x						x						x			x	
Warmouth			x		x	x	x	x					x		x				x						x				x
Slough darter			x		x	x							x						x				x					x	
Common carp		x	x			x	x	x			x		x						x				x						x
Smallmouth buffalo	x	x	x		x	x		x		x	x		x		x				x				x					x	
Channel catfish	x	x	x		x	x		x			x	x		x	x				x					x					x
White sucker		x	x	x	x			x			x	x	x	x				x			x							x	
Northern hogsucker	x	x		x	x							x						x			x						x		
Striped bass	x					x			x	x	x					x		x		x								x	x
Rainbow trout	x	x		x	x		x		x	x		x	x	x	x		x				x						x		

[a]Categories from Hokanson (1977)

[b]Categories from Balon (1975)

[c]Common names from Robbins et al. (1980)

Figure 175. Example of guilding criteria for use in freshwater fishes HSI models: Source (Terrell et al. 1982)

Table 13. Example of habitat Guilds and Blue Sucker life stage categories derived from depth, velocity and substrate use and supplemental radio telemetry for the Colorado River. Source: (Bio-West Inc 2008)

Habitat Guild	Species/Life Stage	Species/Life Stage Abbreviation	Number of Locations Where Observed	Total Number Observed
Riffles	*Percina sciera*	*Psci*	33	121
	Percina carbonaria	*Pcar*	30	95
	Ictalurus punctatus (juvenile, <180 mm)	*IpunJ*	44	640
	Phenacobius mirabilis	*Pmir*	8	65
	Etheostoma spectabile	*Espe*	13	27
	Campostoma anomalum	*Cano*	13	30
	Macrhybopsis spp.	*Maes*	21	280
Shallow Runs	*Cyprinella lutrensis*	*Clut*	66	1989
	Cyprinella venusta	*Cven*	71	1305
	Pimephales vigilax	*Pvig*	32	698
	Notropis volucellus	*Nvol*	40	516
	Micropterus treculii (juvenile, <170 mm)	*MtreJ*	31	91
Deep Runs	*Pylodictis olivaris*	*Poli*	40	107
	Ictalurus punctatus (adult, >180 mm)	*IpunA*	28	71
	Moxostoma congestum	*Mcon*	36	131
	Micropterus treculii (adult, >170 mm)	*MtreA*	13	23
	Carpiodes carpio	*Ccar*	35	215
	Dorosoma cepedianum	*Dcep*	29	451
Shallow Pools / Edge / Backwaters	*Micropterus salmoides*	*Msal*	9	19
	Lepomis megalotis	*Lmeg*	23	490
	Lepomis macrochirus	*Lmac*	21	115
	Lepomis cyanellus	*Lcya*	5	29
	Cichlasoma cyanoguttatum	*Ccya*	11	45
	Gambusia affinis	*Gaff*	14	92
	Poecilia latipinna	*Plat*	6	33
	Fundulus notatus	*Fnot*	6	15
Deep Pools	*Ictiobus bubalus*	*Ibub*	9	16
	Cyprinus carpio	*Carp*	9	18
Blue Sucker Life Stage				
Adult blue suckers / Rapids	*Cycleptus elongatus*	*Celo*	93*	102*
Spawning blue suckers	*Cycleptus elongatus*	*N/A*	10	**

These literature derived recommendations and associated information on the distribution of biological resources coupled with IHA/HEFR hydrological analyses can be used to validate and/or further refine instream flow recommendations. For example, if the hydrological analysis describes a flow regime that generally supports the general life history requirements and/or maximizes habitat suitability criteria values, then this would further reinforce the validity of the recommended flow regime derived from solely from hydrological analysis. In addition, if there are management options available (e.g. control of water releases, removal of migration barriers etc) that may optimize conditions necessary to promote or enhance critical hydrological and water quality parameters necessary to support a critical species function (e.g. migration, reproduction) then this should be explored as a potential future management options. At this stage of development of instream flow regimes it is recommended that an evaluation of the described and proposed hydrological regime be compared to these draft generic and specific biological criteria. A full discussion of these potential criteria and how they can be used to inform and/or further refine the hydrological analysis for development of instream flow recommendations should be conducted by the instream subcommittee of the Trinity-San Jacinto BBEST and eventually the BBEST committee.

Major Findings and Recommendations

1. Water Quality and Relation to Flow Regime

A brief review of water quality variables that may be effected by flow regime and in turn influence aquatic life was provided. Historically anoxia and hypoxia in the upper Trinity River below Fort Worth and Dallas has caused major declines in fish and aquatic organisms. Water quality has steadily improved since the mid-1980s and the incidence of hypoxia is low. However, violation of dissolved oxygen criteria is the most common reason for not supporting aquatic life uses in the Trinity River based on the most recent TCEQ assessment. The relationship of stream flow and dissolved oxygen is variable. During the period before the mid 1980s when wastewater treatment was insufficient and the "black rise" occurred, anoxic water was often associated with rising water levels. However, based on our analysis of historical data it appears that low dissolved oxygen is usually geographically oriented around developed portions of the watershed (near Dallas Fort Worth) and/or occurs more frequently at lower flows. A recommendation would be to maintain flows above 7Q2 or other empirically derived methods to maintain aeration and reduce the probability of hypoxic events. Nu instream flows are not the only factor affecting dissolved oxygen levels since point and non-point source loading (e.g. wastewater facilities, stormwater, agriculture) of organic pollutants also exert a strong influence on dissolved oxygen dynamics and must ultimately be controlled through best management practices and permitting. The fact that the two most common violations of water quality standards are dissolved oxygen and indicator bacteria suggests that some ongoing problems associated with organic loading remain.

2. Geomorphology and Estuarine Loading

Based on past research, current analyses of long-term USGS and TCEQ water quality and discharge data and recent geomorphological studies conducted below Lake Livingston, it appears that sediment and nutrient loading and an analysis of long term data it appears that sediment and nutrient loads in from reservoir have declined as a result of the construction of the dam in 1969. The ultimate impact of reduced nutrient loads on Galveston Bay ecosystem is difficult to assess because local watershed anthropogenic sources of nutrients may have offset the reduced riverine loading. (Jensen et al. 2003) noted that for many years chlorophyll-a levels have been declining in upper Galveston Bay. (Ward and Armstrong 1992) had record a 50% reduction in decadal concentrations of chlorophyll-a in Galveston Bay. Since very little data exist before 1969 it is hard to determine the potential contribution of reduced nutrient loading from the Trinity River. However, the trends were highly correlated with decreasing point source loading in the local watershed in the 1970s and 1980s so this may have been the primary causal factor (Ward and Armstrong 1992). Based on recent data the downward trends has stopped and annual average chlorophyll-a levels are fluctuating around 10 ug/l over the last 5-10 years (Houston Advanced Research Center. 2008. Galveston Bay Status and Trends Website: Water and Sediment Quality Data Portal 2009).

One of the major factors effecting native fish communities within the Trinity River basin is the highly fragmented nature of the watershed due to the high number of dams. Although there is limited pre-reservoir data on fish communities this appears to be one of the major factors leading to declines in certain fluvial specialists that are not adapted to lake conditions found in reservoirs. Studies conducted during the 1950s and 1980s show a major shift from fluvial species (Percidae, Cyprinidae and Ictaluridae) to more invasive and lentic species including shad Clupeidae, and mosquitofish *Gambusia affinis*, and silversides Atherinidae. One of the major factors associated with the decline of the original species composition is the construction of dams and fragmentation of riverine habitat. Highly migratory and diadromous species such as blue catfish, paddlefish, American eel and *Macrobrachium* shrimp now lack the minimum distances needed for spawning and/or can no longer reach spawning areas. Also, physical damage associate with passage through spillways and altered water quality below dam discharges can impact sensitive populations. (Herbert and Gelwick 2003a) found that the presence of dams and downstream reservoirs limited the ability for fluvial stream fish to recolonize adjacent streams and areas after droughts. Other hydrological and geomorphological impacts associated with dams include altered thermal regime, altered flows, reduced dissolved oxygen and reduction in sediment transport and scour of downstream areas (Yeager 1993). It is hard to estimate from a cumulative impacts of all the dams in the river, but since the Trinity River is the most fragmented watershed in the state it is likely large (Chin et al. 2008). Electronic copies of USGS rating curves for key gage sites are included for future analysis.

3. Candidate Biological Metrics for Development of Instream Flow Recommendations.

Targeted instream flow studies which document biological responses to changes in streamflow and associated variables are lacking in the Trinity River. However, based on literature summarized in this report, most notably published habitat suitability models, and current ongoing instream studies in Texas, fish distribution data within the Trinity River, online literature syntheses, and additional published literature we can provide generic and in some cases specific recommendations and guidance on development of instream flow requirements for focal species and by extension similar species within the trophic-reproductive guilds identified by our study and other investigators. Based on our review of the ecology of the focal species several patterns emerge. Open water broadcast spawners typically release their eggs during the mid to late spring and early summer. This corresponds to seasonal period of increasing overall median flows and increased daily fluctuation in flows. Invertebrates however had in many cases extended spawning periods. Many of the focal mussel species are also dependent on focal species and other species within the fish guild as hosts for their larvae. Therefore maintenance of flow sufficient to support these species, maintain sufficient dissolved oxygen and prevent dewatering should support most mussel populations. Several species including largemouth bass, white bass and paddlefish had more specific habitat requirements delineated in accompanying habitat suitability index documents. In some cases such as longear sunfish, largemouth bass and alligator gar it is extremely important to maintain seasonal connectivity with floodplain lakes and oxbows in order to provide necessary velocity refuge areas for spawning, nesting and rearing.

Based on our study it is unclear how extensive the historical distribution of paddlefish may have been in the Trinity River. Currently, all recent historical records of paddlefish have been constrained to areas below Lake Livingston dam although they were stocked in Lake Livingston

during the early 1990s. Therefore it may not be appropriate to develop instream flow recommendations for this species above Lake Livingston.

The only instream recommendations that can be made are either going to be generic or specific depending on the availability of existing habitat suitability criteria that can be linked to easily measurable hydrological features (e.g. flow, gage height etc), availability of HEP and previous IFIM/PHABSIM studies in the basin or similar rivers. This can include substituting or supplementing some of the proposed priority focal species (e.g. paddlefish) with another species within the guild for which we may have habitat suitability criteria. Using habitat suitability criteria developed in adjacent watersheds for the same fish species or specific guilds may be another option. Again, even if ecologically relevant habitat suitability criteria or indices are available, and applicable to the local population, there must be a mechanism to validate these "modeled" predictions of habitat preference and use during varying flow regimes. This will not be a trivial exercise in a river as big and complex as the Trinity River. In addition, similar to other Gulf coast and southeastern rivers the inherent turbidity and depths often limit direction observation of habit use and availability when and if an instream flow study is conducted. For the time being biologists using the data compiled in this report and by others should be able to provide meaningful input to further fine tune and/or validate hydrologically derived recommendations (e.g. IHA, HEFR).

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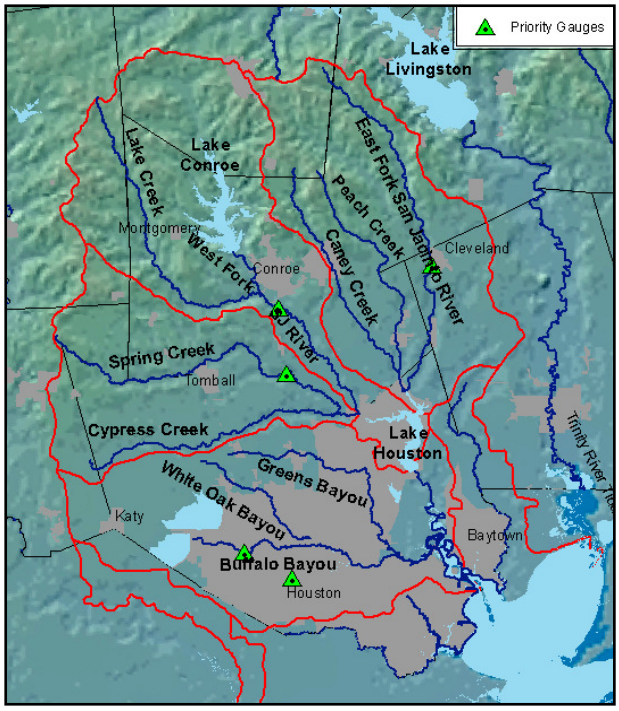
Espey Consultants, Inc.

SAN JACINTO RIVER BASIN SB3 ECOLOGICAL OVERLAY
Final Report



SB3 Science Advisory Committee to the Environmental Flows Advisory Group

Texas Water Development Board

San Jacinto River Authority

September 21, 2009

Project No. 8069.01

SAN JACINTO RIVER BASIN SB3 ECOLOGICAL OVERLAY

FINAL REPORT– September 21, 2009

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1.0 EXECUTIVE SUMMARY

Development of environmental flow guidelines should involve characterization of indicators or ecological processes that respond to changes in flow or flow regime. In an accelerated process where detailed studies are not yet available, the guideline development process necessarily relies upon existing information and existing studies. Indeed, the Senate Bill 3 (SB3) effort is underway exactly because detailed studies have not been completed to evaluate the specific effects of changes to flow regime on many of the river and bay systems in Texas. Therefore, only limited amounts of information are available to identify particular flow rates or flow patterns for specific beneficial ecological processes. The main challenge is attempting to use small point data sets to characterize the natural spatial and temporal variability of water bodies.

This ecological overlay project aims to extract data or information from existing studies that may provide some guidance or may inform development of preliminary flow guidelines, until such time as more detailed studies or information are available. An initial effort to statistically characterize hydrology and flow regime is recently completed (Crespo 2009); later iterations of that hydrology project may be informed by this ecological overlay project to the degree of confidence attributed to the existing information. Ultimately over the long term, detailed site-specific data throughout a system is necessary to characterize habitat or ecological response to changes in flow regime.

Information discovered and presented in this report concentrating on the San Jacinto River basin includes a discussion of focal fish and mussel species (TPWD 1982), a characterization of least-impacted reaches (Moring 2001), status of biota (USGS 2002), nitrogen budgets (Longley et al. 2001), hydrology assessments and water quality assessments. The majority of information was discovered on the West Fork San Jacinto River (SJR) with some information on the East Fork SJR, the SJR below Lake Houston, and other tributaries in lesser amounts.

Coordination with Trinity-San Jacinto Bay-Basin Expert Science Team (TSJ-BBEST) instream flow subcommittee led to identification of priority stream flow gauges; hydrology and water quality information discovery is concentrated near these priority locations. Input from Texas Parks and Wildlife Department (TPWD) on focal freshwater fish and mussel species was considered, as was information on threatened and endangered species. Opinions have been provided by external mussel researchers and by TSJ-BBEST members. This project was developed in coordination with the parallel ecological overlay project in-progress for the Trinity River basin. TSJ-BBEST bay and estuary Salinity-Ecology Workshops have been ongoing and are summarized in minutes contained in a separate report (EC-TES 2009).

Focal instream biological components, including overbank flows, flow pulses, baseflows and seasonality, have been evaluated using habitat requirements of focal species. A matrix of geographic occurrence has been developed for fish and mussel species (Appendix B). Based upon requirements of a select few focal fish species, overbank flows appear beneficial to spotted gar, flow pulses may impact fry of largemouth bass (high velocity) and pallid shiner (high turbidity), and baseflows are beneficial to a number of species that exhibit utilization patterns of shallow riffle habitats including freckled madtom, flathead catfish young of year and dusky darter. Subsistence flow levels may be informed intolerance of largemouth bass to salinity and intolerance of freshwater drum to high temperatures. Spawning of the seven focal fish species is generally between April and June; the largemouth bass spawn earlier, December through March. Despite indication that these flow components may impact or benefit focal species, no site-specific analysis has been discovered to support identification of quantitative flow values for priority locations.

Biology and freshwater fish assemblages have been assessed for a variety of purposes through time; management measures to improve the fisheries have not been recommended because of satisfactory conditions (TPWD 1986). The USGS evaluated biotic integrity at a number of sites throughout the basin

on small and large streams. Six stream sites on the San Jacinto and one on the Trinity were identified as least-impacted and several sites with highly urbanized watersheds are more impacted (Moring 2001). Use of characteristics at the least-impacted sites could improve assessments in the future, but assignment of flow values based upon these findings is challenging.

The five priority gauges identified by the TSJ-BBEST are West Fork San Jacinto River near Conroe; Spring Creek near Spring; East Fork San Jacinto River near Cleveland; Buffalo Bayou at Piney Point and Brays Bayou at Houston. All locations show increase in annual minimum flows, the result of area development including effluent discharges and water management.

One sediment transport analysis is available for the West Fork San Jacinto River (Herrera 1999) that may be useful in future modeling or development of a fluvial sediment overlay (SAC 2009b).

Water quality information gathered near these locations included SWQM data and reports of water quality surveys leading to waste load allocations. Based upon inspection of the data, dissolved oxygen (DO) does not exhibit a discernible relationship with flow; additional analysis or modeling is necessary to develop relationships with flow, flow pulses, temperature or loading. Limited analysis was discovered to characterize sediment and nutrient loading to the bay.

This report represents a draft deliverable to the SB3 Science Advisory Committee (SAC) submitted for review. A presentation of these findings will occur at the September 9, 2009, SAC meeting in Austin, as well as at the September 10, 2009, TSJ-BBEST meeting in Austin. Comments on this draft will be received by the San Jacinto River Authority and Espey Consultants, Inc., until September 14, 2009. The final report will be issued September 21, 2009.

2.0 BACKGROUND

2.1 SCOPE OF WORK

This project aims to provide, in a short timeframe, a compilation of information to guide in development of ecological overlays which may be used by the Trinity-San Jacinto Bay-Basin Expert Science Team (TSJ-BBEST) in support of environmental flow analyses. The focus area of this work is the San Jacinto River (SJR) basin. This work may also be used as a first step in discussion of how ecological overlays may be approached as other basins begin the Senate Bill 3 (SB3) process.

Specific work items include summary of relationships developed and reported in works by others. Relationships of interest include those between flow and biological variables, geomorphologic parameters, water quality or nutrient/sediment loadings. The generic term "flow" encompasses a variety of concepts including river flow regime, flow velocity and freshwater inflow to the bay. The scope of work is provided as Appendix A.

Consultation with members of the TSJ-BBEST, with the Trinity River overlay team, with state agency staff involved in the Texas Instream Flow Program (TIFP) and other experts is a goal of this project. As a result of coordination with the TSJ-BBEST, work is focused on areas near priority gauges identified by the TSJ-BBEST Instream Flow subcommittee (Table 1 and Figure 2). A complete table of gauges in the SJR basin, with notation of beginning and end dates, is provided in Appendix E.

Table 1 – Priority Gages

Station ID	Name	Period of Record
08068000	W. Fork San Jacinto near Conroe, TX	(1926-28) 1939-2009
08068500	E. Fork San Jacinto near Cleveland, TX	1939-2009
08070000	Spring Creek near Spring, TX	1939-2009
08075000	Brays Bayou near at Houston, TX	1936-2009
08073700	Buffalo Bayou at Piney Point, TX	1963-2009

Relevant publications were discovered for this project by searching resources including the recently-developed San Jacinto River Instream Flow Literature Catalogue (TCEQ contract number 582-9-89819). The resulting reports were reviewed for pertinent information. Additional material was gathered through electronic data searches, and communicating with State agency staff involved with the Texas Instream Flow Program. Literature sources are cited where relevant in this report; a companion archive of relevant electronic reports is distributed with the final report.

2.2 BASIN SETTING

The San Jacinto River Basin (Figure 1 and Figure 2) comprises 3,962 total square miles spanning two distinct zones divided by Lake Houston. The watershed upstream of Lake Houston comprises 2,837 square miles and includes major subwatersheds of Spring Creek, West Fork SJR and East Fork SJR. The upper watershed is within the Piney Woods Ecoregion (Figure 3) and area geology is characterized as Pliocene or Miocene (Figure 4). Three priority gauges fall near the geological division between the Pliocene zone and more recent Quatenary zone (Figure 4).

The watershed downstream of Lake Houston comprises 1,125 square miles and includes Brays Bayou, Buffalo Bayou, White Oak Bayou and Greens Bayou as well as the lower reach of the San Jacinto River downstream of Lake Houston to Galveston Bay. The lower watershed is in the Gulf Coastal Prairie ecoregion and Quaternary geological zone. Both land use land cover (Figure 5 and Table 2) and soils

(Figure 6) characteristics of the upper watershed are more diverse than the largely urban and developed area in the lower watershed.

By comparison to the lower Trinity River basin, limited wetlands are exhibited in this basin (Figure 7). Some freshwater emergent wetlands are evident along the upper Cypress Creek and a narrow band of freshwater emergent and forested/shrub wetlands are evident along the Lake Creek corridor. Additional analysis of connectivity to determine what pulse or overbank flow values benefit inundation of these wetlands is recommended if flow guidelines are considered for these areas.

Table 2 - Land Use Land Cover distribution by sub-basin (Homer et al. 2004)

	Spring Creek	West Fork SJR	East Fork SJR	Lower-SJR
Water	0.5%	4.8%	0.5%	2.2%
Developed	24.8%	14.6%	10.9%	65.4%
Barren	0.5%	0.4%	0.1%	0.5%
Forest	23.6%	32.1%	44.0%	7.3%
Shrub/Grass	11.1%	13.5%	18.2%	4.1%
Agricultural	31.0%	20.0%	8.3%	13.3%
Wetlands	8.5%	14.6%	17.9%	7.1%
Total Area (sq. mi.)	755	1,080	1,002	1,125

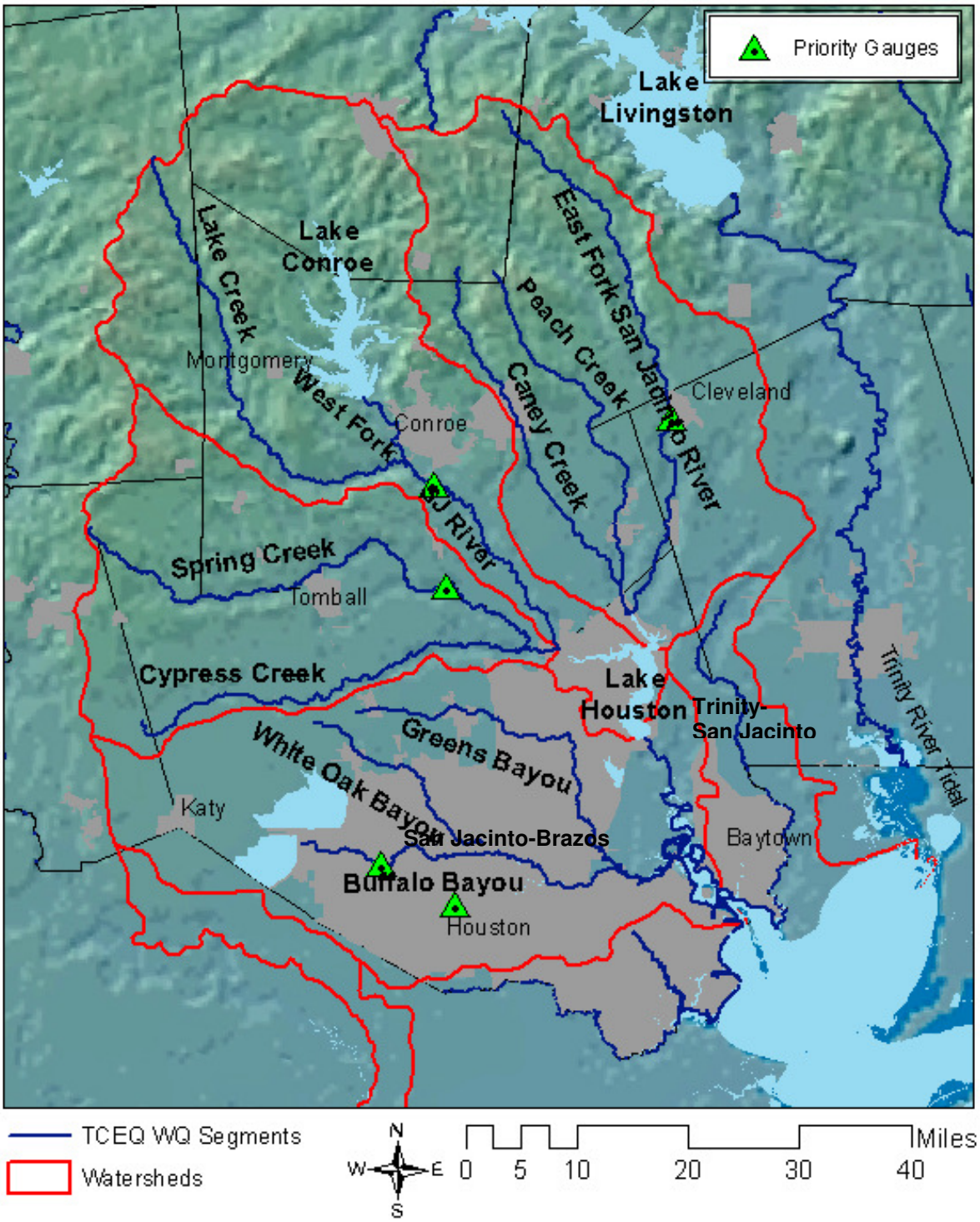

Figure 1 - San Jacinto River and Coastal Basins over terrain map

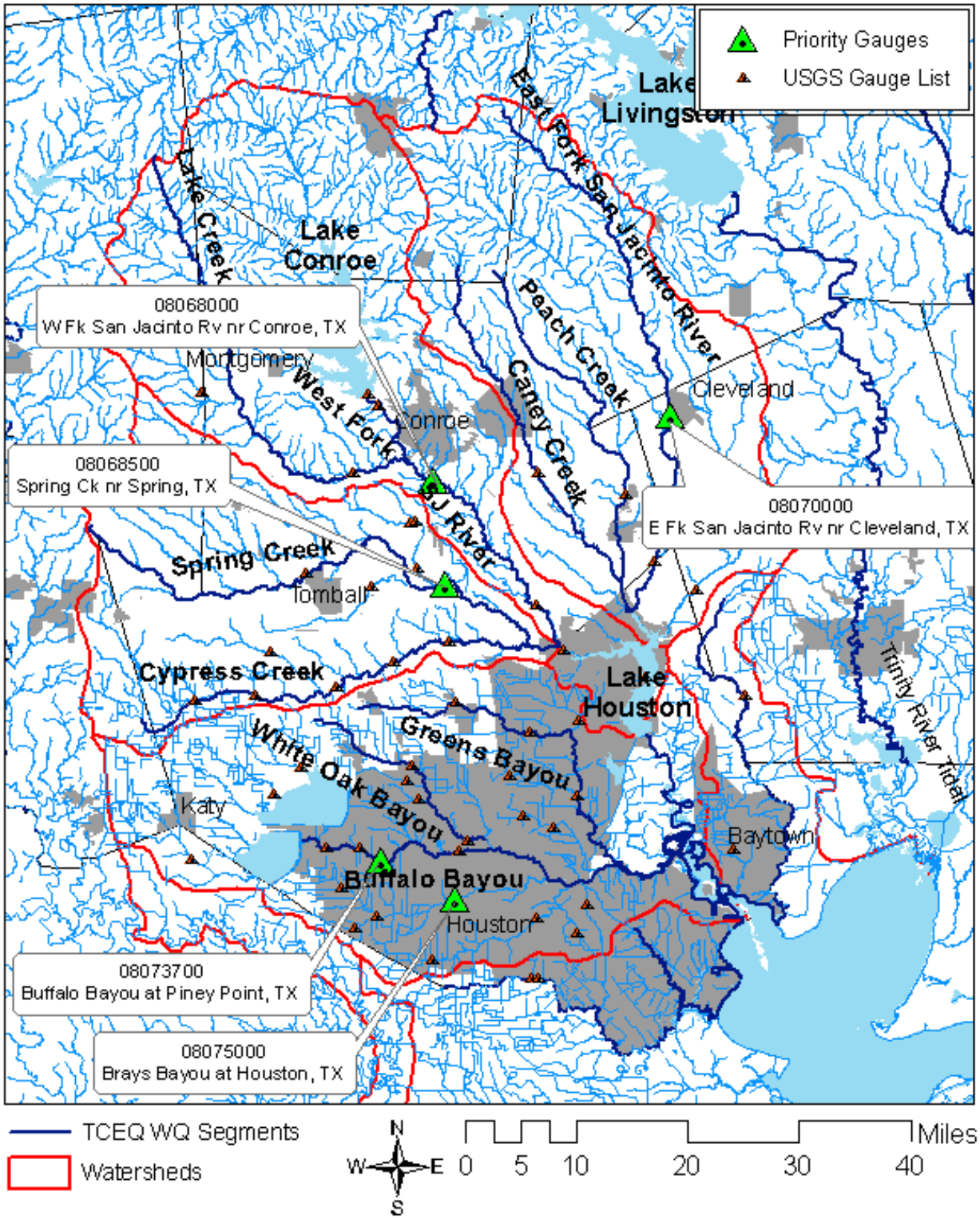

Figure 2 - Historical and current USGS gauges, BBEST Priority gauges emphasized, NHD stream lines shown

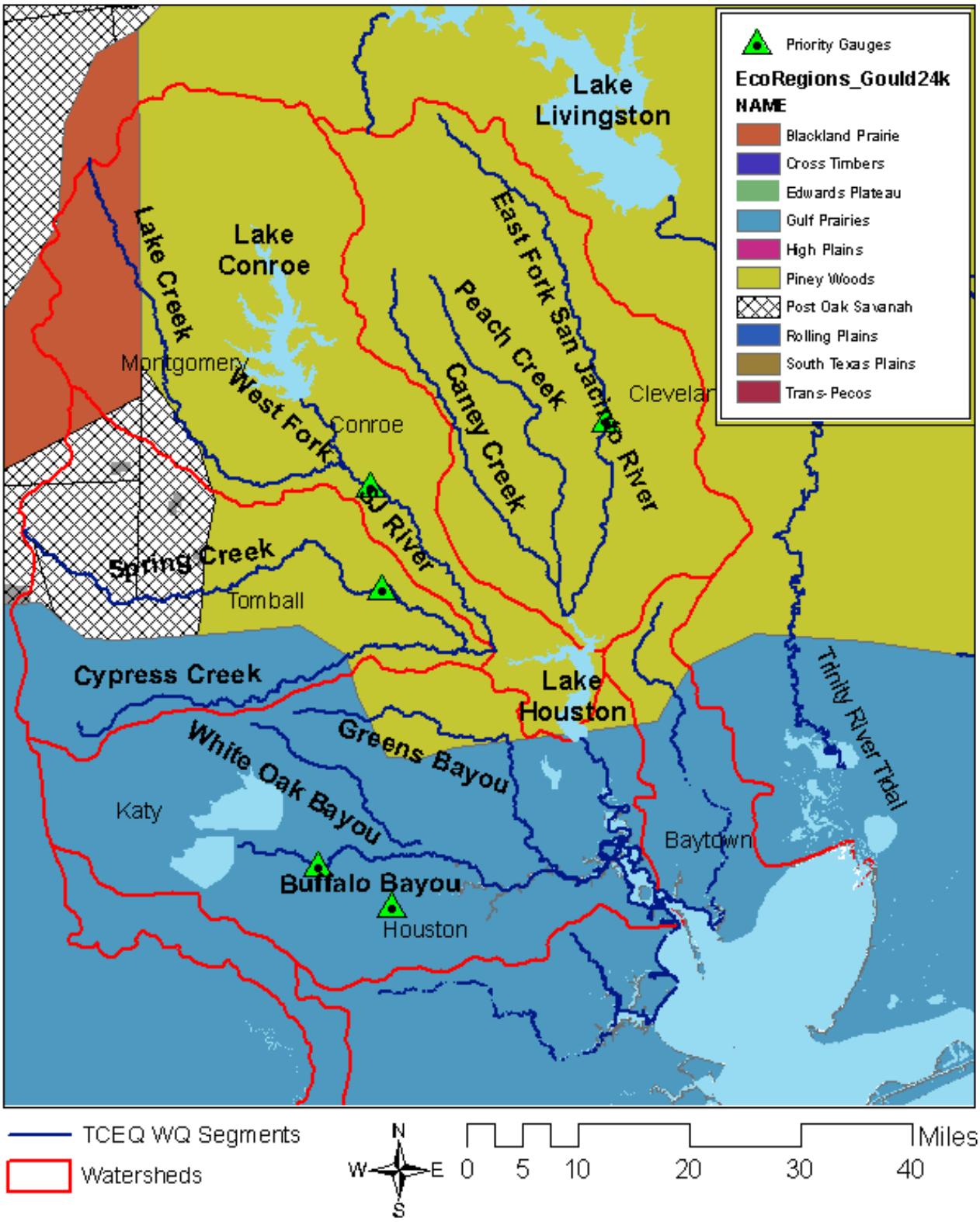

Figure 3 - Ecoregions (TPWD, Gould 24k)

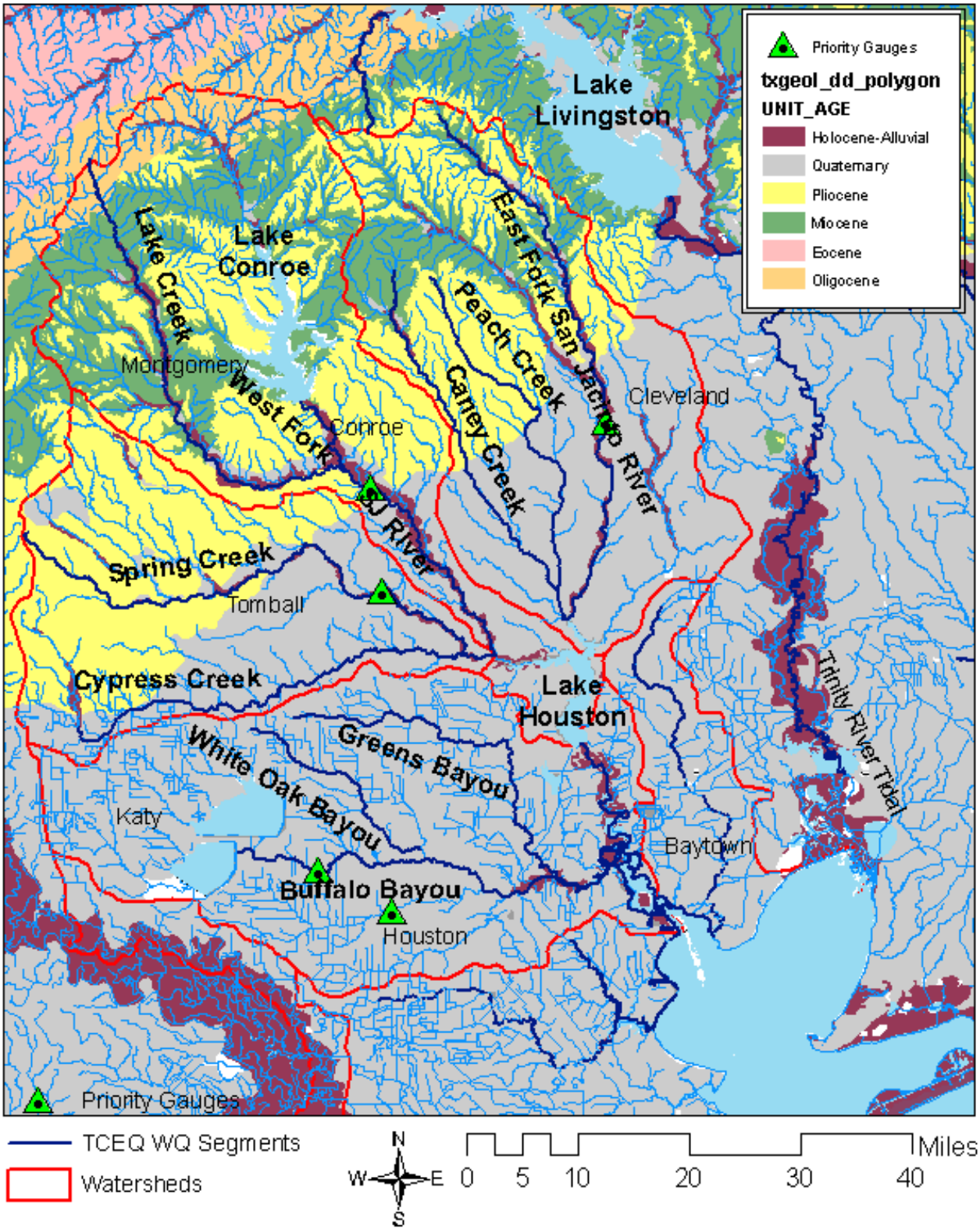

Figure 4 – Geology (USGS, GAT)

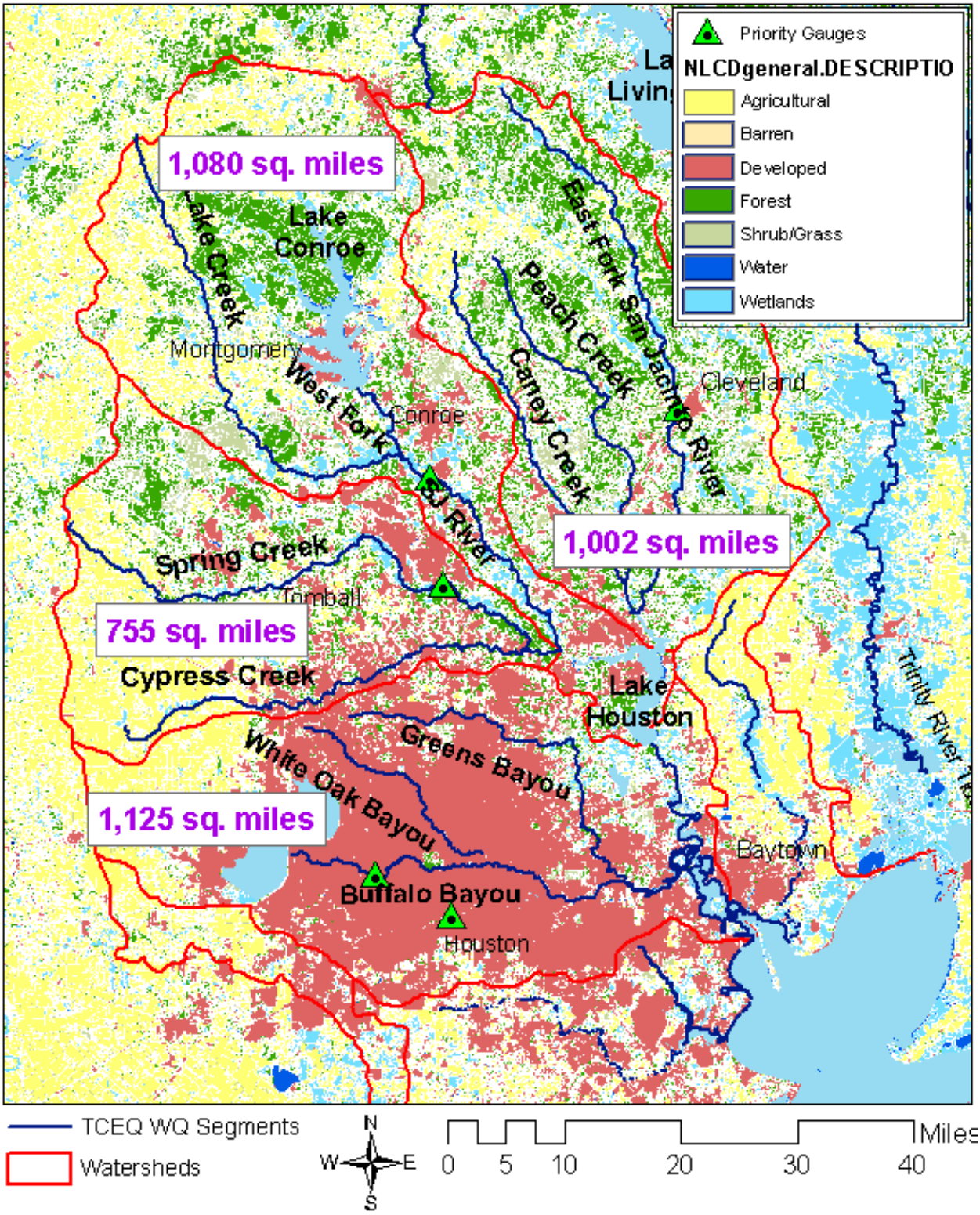

Figure 5 - Land Use Land Cover (NLCD 2001 – Homer et al. 2004)

Figure 6 - SSURGO soils areas (NRCS 2007)

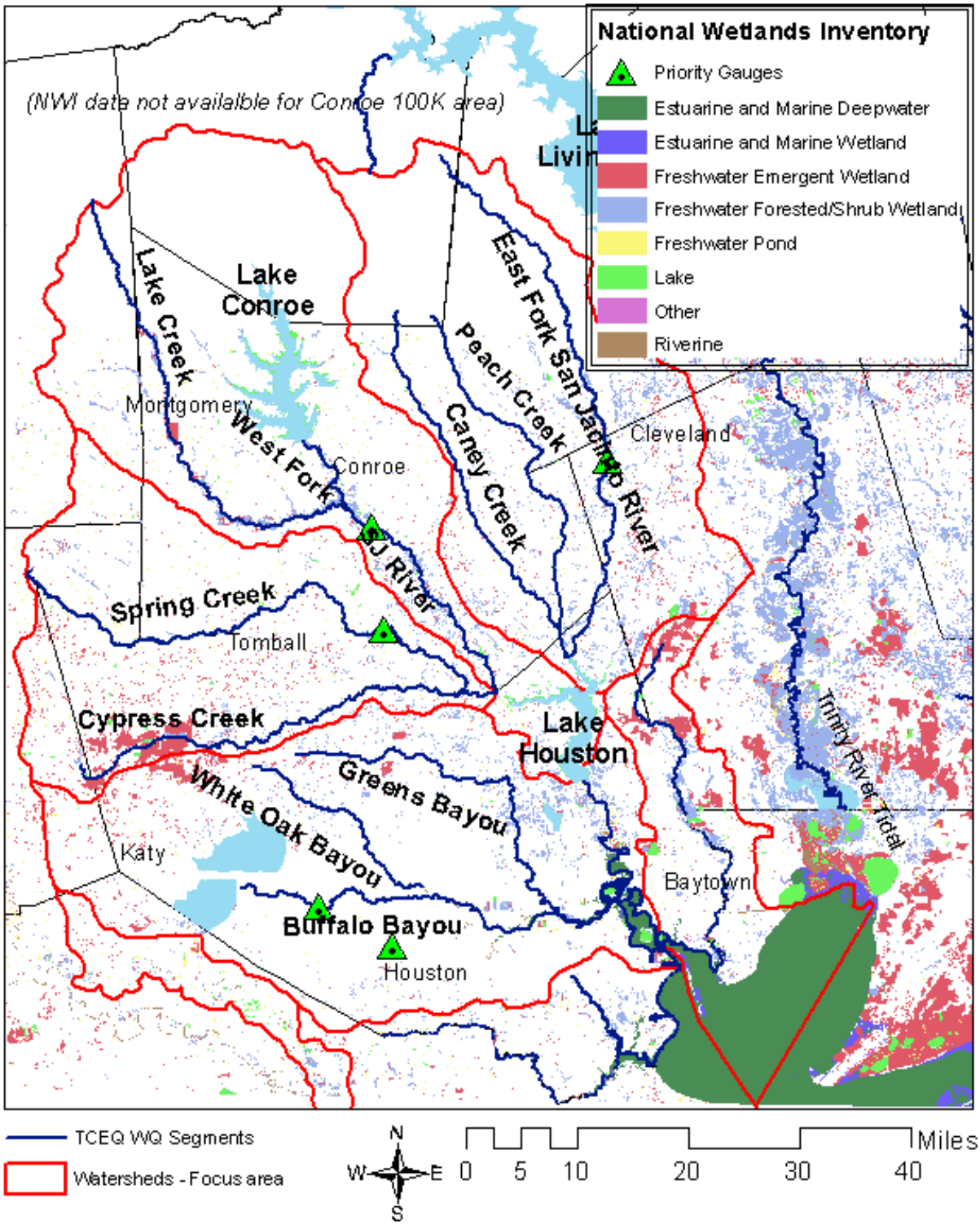

Figure 7 - National Wetlands Inventory (1992-94)

3.0 FOCAL FISH AND MUSSEL SPECIES AND FLOW COMPONENTS

Literature, data and expert opinion were used to generate fish and mussel occurrence matrices. The fish occurrence data includes a total of 117 species within 25 Families of fish. Mussel occurrence data reports a total of 3 Families of mussels with a total of 51 species plus one Macrobrachium shrimp. Spreadsheets summarizing occurrence include information from nine sources for fish and five sources for mussel data. The spreadsheets are provided electronically and contain occurrence data identified in this study. Some of the San Jacinto River Basin occurrence data include the actual number of specimens collected/observed, collection date, exact location (lat. and long.), water quality information and flow rate or velocity. Where available, this information is included. Other data sources identify relative abundance and others identify simple presence/absence. No effort has been made in this compilation effort to verify reported values using museum or voucher records. Information related to geographic distribution has been retained where possible. Condensed summary matrices (one each for fish and mussels) are provided in Appendix B.

The ultimate goal of this project is to develop ecological overlay information to support Senate Bill 3 environmental flow recommendations. The selected reports were reviewed for specific relationship information which included fish and mussel occurrences related to stream velocity, stream discharge, water quality, salinity, sediment loading, turbidity, etc. Where available, data specific to samples was incorporated as the "Relations" worksheet of the attached fish and mussel spreadsheet. Reference 3 (Moring et al. 1998) of this spreadsheet page contains site specific San Jacinto River Basin species, stream velocity, dissolved oxygen, and secchi disc data.

Concurrent with the development of the species occurrence lists, TPWD staff generated a TPWD Trinity – San Jacinto River Draft Focus Species List. In addition, the TPWD Rare and Endangered Species summaries were consulted for information related to the SJR basin. Limited review and comment has been provided by state agencies, university researchers, BBEST team members; additional information has been incorporated into a Modified TPWD Trinity-SJR Focus Species List (Appendix B), including incorporation of mussel information from Dr. Howells and Marsh May (TPWD) that includes data collected by Dr. Burlakova (formerly Stephen F. Austin University). Relevant species-specific information or characteristics for San Jacinto River basin species have been added to the list.

3.1.1 Focal freshwater fish species short list

A short list of focus species is here presented based upon information incorporated into the modified focal species list (Appendix B). Short list species are selected based on their occurrence in the SJR basin, tolerance limits, observed habitat requirements or other parameters discovered in the literature. Rationale is summarized below with information on how the species requirements can be related to flow. Two significant sources of information are (1) the Texas Freshwater Fishes website maintained by Dr. Tim Bonner at Texas State University (Hassan-Williams and Bonner 2009) and (2) the Fishes of Texas project overseen by Dr. Dean Hendrickson at University of Texas – Texas Natural History Collections (UT-TNHC 2009). Mapping and spatial distribution information derived from the UT-TNHC data is provisional and inclusion in this project report is subject to approval by UT staff. A map of all draft UT-TNHC data, divided into three time periods, is provided in Figure 8. Distribution of each short-list species is provided in Figure 9 through Figure 15. Additional spatial distribution information is provided in tabular form in Appendix C, based upon records contained in 10 literature and report references.

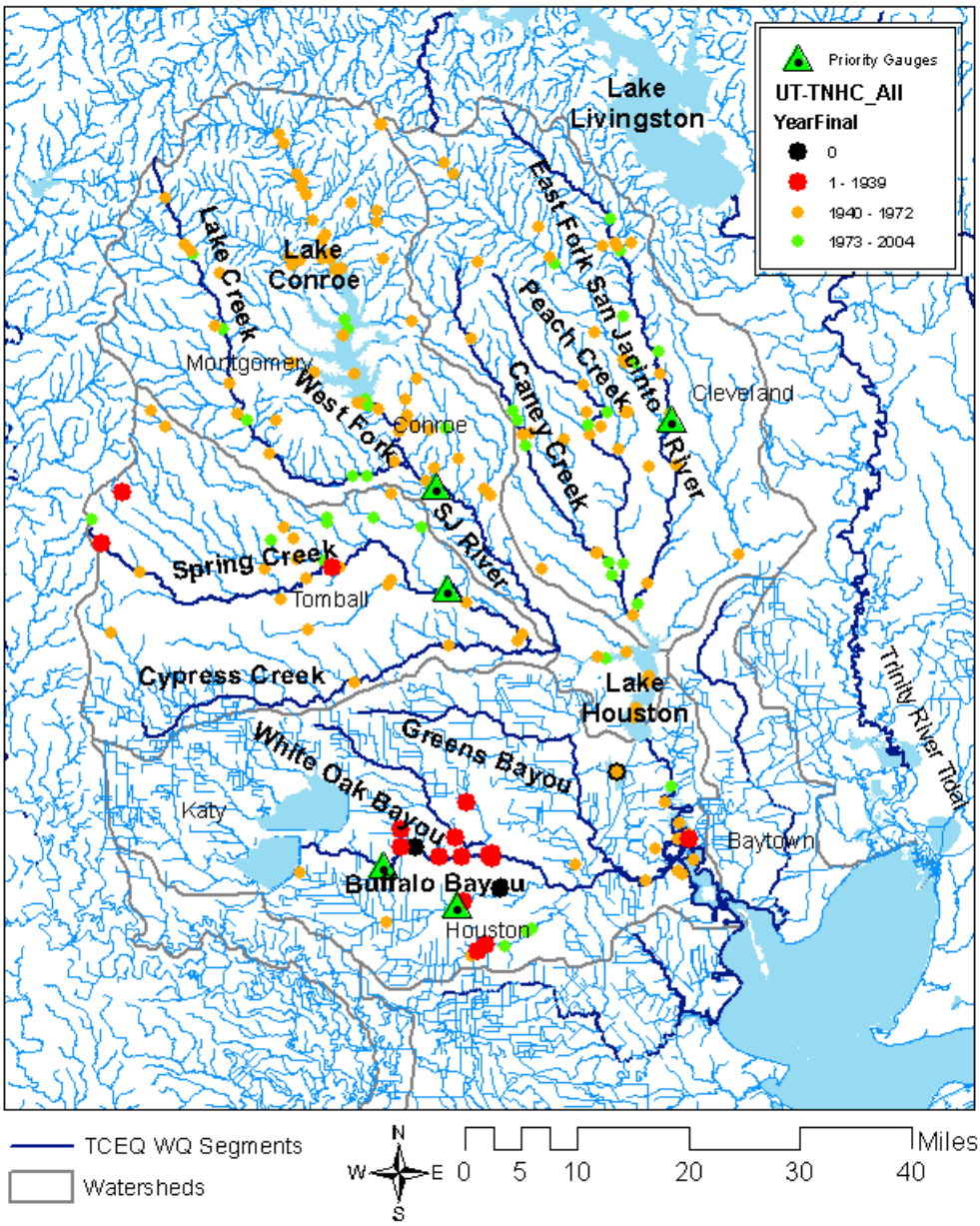

Figure 8 - DRAFT - UT-TNHC - Distribution of all records

Hybopsis amnis (pallid shiner)
- Limited recent occurrence data available
- Turbidity and siltation intolerance, adults <45 NTU; juveniles <85 NTU (Kwak 1991)
- Floodplain access is important for successful spawning or survival of young fish.
- Found in quiet waters over sand-silty bottoms, intolerant of heavy siltation and pollutants (Clemmer 1980).

Flow Component Relationship:

- Seasonality: In Texas, the data indicates May June spawning time. (Bonner)
- Flow Pulses: Potential that Turbidity tolerance may be affected by changes in pulse character

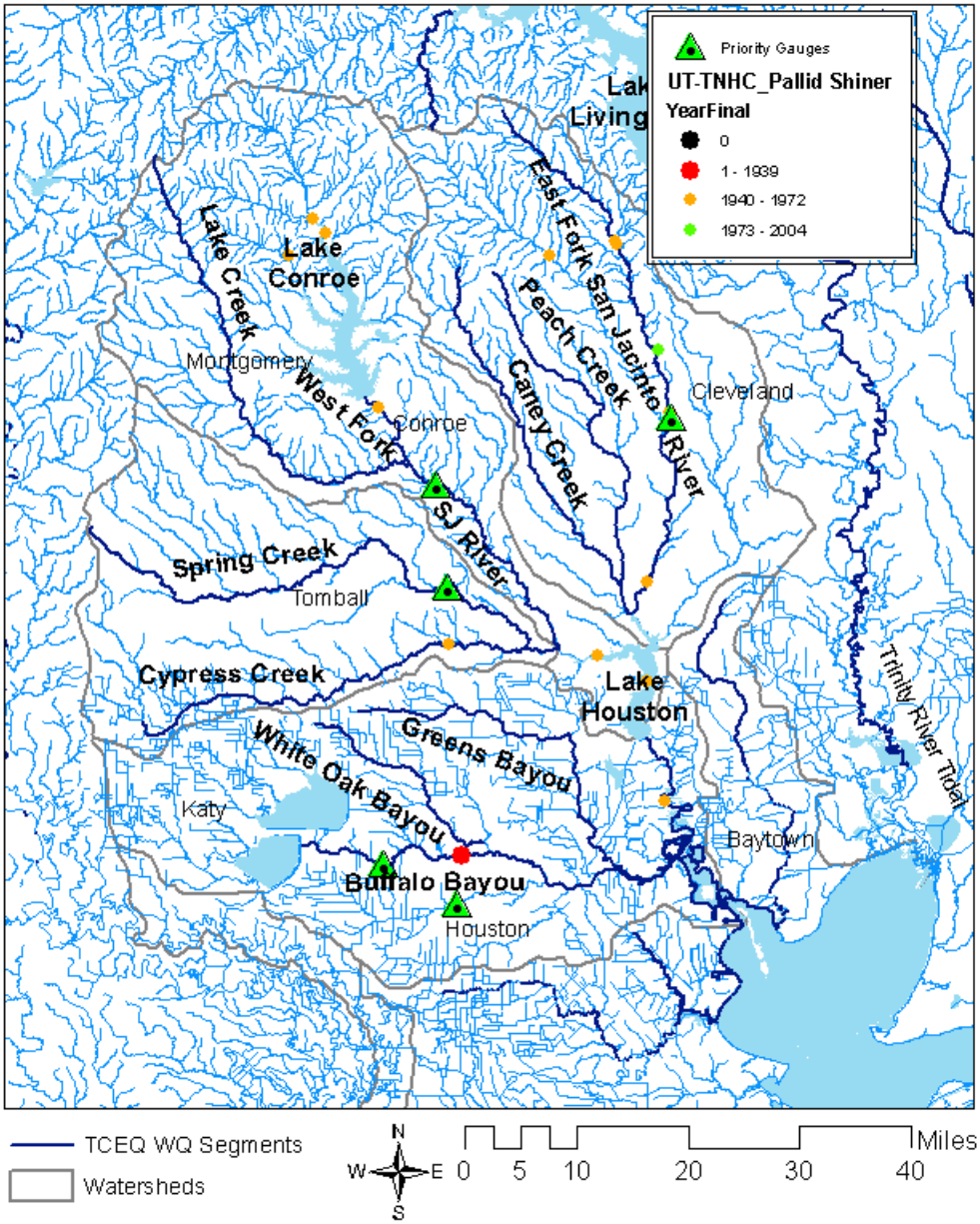

Figure 9 - DRAFT UT-THNC - Pallid shiner distribution

Noturus nocturnus (freckled madtom)
- Limited occurrence data available
- Fluvial specialist having a narrow range of habitat use.
- Inhabits clear to moderately turbid streams of medium to large size having permanent flow.
- Found in riffles over gravelly or rocky bottom (Rhode 1980; Urges 2003)

Flow Component Relationship:

- Seasonality: Spawning during summer months in southern Mississippi (Clark 1978)
- Baseflows: Maintenance of gravelly riffles

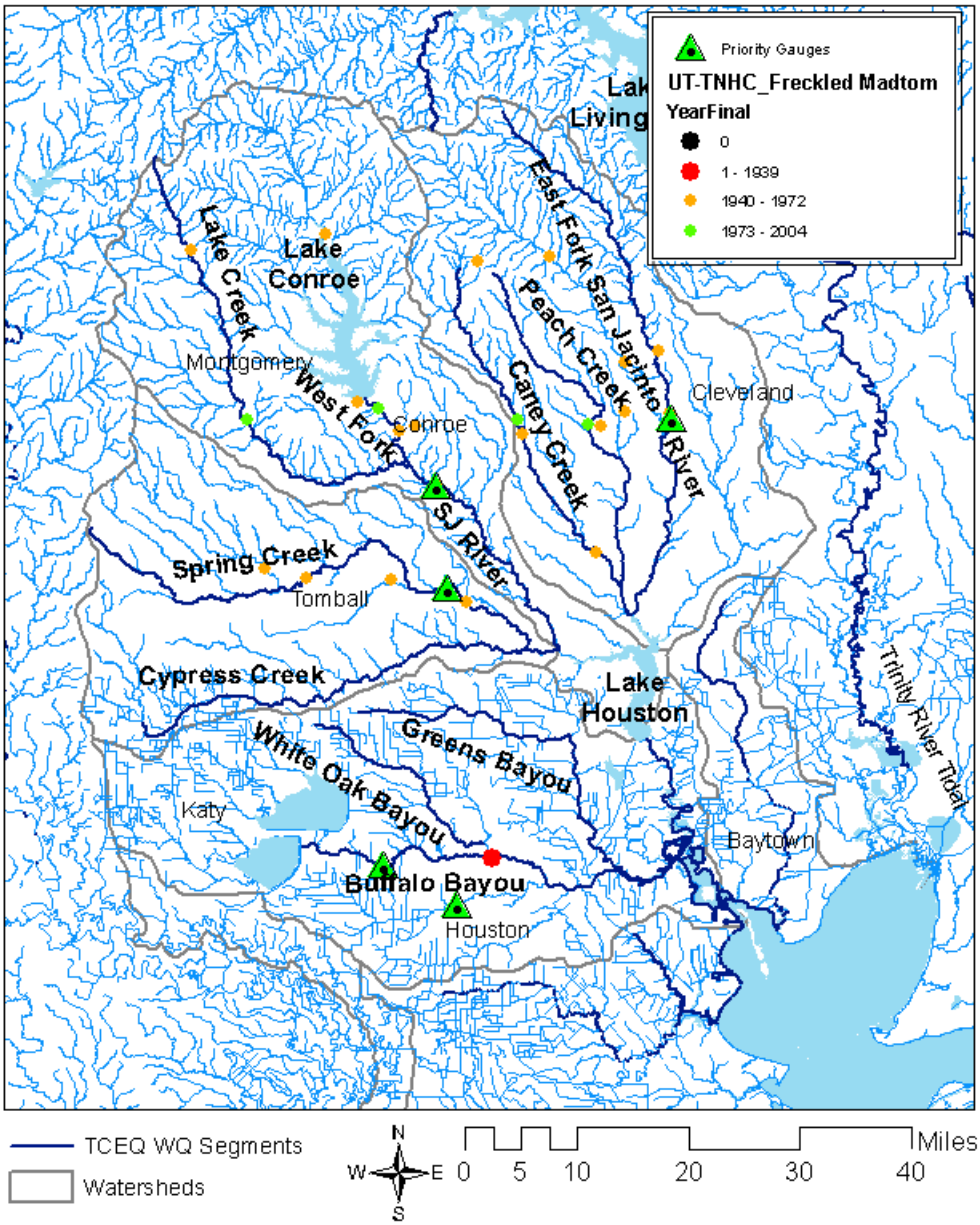

Figure 10 - DRAFT UT-TNHC - Freckled madtom distribution

Pylodictis olivaris (flathead catfish)
- Limited occurrence data available; museum vouchers pre-1973; upper watersheds.
- Host to glochidia of several species of mussels found in the SJR basin
- Young-of-the-year live in rubble bottomed riffles until between 2 and 4 inches in length (Minkley and Deacon 1959)

Flow Component Relationship:

Seasonality: Spawning season in Texas is late June and July (Hubbs et al. 1953; Munger and Deacon 1959)

Baseflows: Maintain rubble-bottom riffles in July through Fall.

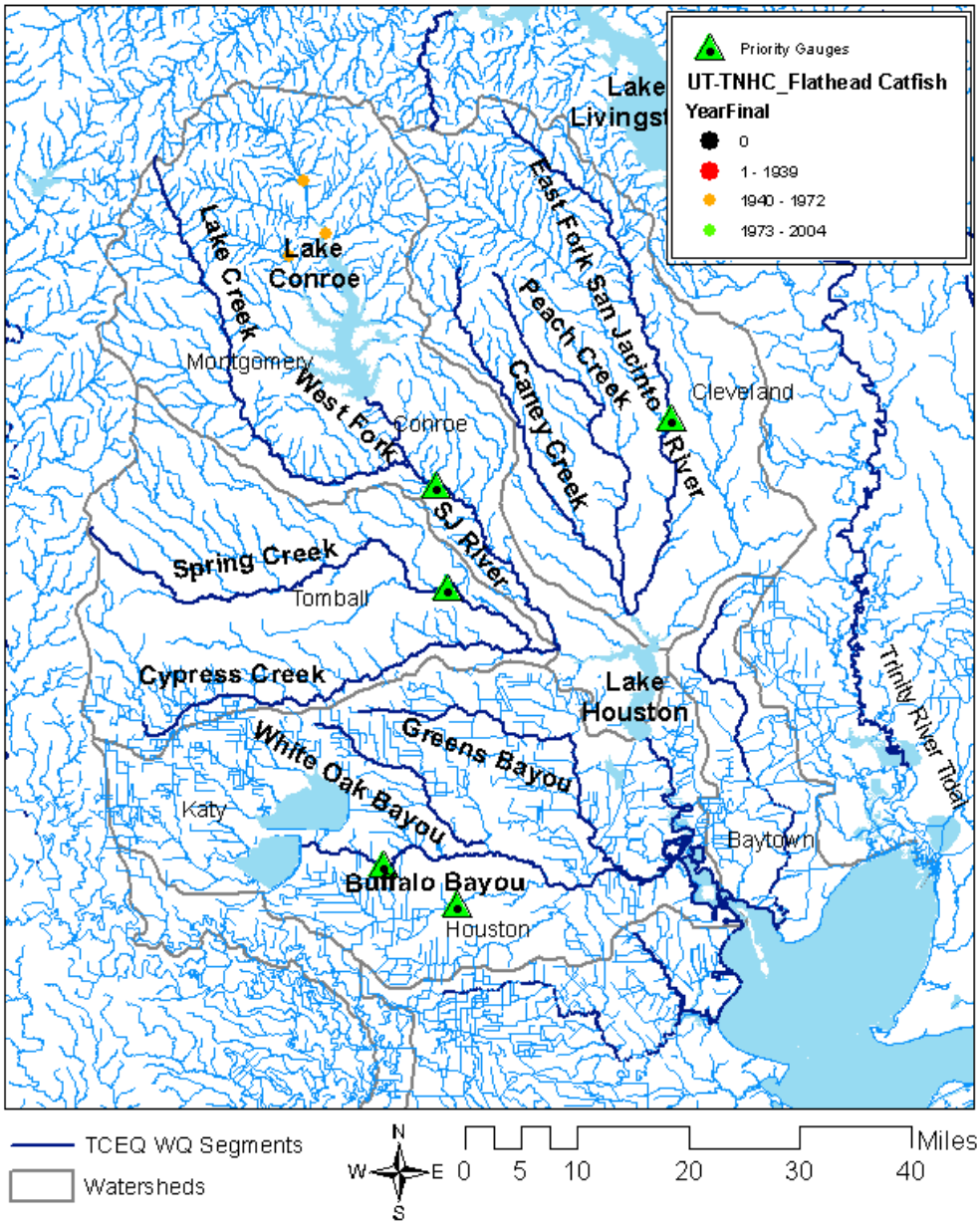

Figure 11 - DRAFT UT-TNHC - Flathead Catfish distribution

Aplodinotus grunniens (freshwater drum)
- Occurrence data available, observed in EFSJR and WFSJR
- Individuals have been observed to become distressed when water temperatures exceed 25.6°C, and when dissolved oxygen concentrations remain low over an extended period (Priegel 1967b).

Flow Component Relationship:

- Seasonality: Spawning season during May and June
- Baseflows: Maintain summer temperatures and DO

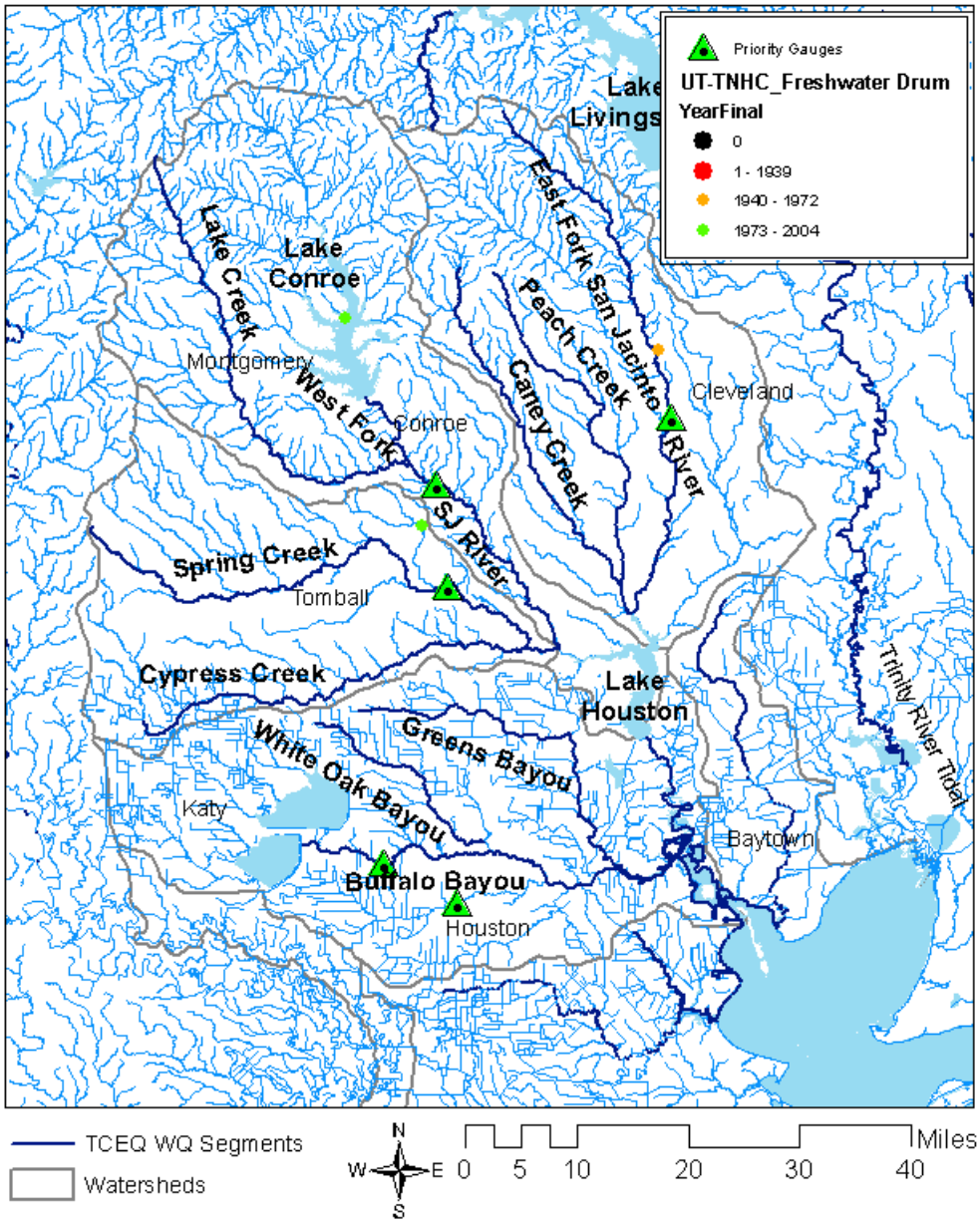

Figure 12 - DRAFT UT-TNHC – Freshwater drum distribution

Micropterus salmoides (largemouth bass)
- Occurrence data available, widespread
- Fry cannot survive for extended periods in salinities >6 ppt and embryo >10.5ppt (Stuber et al. 1982)
- Optimal current velocities for fry are < 4 cm/sec (Hardin and Bovee 1978), and fry cannot tolerate current velocities > 27 cm/sec (Macleod 1967; Laurence 1972).

Flow Component Relationship:

- Seasonality: Spawning season late winter to early spring with water temperatures 16-22` C
- Baseflows: Maintain salinity above 6 through summer for fry.

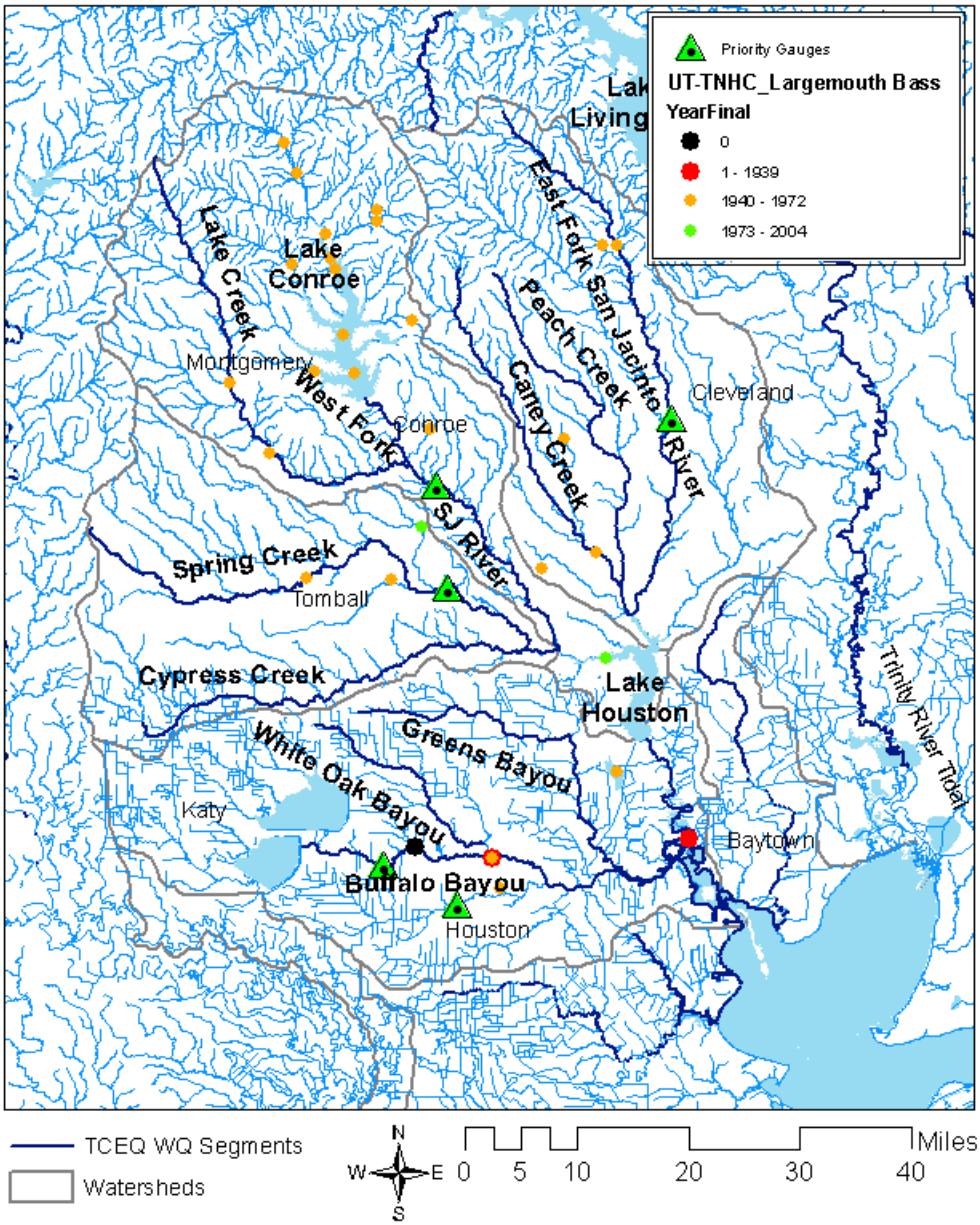

Figure 13 - DRAFT UT-TNHC - Largemouth bass distribution

Percina sciera (dusky darter)
- Occurrence data available, observed in EFSJR and WFSJR
- Herbert and Gelwick (2003) found this fluvial specialist associated with the free-flowing East Fork SJR
- Most common over gravel or gravel and sand raceways; occupying midwater stratum; often found in current in accumulations of branches and leaves (Page and Smith 1970; Page 1980; Page 1983).
- Rock and gravel spawners (Page and Smith 1970; Simon 1999).

Flow Component Relationship:

- Seasonality: Spawning season in the Colorado River near Austin is from February through June over gravelly substrates (Hubbs 1961).
- Baseflows: Spawn in gravel riffles at depths of 30-90 cm (Page and Smith 1970; Page 1983). Spawning and mesohabitat requirements indicate a preference for shallow riffles.

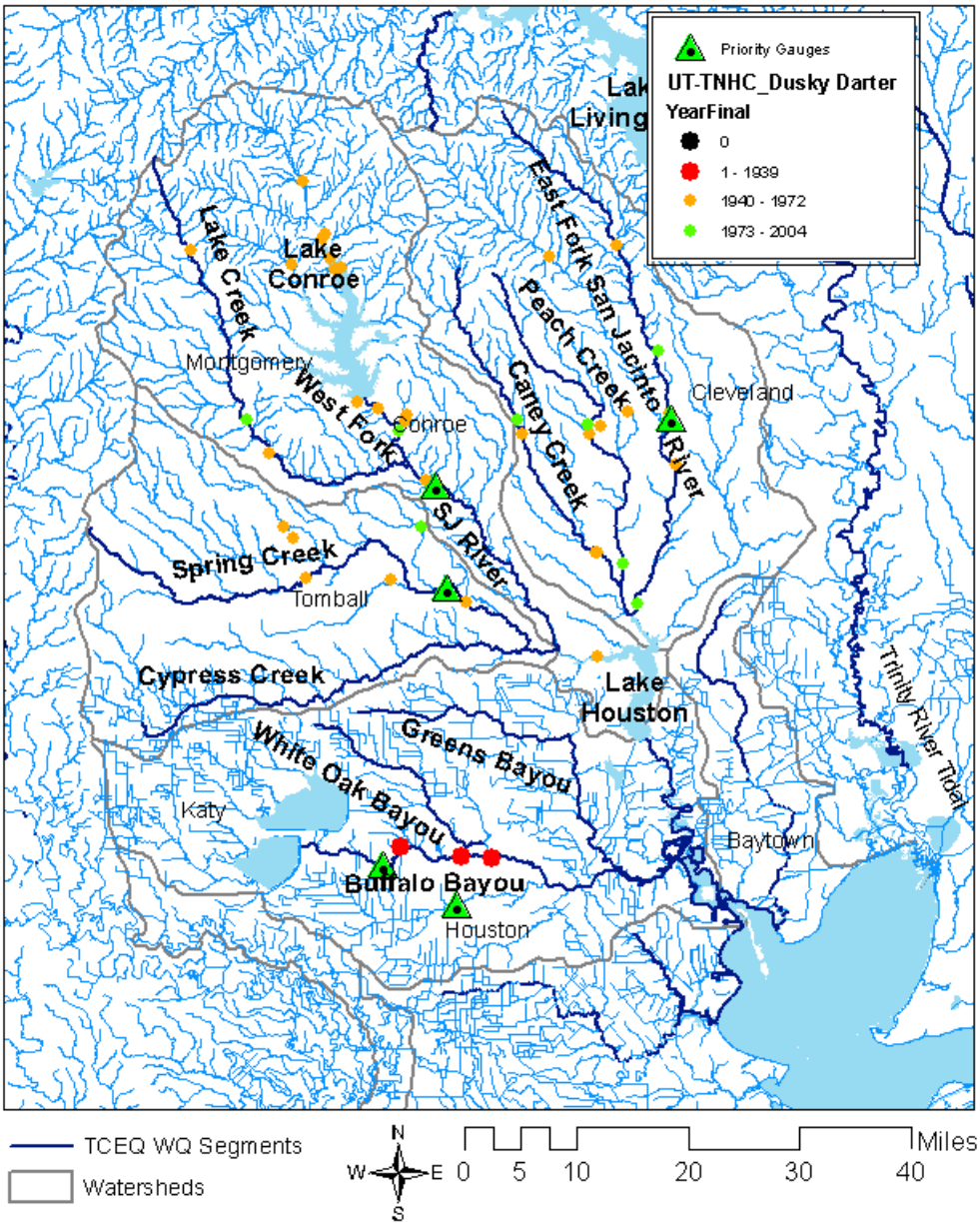

Figure 14 - DRAFT UT-TNHC - Dusky darter distribution

Lepisosteus oculatus (spotted gar)
- Robertson et al 2008, and Winemiller et al 2000, found Spotted gar to be more abundant in proximity to floodplain habitats (oxbows).
- The nature of oxbow formation and succession requires sufficient flow to connect the river with the floodplain habitats to allow access of spotted gar to these habitats.
- Spotted gars prefer backwater/floodplain habitats for reproduction. They spawn in submerged living/dead plants (Lee et al 1980), and prefer the slack waters found in backwater and floodplain habitats.

Flow Component Relationship:
- Seasonality: Literature indicates spring spawning in quiet, weedy backwaters.
- Flow Pulses: Spring flow pulses to allow access to backwaters

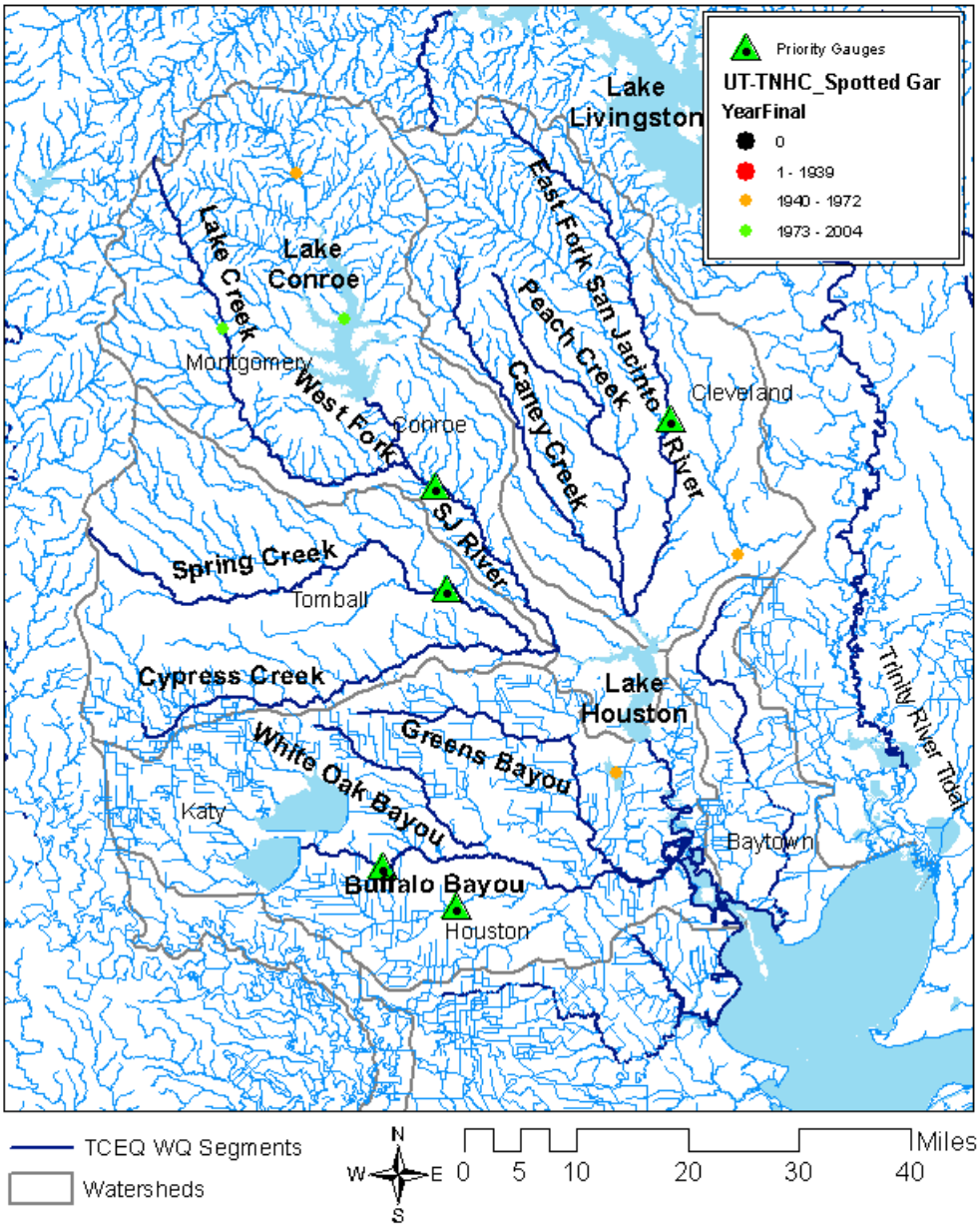

Figure 15 - DRAFT UT-TNHC - Spotted Gar distribution

3.1.2 Focal mussel and invertebrate species short list

Mussel and invertebrate species identified by TPWD and by USFWS are provided below. Spatial distribution information is limited and is provided in tabular form in Appendix B.

Fusconaia askewi (Texas pigtoe)
- found in sand and gravel substrate (Ansley 1998)

Tritogonia verruscosa (Pistolgrip)
- typical of oxygen rich riffles and runs

Lampsilis teres (Yellow sandshell)
- intolerant of drought and dewatering; actively follow flood flow onto land, then retreat back as flows return to channel
- found in sand and gravel substrate (Ansley 1998)
- glochidia hosts include green sunfish, warmouth, and largemouth bass

Quadrula apiculata (Southern mapleleaf)
- generalist but sensitive to dewatering (USFWS, Cherrish Stevens/Dr. Howells, personal communication 2009).
- found in sand and gravel substrate (Ansley 1998)

Macrobrachium ohione (Ohio shrimp)
– inhabits main stem rivers; migratory species

3.2 INSTREAM FLOW COMPONENTS

Statistical approaches to describe instream flow regime using historical gauge records have been summarized (SAC 2009a) and subsequently discussed throughout this evolving SB3 process. Among participants in the process, a degree of uncertainty exists on the meaning of flow components, and a greater degree of uncertainty exists on the use or application of flow regime statistics in development of environmental flow guidelines.

A useful set of initial steps in the flow guideline development process may be for each group to concisely and clearly identify (step 1) which flow components are relevant to each priority stream segment; (step 2) levels of data, analyses and/or expert judgment acceptable in characterization in each flow component; (step 3) clear purposes or goals for each flow component; and (step 4) an indication of when and/or how often each flow component is relevant.

A wide range of purposes, ecological roles and evaluation approaches are proposed for four flow components (SAC 2009c-Table 1, SAC 2009a). Description excerpts from the Hydrologic Methods document (SAC 2009a) for each regime component are provided in Figure 16 (organized per the graphic matrix framework from SAC 2009a).

Overbank Flows	Overbank flows are infrequent, high magnitude flow events that produce water levels that exceed channel banks and result in water entering the floodplain. A primary objective is to maintain riparian areas associated with riverine systems, eg, transport sediments and nutrients to riparian arease, recharge floodplain aquifers, and provide suitable conditions for seedlings.											
High Flow Pulses	High flow pulses are short duration, high magnitude (but still within channel) flow events that occur during or immediately following reainfall events. They serve to maintain important physical habitat features and connectivity along a stream channel.											
Base Flows (cfs)	Base flows represent the range of "average" or "normal" flow conditions in the absense of significant precipitation or runoff events. Base flows provide instream habitat conditions needed to maintain the diversity of biological communities in streams and rivers.											
Subsistence Flows (cfs)	Subsistence flows are low flows that occur during times of drought or under very dry conditions											
	Dec	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
	Winter			**Spring**			**Summer**					

Figure 16 – SAC 2009a, NRC 2005 and TIFP 2008 descriptions of flow components

3.2.1 San Jacinto River Basin flow components

Only limited quantitative data or analysis was discovered to identify appropriate instream flow values on the basis of fish or mussel habitat utilization. The data and analyses discovered and evaluated to date are lacking sufficient detail to characterize specific flow rates or flow ranges that provide specific habitat conditions. In addition, quantitative measures defining bounds of habitat conditions (e.g., range of suitable velocities) are not quantified for all species and/or guilds, so consideration of the inter-relation of habitat suitability amongst the full population is not able to be evaluated. Finally, relationships are not available to characterize how habitat conditions change with changing flow. All of these factors should be evaluated quantitatively in the future to increase confidence in any flow guideline or recommendation.

Given the limitations noted above, evaluation of focal species provides only limited information suitable for informing development of flow guidelines. Some focal species have life cycle or habitat utilization characteristics that speak to instream flow components (Table 3). Given a wide range of turbidity in the San Jacinto basin (where limited data is available in the SWQM database) from zero to 200 NTU with 65% of records exceeding 45 NTU, turbidity needs of the pallid shiner require additional basin-specific study. Similarly, temperature needs of the freshwater drum require basin-specific studies; that 33% of temperature measurements near priority San Jacinto basin priority gauges are above 25.6 degrees C.

A potential basin-specific purpose matrix for watercourses in the San Jacinto River basin (Figure 17) is presented with goals (step 3) and timing (step 4) of flow components based upon the focal fish species. With additional data or analysis, an individual matrix could be developed for each priority reach (step 1) and specific flow rates or ranges could be developed to identify critical thresholds.

Potential flow components should be evaluated by the TSJ-BBEST in consideration of the level of quantitative data available to support each flow component (step 2).

Table 3 – Potential flow components and focal species

<u>Flow Components</u>
Overbank flows
Spotted gar – spring overbank habitats may be beneficial for spawning
Flow pulses
Pallid shiner – turbidity intolerance >45 NTU (adults) and >85 NTU (juveniles)
Largemouth bass – fry are intolerant to velocity >27cm/s
Base flows
Freckled madtom – habitat utilization is largely gravelly riffles
Flathead catfish – young of year require rubble-bottom riffles July – Fall
Dusky darter – spawn over gravel riffles 30-90cm deep February through June
Subsistence flows
Freshwater drum – intolerant of temp. >25.6`C and extended periods of low DO
Largemouth bass – salinity intolerant > 12ppt

<u>Seasonality</u>
Maintenance of spawning habitats important between **April** and **June** for most species.
Bass spawn earlier – late winter to early spring at temperatures between 16 and 22`C

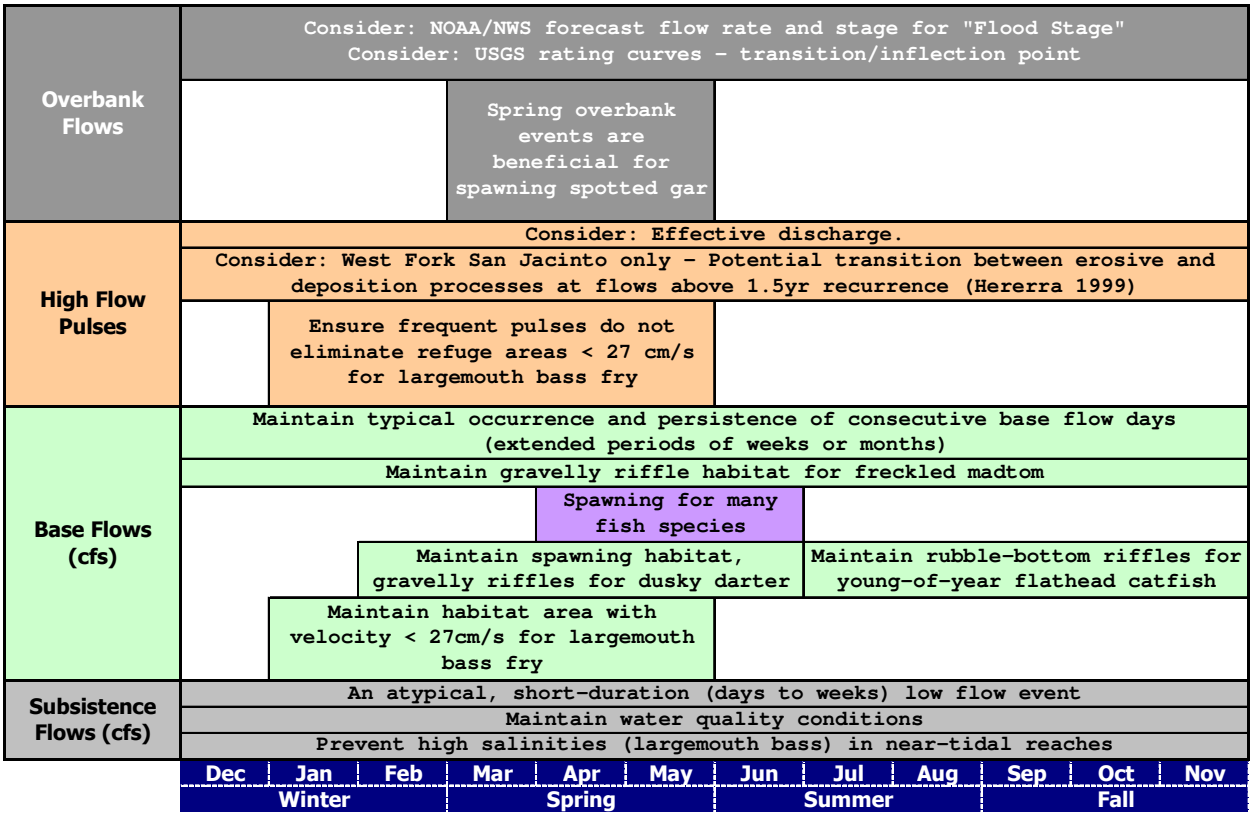

Figure 17 – San Jacinto River - potential flow component purpose matrix, based upon focal species

4.0 OVERLAY INFORMATION

This section presents a concise review of information within the San Jacinto River basin related to ecological condition, hydrology, water quality, physical processes and nutrient/sediment loading to the bay.

4.1 BIOLOGY

Three companion reports discovered describe data collection and site characterization leading to a waste load allocation study for the West Fork San Jacinto River between Lake Conroe and the headwaters of Lake Houston (TWC 1986). Stream substrate was fine sand throughout the reach and flow steadily increases downstream as a result of significant effluent discharges (TDWR 1981, Twidwell 1983). Stream velocities ranged from 0.5 feet per second (fps) in the upper reaches to 1 fps in the middle reaches under normal flow conditions throughout the reach with flow ranging from 7 cfs to 100 cfs (TDWR 1981). Similar velocity patterns (0.34 fps to 0.45 fps) were observed for lower flow conditions (7 cfs to 47 cfs) during a later study (Twidwell 1983). Macrobenthic data indicated little utilization of predominantly sandy substrate conditions; however, areas with gravelly riffles suitable for sampling macrobenthos indicated high diversity indicative of clean water conditions during December 1979 (TDWR 1981).

During 1984, the West Fork San Jacinto River downstream of Lake Conroe to the headwaters of Lake Houston were surveyed and assessed for water quality, fish habitat, fish communities, recreational fishing and harvest. Changes to management practices for the period 1985-1989 were not recommended because no pollution problems were found; fish habitat appeared to be adequate for the existing resource; and fish community appeared to be in relatively good condition (TPWD 1986). The total species collected in this reach was 48, whereas a study completed in 1967-68 that included this reach and smaller tributaries collected 59 species of fish (TPWD 1986).

The San Jacinto River from Lake Houston downstream to the Houston Ship channel was sampled for the period during February 1971 and August 1971, following a period where no releases had been made from Lake Houston since November 1970 (TPWD 1972). Freshwater flow consisted of small amounts from dam seepage and from tributary Gum Gully. Low DO (1.2 – 4 mg/L) was observed near the confluence with the ship channel during February 1971. Low DO (1.2 mg/L) and high chlorides (185 mg/L) were observed in August associated with a fish kill at Station 3 near the Houston Ship Channel. All other areas indicated conditions suitable for the fish population (TPWD 1972).

Descriptions from 1997-1998 field studies throughout the basin characterize the water courses as meandering channels with common riffles/pool near bends and runs in straight sections (Moring 2001). Velocity, depth, substrate type and distribution data was measured in the field during the same study. Based upon a multivariate structural and riparian, channel and environmental (RCE) indices and biotic indices developed from field data, seven least-impacted reference reaches were identified: Big Creek (Trinity River basin tributary with similar characteristics to SJR basin watercourses), Branch Creek, three reaches on the East Fork San Jacinto River, Luce Bayou and Caney Creek near Willis (Moring 2001) (Figure 19).

Bayou reaches with urbanized watersheds and little riparian or forest cover exhibited lower (less desirable) stream-habitat integrity and biotic indices (Moring et al. 2001). A statistically significant multiple regression equation was developed ($r = 0.69$, $F(3,27)=8.04$, $p=0.0006$) to relate population density, percent of forest land use and two index measures (Figure 18).

$$\bar{Y} = 5.73 + 0.065 + 6.32 - 0.002$$

(biological integrity)	(RCE maximum)	(percent forest land use)	(people per square mile)

Figure 18 - Multiple regression predictor of biotic integrity (Moring et al. 2001)

DO was measured May 17-July 18, 2000 and found to be low (median 3.83 mg/L) on the Spring Creek 303D listed site (USGS 2002) but not low at the reference sites. The biological integrity score (based upon benthic macroinvertebrate collections) at the Spring Creek site (15) was above median (14) compared to other reference sites; in the earlier study (Moring 2001) the score was 17 at both sites potentially reflecting seasonal or annual variability in abundance. The number of fish species collected at the site (12) was above-median (16). The and RCE indices were not much lower at Spring Creek site compared to other reference sites in the basin with much higher DO.

In summary, the ecology of the San Jacinto River basin upstream of Lake Houston appears to be in good condition. Some areas (e.g., Cypress Creek) may be experiencing impacts by development, management or effluent flows as exhibited in DO, lead and/or bacteria measurements, but assessments of ecological condition indicate few, if any, long-term problems. Discovery of more detailed, more recent studies may provide better information.

Information discovered to assess the ecological condition indicated more-impacted watercourses in the lower San Jacinto River basin, including the below-Lake Houston reach of the San Jacinto River and the Bayou watercourses in highly developed metropolitan areas within and surrounding the City of Houston. Buffalo Bayou, White Oak Bayou, Greens Bayou and Cypress Creek exhibited relatively lower ecological condition than upper watershed watercourses that are less impacted.

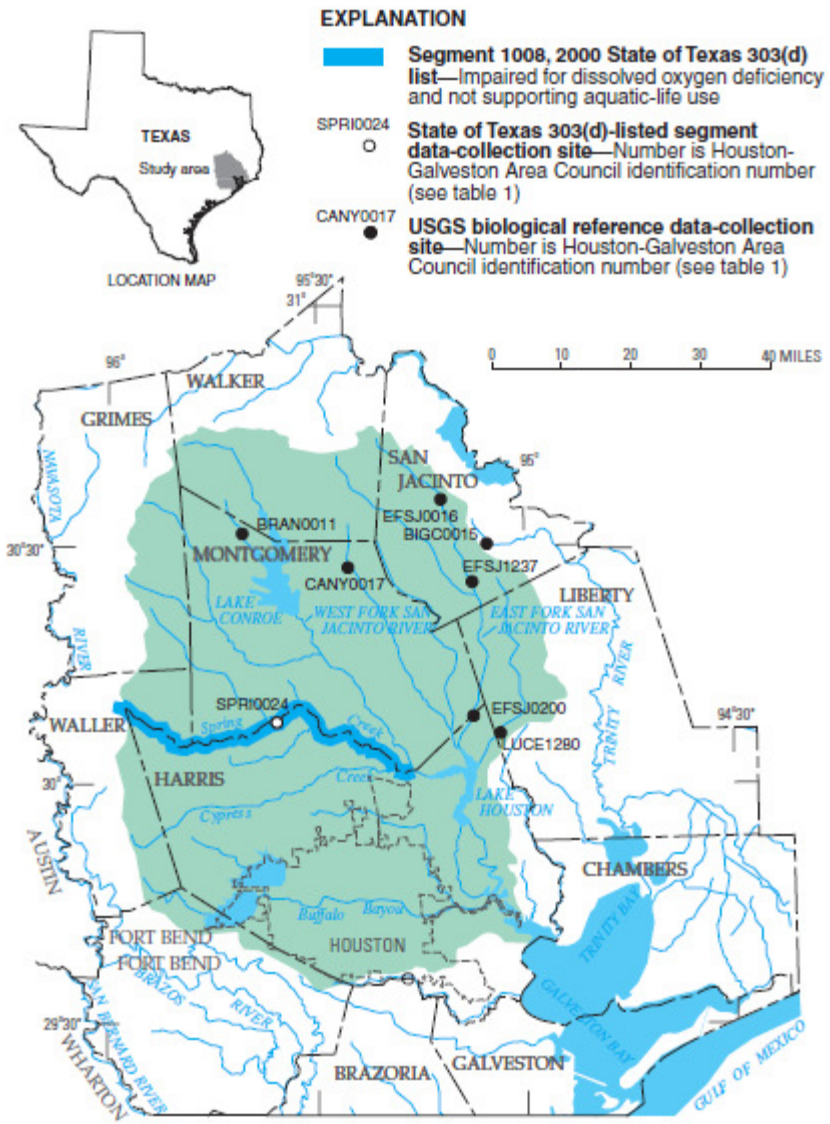

Figure 1. San Jacinto River Basin and data-collection sites.

Figure 19 - Least-impacted reference sites and listed Spring Creek site (USGS 2002)

4.2 HYDROLOGY AND HYDRAULICS

A detailed hydrological analysis for priority gauges in the Trinity and San Jacinto Rivers watershed is examined in (Crespo 2009); no review of that coincident work has been made in this project.

At priority gauges, 7Q2 from TCEQ (TCEQ 2009) are provided in Table 4. While these values are typically used for purposes associated with water quality permitting, they are, by definition hydrological statistics, indicative of the seven-day low flow event with recurrence interval of two years based upon the period analyzed and are useful for comparing to historical 7-day minimum flows.

Table 4 - TCEQ 7Q2 values for SJR basin gauges

Segment	Site Code	Site Name	Start Year	End Year	7Q2 (ft3/s)
902	08067500	Cedar Bayou nr Crosby, TX	1972	1996	0.3
1003	08070200	E Fk San Jacinto Rv nr New Caney, TX	1984	1996	22.6
1003	**08070000**	**E Fk San Jacinto Rv nr Cleveland, TX**	**1973**	**1996**	**18.2**
1004	08068090	W Fk San Jacinto Rv abv Lk Houston nr Porter, TX	1984	1996	26.6
1004	**08068000**	**W Fk San Jacinto Rv nr Conroe, TX**	**1974**	**1996**	**20.3**
1004	08067650	W Fk San Jacinto Rv bl Lk Conroe nr Conroe, TX	1975	1989	0.1*
1004	08067610	Lk Conroe Outflow Weir nr Conroe, TX	1974	1989	0.1*
1008	**08068500**	**Spring Ck nr Spring, TX**	**1975**	**1996**	**15.4**
1009	08069000	Cypress Ck nr Westfield, TX	1979	1996	17.6
1009	08068800	Cypress Ck at Grant Rd nr Cypress, TX	1983	1996	1.2
1009	08068740	Cypress Ck at House-Hahl Rd nr Cypress, TX	1976	1996	0.2
1009	08068720	Cypress Ck at Katy-Hockley Rd nr Hockley, TX	1976	1996	0.1*
1010	08070500	Caney Ck nr Splendora, TX	1973	1996	14.2
1011	08071000	Peach Ck at Splendora, TX	1960	1977	7.2
1014	08074000	Buffalo Bayou at Houston, TX	1962	1975	25.4
1014	**08073700**	**Buffalo Bayou at Piney Point, TX**	**1985**	**1996**	**50.6**
1014	08073600	Buffalo Bayou at W Belt Dr, Houston, TX	1980	1996	43.3
1014	08073500	Buffalo Bayou nr Addicks, TX	1980	1996	23
1015	08067900	Lake Ck nr Conroe, TX	1969	1989	2.8
1016	08076000	Greens Bayou nr Houston, TX	1980	1996	20.7
1016	08075900	Greens Bayou nr US Hwy 75 nr Houston, TX	1981	1996	11.8
1017	08074500	Whiteoak Bayou at Houston, TX	1980	1996	29.1
1102	08077000	Clear Ck nr Pearland, TX	1963	1992	0.5
1108	08078000	Chocolate Bayou nr Alvin, TX	1966	1996	1.5

Using all available gauge records for the entire period of record, the 7-consecutive-day minimum flow (Min 7Q) for each year is depicted at each priority gauge. Minimum annual seven-consecutive-day (Min7Q) flows in the West Fork SJR at Conroe have changed over time, although have remained somewhat consistent for the post-Lake Conroe (post-1972) period (Figure 20). Min7Q flows in Spring Creek have exhibited a gradual rise coincident with increased development and increased wastewater effluent discharges (Figure 21). At the East Fork SJR near Cleveland site, a more erratic pattern is evident where the 1950-1970 period is generally lower than the recent period (Figure 22). Min7Q for both Buffalo Bayou (Figure 23) and Brays Bayou (Figure 24) has exhibited a dramatic rise since the beginning of gauge records.

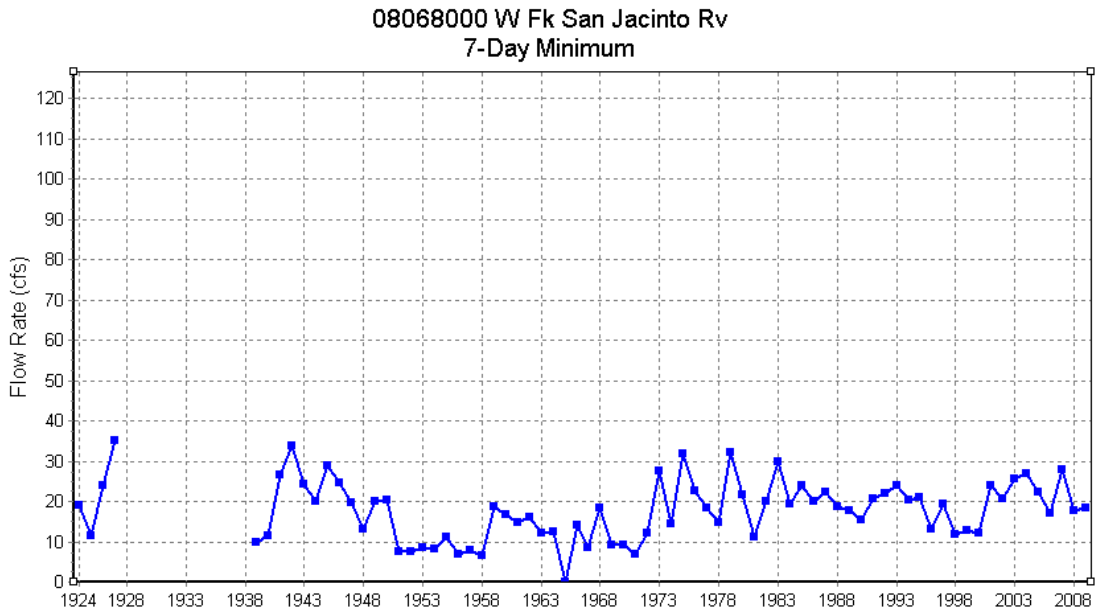

Figure 20 - Min 7Q, W Frk SJR near Conroe

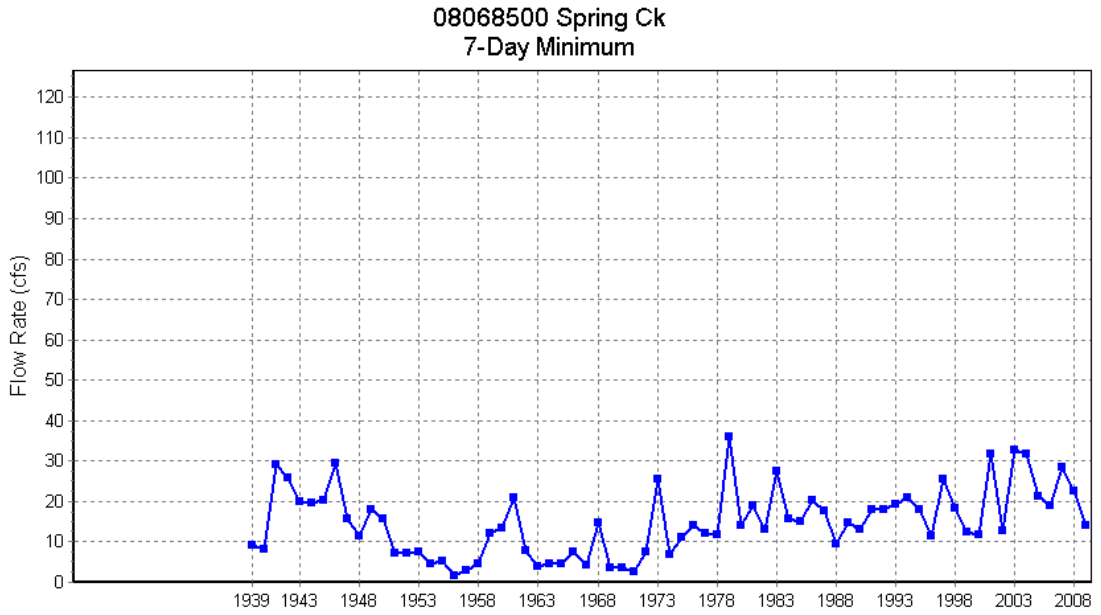

Figure 21 - Min 7Q for Spring Creek near Spring

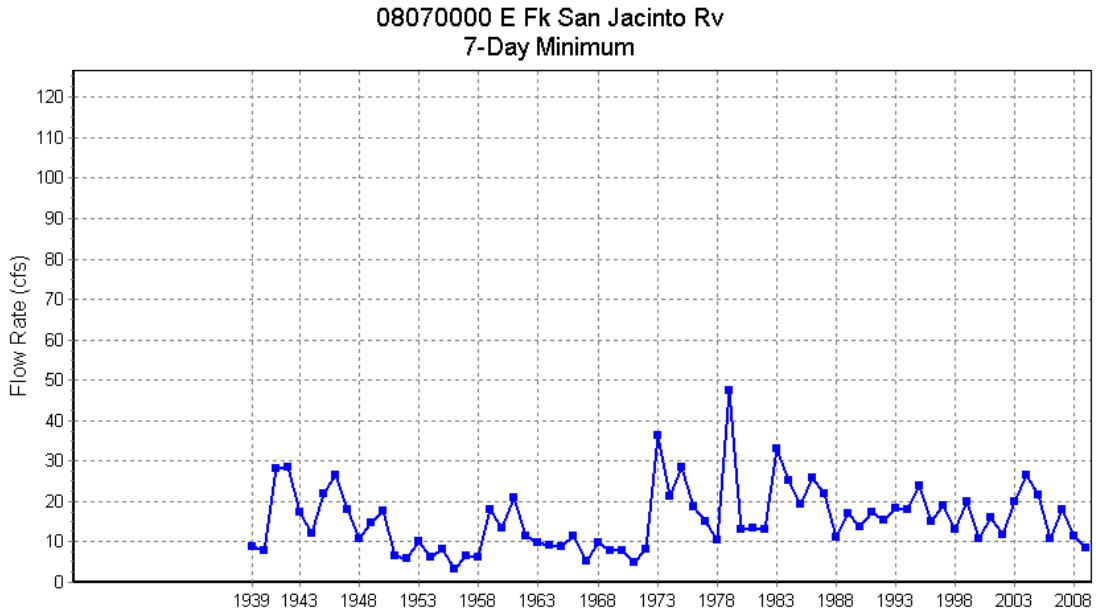

Figure 22 - Min 7Q for E Frk SJR near Cleveland

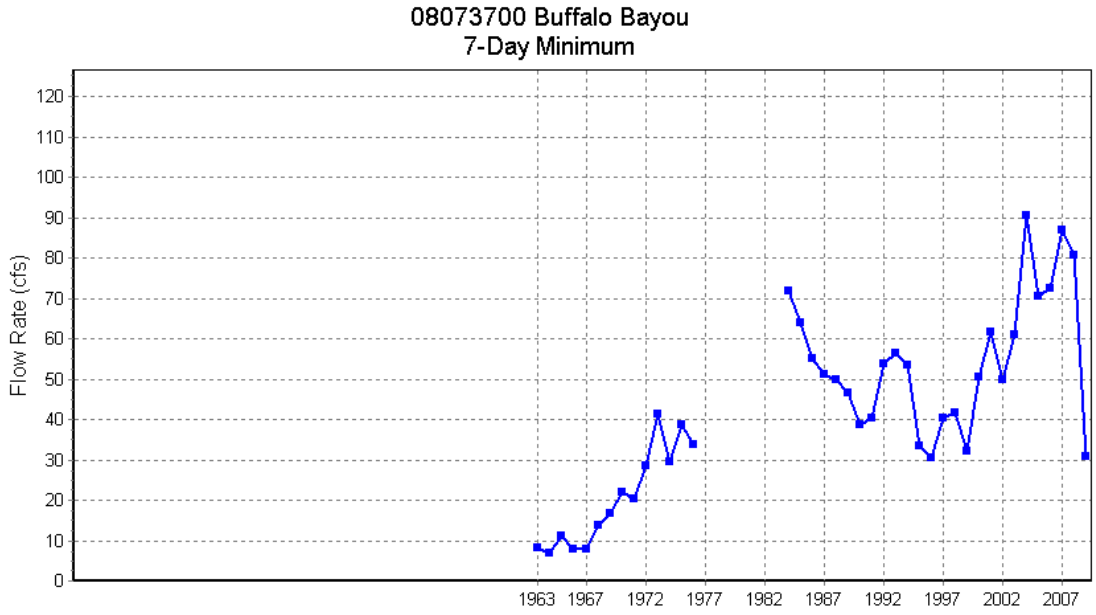

Figure 23 - Min 7Q for Buffalo Bayou at Piney Point

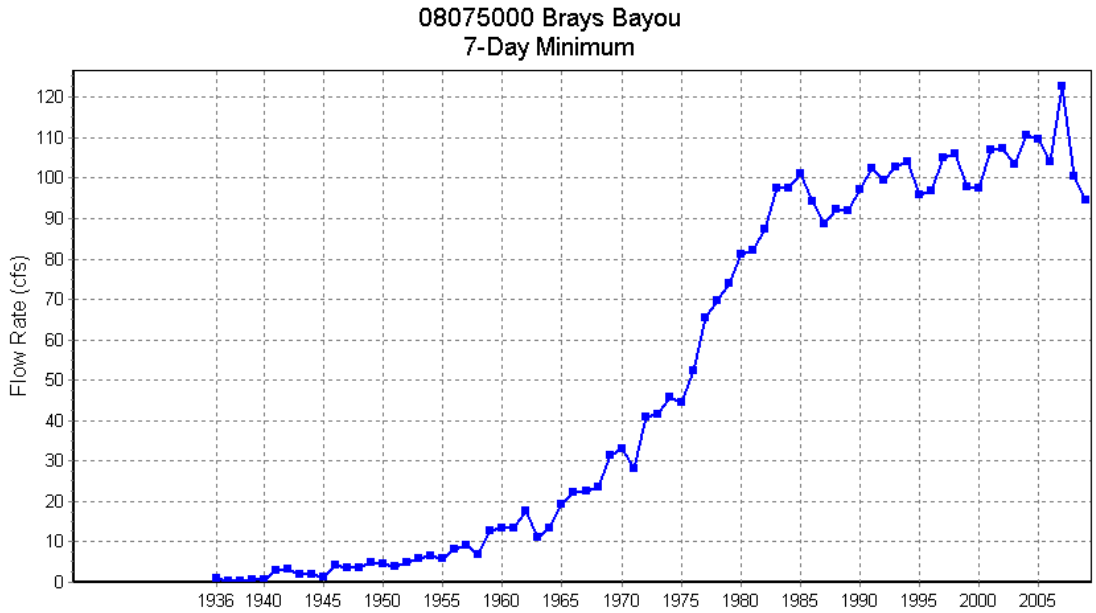

Figure 24 - Min 7Q for Brays Bayou at Houston

4.3 PHYSICAL PROCESSES

Numerous estimates of suspended sediment load have been located; however, quantitative data on bedload have not been discovered. One estimate of the percentage of total load attributable to the bedload component is 20-25% (USDA 1952).

For one site on the W. Fork San Jacinto River just upstream of the headwaters of Lake Houston, investigations of the Hallet point bar indicate a transition in sediment transport regime from erosive processes below the 1.5 year recurrence interval flow to depositional processes above the 1.5 year flow (Herrera 1999). The erosive processes below the 1.5 year flow establish the overall morphology of the bar (Herrera 1999). The 1.5 year flows was identified as 5,200 cfs before Lake Conroe was completed (1973) to 8,000 cfs for the period following completion. For the entire period of record at the W Frk SJR at Conroe gauge, the 1.5 year flow is 7,000 cfs. Based upon cross-section surveys, this flow is lower than a bank-full condition at this particular site that occurs approximately once per four years with magnitude near 18,000 cfs (Herrera 1999).

Information benefitting a sediment transport analysis such as proposed in the Fluvial Sediment overlay (SAC 2009b) is contained in Herrera 1999. Data and information includes sinuosity (1.3), width-depth ration (35), slope (0.0009), qualitative grain-size (descriptions but no sieve analyses), cross-section measurements and mapping of morphology changes for a series of flood events for the particular study site and immediately surrounding areas (Herrera 1999).

The annual average suspended sediment load of the East Fork San Jacinto River is 17 ac-ft per year, ranging from 0 ac-ft in 1971 to 41 ac-ft in 1975, based upon 29 years of record 1953 through 1982 (Quincy 1988).

Additional sediment data:

Sediment load for W. Fork San Jacinto:
SJRA 1981 - LP 168: 363,200 lb/day TSS in 1980
504,800 lb/day TSS (projected year 2000)

Sediment load for E. Fork San Jacinto:
SJRA 1981 - LP 168: 189,800 lb/day TSS in 1980
211,400 lb/day TSS (projected yr 2000)

TDWR 1981: 0.037 ac-ft sediment / square mile annual contribution captured by Lake Houston

TWDB daily suspended sediment data (1964-1989); Texas sampler

Sediment transport for the Trinity
Extensive work has been completed with TWDB funding by Slattery and Phillips.
http://www.twdb.state.tx.us/RWPG/rpgm_rpts/IndividualReportPages/2002483440_LowerTrinity.asp

Suspended sediment load estimates are provided for the Trinity River near Rosser, Crocket and Romayor, and Chambers Creek and Long King Creek in Quincy (1988).

4.4 WATER QUALITY

TCEQ water quality data downloaded from the SWQM reporting system was obtained near each priority gauge. Dissolved Oxygen (DO in mg/L) was linked to USGS streamflow (cfs) records at each station (Figure 25 through Figure 29). Select records indicate occurrences where DO drops below 4 mg/L at each of the gauges; however, these low-DO occurrences occur across a range of flow rates so relationships are not apparent based upon data alone. Additional analysis is required to diagnose reasons for low DO periods, including temperature (seasonality), consistent loading (e.g., from a wastewater treatment plant), irregular loading condition (short-term response to a flow pulse or to a large effluent discharge) or time of day (considering diurnal photosynthesis/respiration cycle).

Two intensive surveys in 79 (winter good conditions, TDWR 1981) and 81 (summer poor conditions, Twidwell 1983) were conducted and used to develop a QualTX model and Waste Load Allocation for West Fork San Jacinto River (TWC 1986). Data including channel characteristics, loading, travel time, stream velocity and water quality data are included in these reports. For warm summer conditions (July 1982) and lower flow conditions (7 cfs to 47 cfs), the follow up study (Twidwell 1983) discovered areas with dissolved oxygen (DO) sag for approximately 10 miles downstream of the major treatment discharge (Twidwell 1983); construction of a new WWTP plant was anticipated to significantly improve water quality conditions and DO near the Conroe stream gauging station indicate significantly higher DO values in the 1990s (Figure 25). Low DO events have been measured in the 2000s (Figure 25); detailed investigation of these events may yield information on causes or relationships with flow.

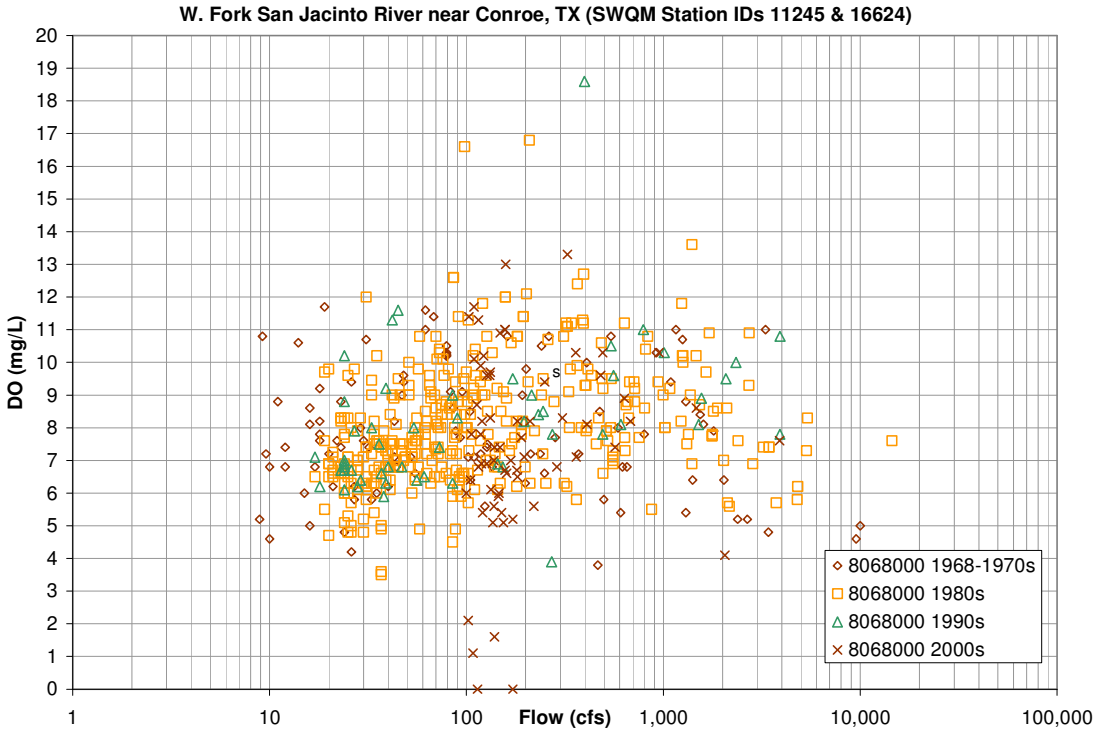

Figure 25 - SWQM DO (mg/L) vs USGS Flow (cfs) for W Frk SJR near Conroe

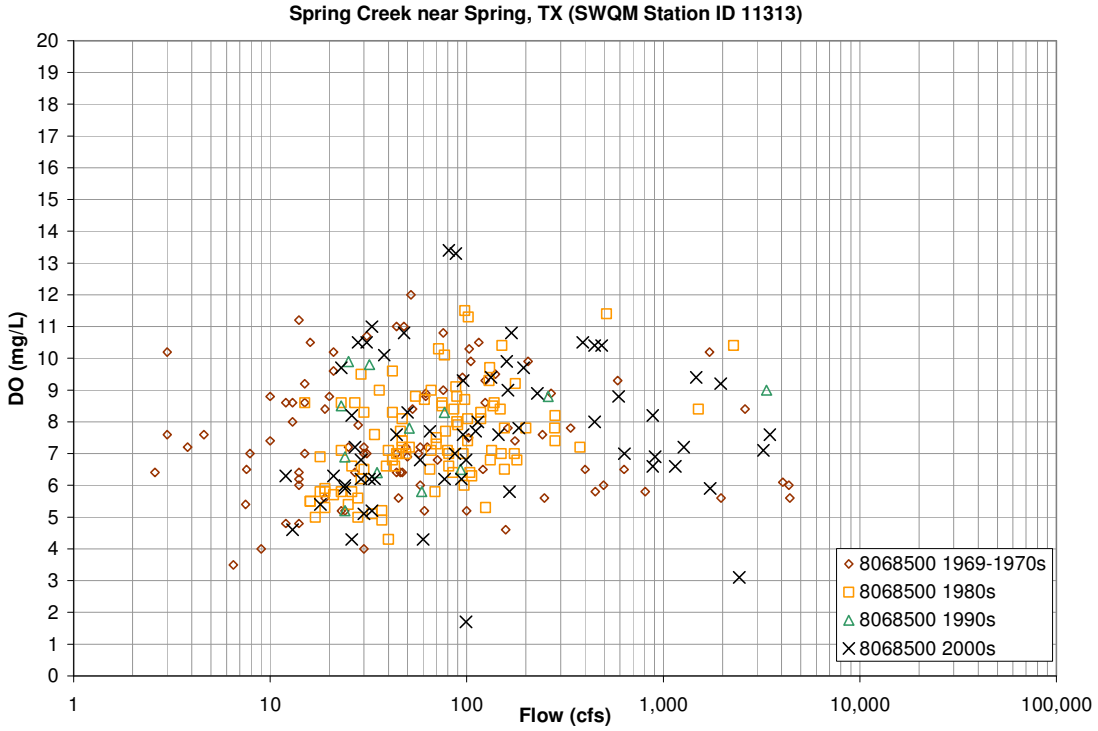

Figure 26 - SWQM DO (mg/L) vs USGS Flow (cfs) for Spring Creek near Spring

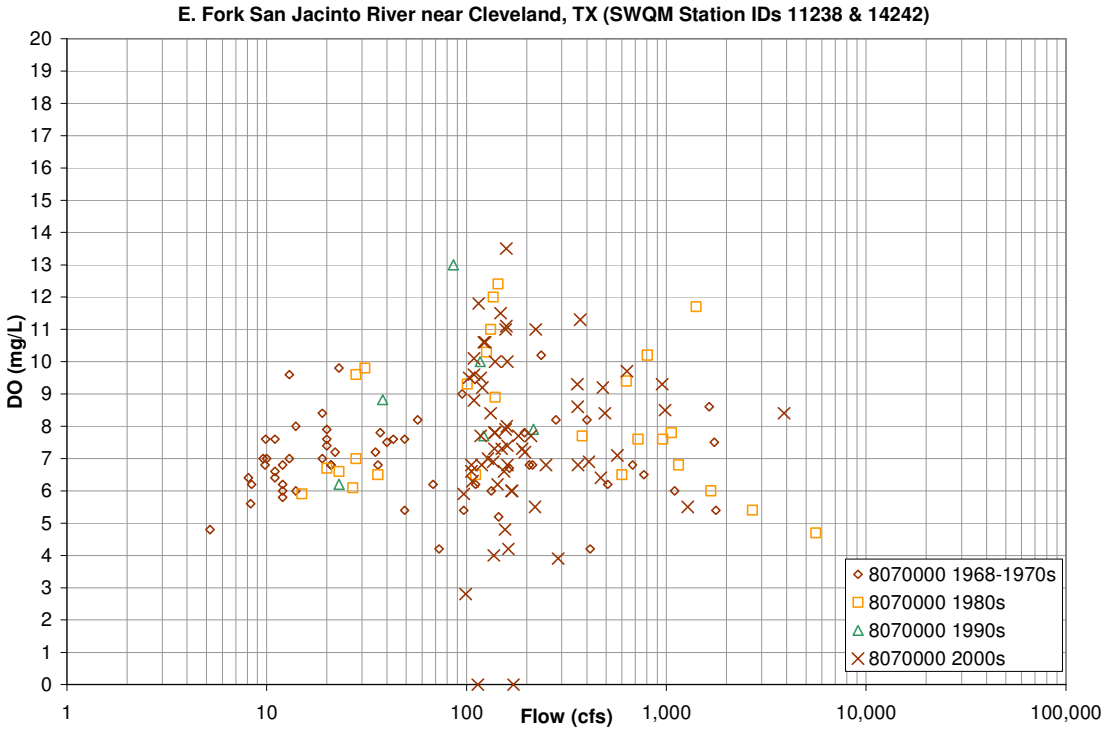

Figure 27 - SWQM DO (mg/L) vs USGS Flow (cfs) for E Frk SJR nr Conroe

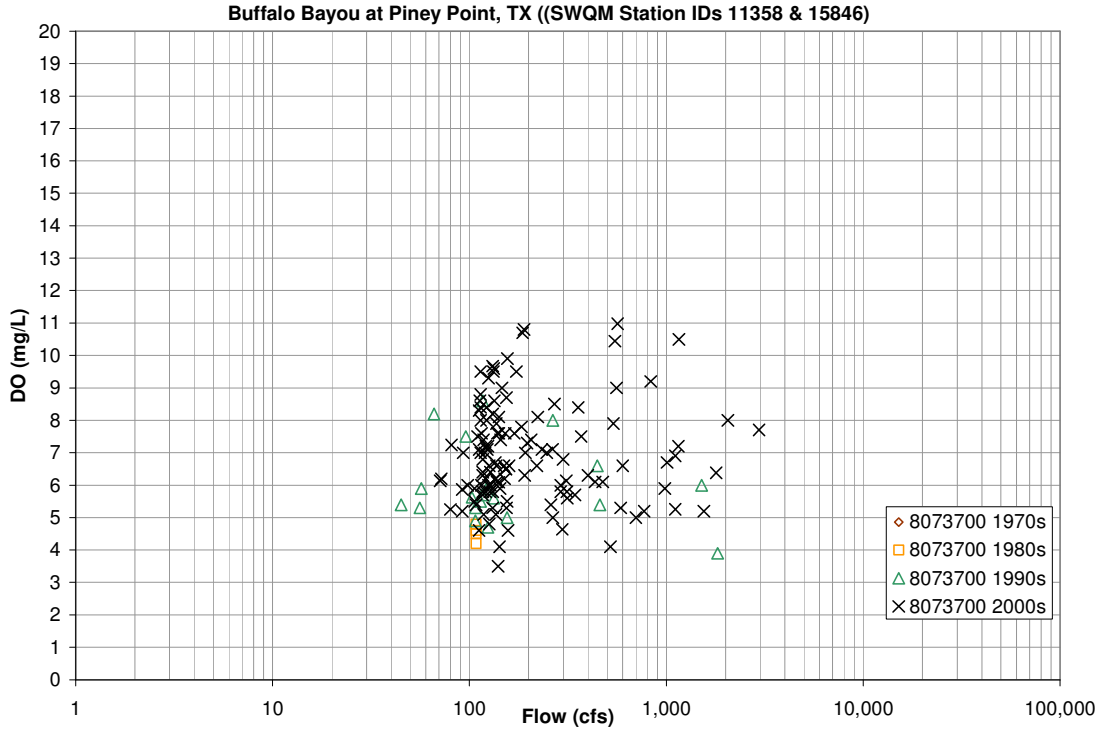

Figure 28 - SWQM DO (mg/L) vs USGS Flow (cfs) for Buffalo Bayou at Piney Point

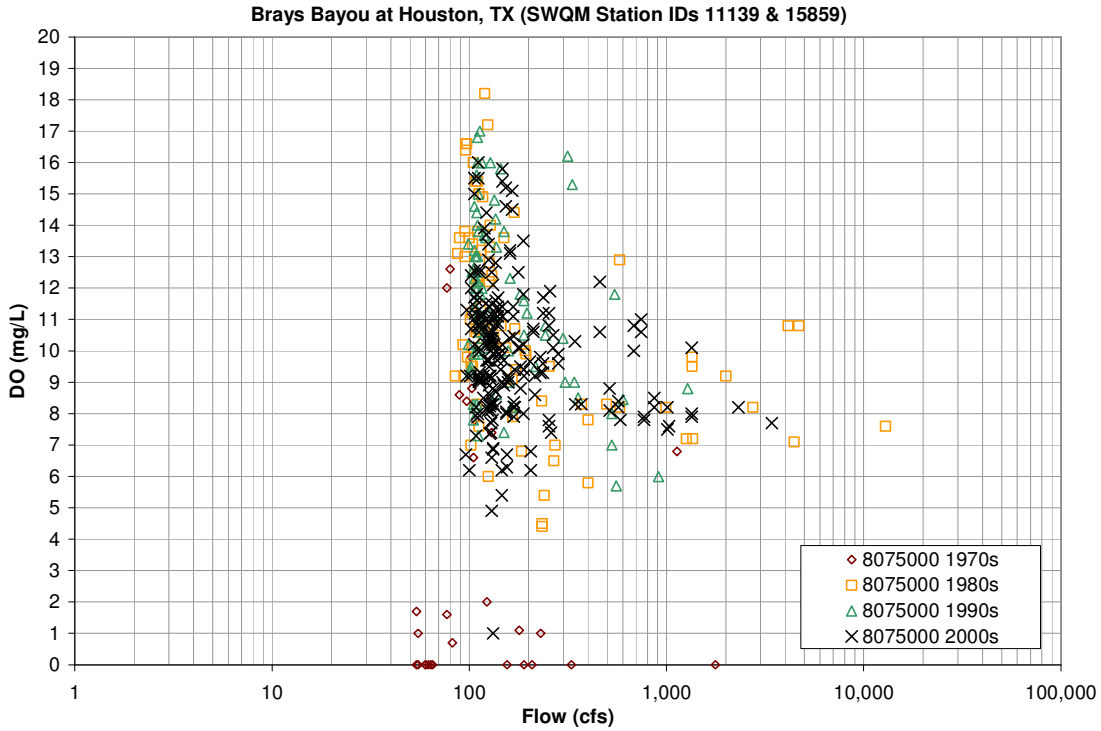

Figure 29 - SWQM DO (mg/L) vs USGS Flow (cfs) for Brays Bayou at Houston

4.5 SEDIMENT AND NUTRIENT LOADING TO THE BAY

To date, no relationships have been discovered between nutrient or sediment loadings to Galveston Bay with freshwater inflow from the San Jacinto River basin. Quantitative values to begin to develop such loading estimates have been compiled and may be used as a starting place for other future projects that may develop loading estimates.

Relevant data estimates reported in existing reports are noted below.

4.5.1 Bay Sediment

Bay Volume:
Estimates of the volume of Galveston bay indicate a fluctuation in volume through the last century. USDA 1952 (see appendix, page 125) describes a 10% net decrease in bay volume from 1898 (1,895,000 ac-ft) to 1937 (1,644,000 ac-ft) because of decreased depths in the delta areas. For a more recent period, Longley et al. (1994) estimate that bay depth has increased between 0 and 1.5 feet for the period 1968 to 1977 based upon NOAA soundings; the cause of deepening is hypothesized to be related to subsidence.

Sediment delivery:
USDA 1952 (see appendix, page 125) provides estimates of suspended sediment load at Romayor (4,396 ac-ft/year) and Huffman (657 ac-ft/year) calculated from 4-year record to 1948; bedload material is hypothesized to be 20-25% of suspended material. With volume of sediment not measured (bedload) assumed to be 25% of suspended material, total annual sediment load to Galveston Bay is 6,300 ac-ft/year for the period analyzed.

Longley et al. (1994) estimate TSS load passing Romayor for the period 1969-86 to be 526 acft/yr; this is much less than for the period 1936-71 is 2,573 acft/yr. Suspended sediment load contributed by the San Jacinto basin below Lake Houston, including Buffalo Bayou is 220.9 acft based on data from 1979. Since completion of Lake Houston in 1953, there is a significant reduction in the amount of sediment delivered from the SJR (Longley et al. 1994).

Additional sediment data:

SJRA 1981 – LP168

- Cedar Bayou
  - 156,200 lb/day TSS in 1980
  - 156,200 lb/day TSS (projected yr 2000)
- Chocolate Bayou above tidal
  - 10,000 lb/day TSS in 1980
  - 10,000 lb/day TSS (projected yr 2000)
- Chocolate Bayou, below tidal
  - 81,400 lb/day TSS in 1980
  - 127,400 lb/day TSS (projected yr 2000)
- Chocolate Bay
  - 90,000 lb/day TSS in 1980
  - 132,200 lb/day TSS (projected yr 2000)
- Moses Lake
  - 65,800 lb/day TSS in 1980
  - 77,000 lb/day TSS (projected yr 2000)
- Trinity Bay
  - 141,400 lb/day TSS in 1980
  - 146,600 lb/day TSS (projected yr 2000)

4.5.2 Bay Nutrients

Nutrient loadings based upon 1970-1977 datasets are provided in LP113 (TDWR 1981, see Section 6). Loadings are provided for inorganic Nitrogen, organic nitrogen, total phosphorus and TOC, by station by month (min and max) (see p212 in the PDF).

Longley et al. (1994) includes calculations of major nutrient loadings for 1977-1987 period data.

Longley et al. (2001) (Appendix to the Analysis of Freshwater Inflows) notes a trend of decreasing nutrients, likely from increasing treatment of waste water flows (Table 5).

Table 5 - Annual total nitrogen budget in Galveston Bay 1988-1990 (Longley et al. 2001)

Annual total nitrogen budget for the Galveston Bay system, 10^6 g /y TN.

	1988	*1989*	*1990*
Inputs from Freshwater Inflows			
Gaged streamflow	8360	25900	35090
Ungaged runoff	3320	9590	5890
Wastewater	7250	7290	7570
Direct rain	570	760	700
Total	19500	43550	49250
Nitrogen Fixation	560	560	560
Inputs from Entrained Tides	2330	2440	2240
Total Inputs	22390	46550	52050
Outflows			
Net water balance outflow	-3090	-14610	-14530
Entrainment outward	-22320	-27770	-24060
Total Outflows	-25420	-42380	-38590
Transport Balance	-3590	3610	12900
Denitrification	-3680	-3680	-3680
Sediment Burial	-690	-2280	-2620
Fisheries, Fish migration	-770	-1070	-1430
Total Losses	-30560	-49410	-46320
Water Column Storage	170	270	-360
Remainder	-8000	-2590	5370

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Appendix **A – Scope of Work**

Exhibit A

Scope of Work

Development of Ecological Overlay Information and Data for Support of Senate Bill 3 Environmental Flow Recommendations

The Senate Bill 3 (SB3) Science Advisory Committee (SAC) requests the compilation of information to guide in the development of an ecological overlay which can be used to support environmental flow recommendations. In an effort to evaluate the availability of useful information, the contractor will review existing data and literature developed under previous studies for the San Jacinto River basin and Galveston Bay, and will summarize aquatic, biological, riparian, and river flow relationships for the areas mentioned above, concentrating on the San Jacinto River basin.

Work items:

1) Summarize relationship of behavioral, physiological, or demographic variables for focal aquatic and riparian biological components (*e.g.*, species, communities, guilds) to short-term or long-term variation in flow velocity or flow regime.
2) Summarize relationship of geomorphologic parameters to flow velocity or flow regime.
3) Summarize relationship of parameters of water quality to flow velocity or flow regime.
4) Summarize relationship of nutrient and sediment loadings to freshwater inflow regimes to the bay.
5) Develop a matrix representing the geographic occurrence of for fish and mollusk species throughout the San Jacinto River based upon existing literature and consultation with known experts working in this area. This is to be a qualitative effort, simply presence /absence. The matrix need not be a quantitative estimate of population numbers, but rather a geographic checklist of species occurrences.
6) Coordinate development of focal biological components with staff of state agencies involved in the Texas Instream Flow Program (http://www.twdb.state.tx.us/InstreamFlows/index.html). Information sources are currently under development as part of state agency efforts under Senate Bill 2, and are anticipated to be made available to the contractor.
7) Consult with members of the Trinity and San Jacinto Bay and Basin Science Team (BBEST) to provide additional guidance with regard to focal biological resources, geomorphologic parameters, and water quality parameters that are likely to be sensitive to flow variation or serve as valuable indicators of the overall status of the aquatic and riparian ecosystems. The contractor may also suggest additional indicators during the review.
8) Utilize a prioritized list of items (questions), which will be provided by the SAC following consultation with the Trinity and San Jacinto BBEST, to facilitate the review process.

Exhibit A, Page 1

9) Coordinate with the Trinity River Authority to equitably divide tasks outlined in the scope of work and to develop a final summary report.
10) Attend SAC and Trinity and San Jacinto BBEST meetings in August 2009 to report on status and progress of tasks.
11) Reports of progress covered at SAC and BBEST meetings, including draft results, should be distributed electronically as appropriate between meetings.

Deliverables:

1) Summary report that includes graphical representations and/or tabular information revealing key relationships between flow variation and the ecological indicators. The report should include the requested species occurrence matrix. The report and project deliverables should be developed in coordination with the Trinity River Authority to facilitate use of the information by the Trinity and San Jacinto BBEST.
2) Graphical and tabular data shall be delivered in an appropriate digital format, *e.g.*, spreadsheet files, ASCII files, etc., and all relevant source documents will be scanned and delivered with the summary report.
3) The final version of the summary report, in electronic format, will be completed no later than September 21, 2009.

Appendix **B – Species Lists**

CONDENSED LIST OF FISH AND MUSSEL SPECIES OCCURRENCE

Species List - Fish **San Jacinto River**			**Ref. 1** TSU	**Ref. 2** 1997 **% Abundance**		**Reference 3** USGS 1997-98 **# Collected**									**Ref. 4** 1998	**Ref. 5** **TPWD** **Rare**		**Ref. 6** 1996	**Ref. 7** 2000	**Ref. 8** 69-72	**Ref.9** UT - TNHC		
		TPWD draft focal species list 2009-08-12	**San Jacinto River Basin**	**W. Fork San Jacinto River**	**E. Fork San Jacinto River**	**E. Fork San Jacinto River**	**W. Fork San Jacinto River**	**Garners Bayou**	**Greens Bayou**	**Buffalo Bayou**	**Cedar Bayou**	**Dickenson Bayou**	**White Oak Bayou**	**Luce Bayou**	**Upper Basin**	**Upper SJR Basin**	**Harris County**	**Lower San Jacinto Riber Basin**	**Upper San Jacinto River Basin**	**San Jacinto - Lake Houston Subbasin**	**San Jacinto River Basin pre-1940**	**San Jacinto River Basin 1940-1972**	**San Jacinto River Basin 1973+**
Scientific Name	**Common Name**																						
Lepisosteidae																							
Atractosteus spatula	alligator gar		X																				
Lepisosteus oculatus	spotted gar	X	X			8	13	1	13	25	2	2			1			4		X		X	X
Lepisosteus osseus	longnose gar		X			2	1			14										X			
Lepisosteus platostomus	shortnose gar						13													X			
Petromyzontidae																							
Ichthyomyzon castaneus	chestnut lamprey																						X
Ichthyomyxon gagei	southern brook lamprey		X	0	8.5															X		X	X
Amiidae																							
Amia calva	bowfin		X		<0.1					2													X
Anguillidae																							
Anguilla rostrata	American eel		X													X	X						
Clupeidae																							
Alosa chrysochloris	skipjack herring		X																				
Brevoortia patronus	gulf menhaden																				X		
Dorosoma cepedianum	gizzard shad		X			17	186	2	3	658					5			3	1	X		X	X
Dorosoma petenense	threadfin shad		X				8			1								496		X			X
Engraulidae																							
Anchoa mitchilli	bay anchovy																	10					X
Cyprinidae																							
Carassius auratus	goldfish		X																				
Ctenopharyngodon idella	grass carp		X				2			3								3					X
Cyprinella lutrensis	red shiner		X	0.6	0.1	9	472	25	355	6	19		60								X	X	X
Cyprinella venusta	blacktail shiner		X	3.9	1.4	234	665				3			6	82			1	5			X	X
Cyprinus carpio	common carp		X				5		5	10			1					4		X			X
Hybognathus nuchalis	Mississippi silvery minnow		X																			X	
Hybognathus placitus	plains minnow		X																				
Hybopsis amnis	pallid shiner	X	X				1															X	X
Luxilus chrysocephalus	striped shiner		X																	X			

Species List - Fish **San Jacinto River**			**Ref. 1** TSU	**Ref. 2** 1997 **% Abundance**		**Reference 3** USGS 1997-98 **# Collected**									**Ref. 4** 1998	**Ref. 5** **TPWD** **Rare**		**Ref. 6** 1996	**Ref. 7** 2000	**Ref. 8** 69-72	**Ref.9** UT - TNHC		
		TPWD draft focal species list 2009-08-12	**San Jacinto River Basin**	**W. Fork San Jacinto River**	**E. Fork San Jacinto River**	**E. Fork San Jacinto River**	**W. Fork San Jacinto River**	**Garners Bayou**	**Greens Bayou**	**Buffalo Bayou**	**Cedar Bayou**	**Dickenson Bayou**	**White Oak Bayou**	**Luce Bayou**	**Upper Basin**	**Upper SJR Basin**	**Harris County**	**Lower San Jacinto Riber Basin**	**Upper San Jacinto River Basin**	**San Jacinto - Lake Houston Subbasin**	**San Jacinto River Basin pre-1940**	**San Jacinto River Basin 1940-1972**	**San Jacinto River Basin 1973+**
Scientific Name	**Common Name**																						
Lythrurus fumeus	ribbon shiner	X	X	9.2	4.3														13	X		X	X
Lythrurus umbratilis	redfin shiner		X	1.3	4.3														1	X		X	X
Macrhybopsis aestivalis	speckled chub						1																
Macrhybopsis hyostoma	shoal chub		X																				
Notemigonus crysoleucas	golden shiner		X	0.4	0.1															X		X	X
Notropis amabilis	Texas shiner		X																	X			
Notropis atherinoides	emerald shiner																		8	x			X
Notropis atrocaudalis	blackspot shiner	X	X	3.9	4.9		4												33	X		X	X
Notropis blennius	river shiner					1																	
Notropis buchanani	ghost shiner		X																	X			
Notropis potteri	chub shiner		X																			X	
Notropis sabinae	Sabine shiner		X																	X			X
Notropis shumardi	silverband shiner		X																				
Notropis stramineus	sand shiner						8								10								
Notropis texanus	weed shiner		X																				
Notropis volucellus	mimic shiner		X	<0.1	0															X		X	X
Opsopoeodus emiliae	pugnose minnow		X	0.1	0.1	1	2													X	X	X	X
Phenacobius mirabilis	suckermouth minnow																			X			
Pimephales promelas	fathead minnow		X				1				3											X	
Pimephales vigilax	bullhead minnow		X	2.9	<0.1	85	851	52	117	207	29		365		96				53	X		X	X
Semotilus atromaculatus	creek chub		X																				
Catostomidae																							
Carpiodes carpio	river carpsucker		X			2	33													X		X	X
Cycleptus elongatus	blue sucker		X													XT							
Erimyzon oblongus	creek chubsucker	X	X	0.7 (I)	1.5 (I)											X T	X T		2	X		X	
Erimyzon sucetta	lake chubsucker		X	0.2	0															X		X	X
Ictiobus bubalus	smallmouth buffalo		X			1				5								6		X		X	

Species List - Fish **San Jacinto River**			**Ref. 1** TSU	**Ref. 2** 1997 **% Abundance**		**Reference 3** USGS 1997-98 **# Collected**									**Ref. 4** 1998	**Ref. 5** **TPWD** **Rare**		**Ref. 6** 1996	**Ref. 7** 2000	**Ref. 8** 69-72	**Ref.9** UT - TNHC		
		TPWD draft focal species list 2009-08-12	**San Jacinto River Basin**	**W. Fork San Jacinto River**	**E. Fork San Jacinto River**	**E. Fork San Jacinto River**	**W. Fork San Jacinto River**	**Garners Bayou**	**Greens Bayou**	**Buffalo Bayou**	**Cedar Bayou**	**Dickenson Bayou**	**White Oak Bayou**	**Luce Bayou**	**Upper Basin**	**Upper SJR Basin**	**Harris County**	**Lower San Jacinto Riber Basin**	**Upper San Jacinto River Basin**	**San Jacinto - Lake Houston Subbasin**	**San Jacinto River Basin pre-1940**	**San Jacinto River Basin 1940-1972**	**San Jacinto River Basin 1973+**
Scientific Name	**Common Name**																						
Minytrema melanops	spotted sucker		X	0.2	0.5		3				2									X		X	X
Moxostoma congestum	gray redhorse		X																				
Moxostoma poecilurum	blacktail redhorse	X	X	0	<0.1	43	11								9					X		X	X
Ictaluridae																							
Ameiurus melas	black bullhead		X	0.2	0.1		3												1	X		X	
Ameiurus natalis	yellow bullhead		X	1.6	3.6	4	6	3	1	4	4		2						38	X		X	X
Ictalurus furcatus	blue catfish		X			1				14								4		X			X
Ictalurus punctatus	channel catfish		X	<0.1	0.1	14	51		2	39	15				2			2		X		X	X
Noturus gyrinus	tadpole madtom		X	<0.1	0	6	33			1			2	1	2					X		X	X
Noturus nocturnus	freckled madtom	X	X	0.4	1.3	1	2								1					X		X	X
Pylodictis olivaris	flathead catfish	X	X			1	4				1							2		X		X	
Loricariidae																							
Pterygoplichthys disjunctivus	vermiculated sailfin catfish (I)																						X
Pterygoplichthys multiradiatus	plecostomus																						X
Esocidae																							
Esox americanus	redfin/grass pickerel		X	0.2	0.9	6	4							1					1	X		X	X
Salmonidae																							
Oncorhynchus mykiss	rainbow trout		X																				
Aphredoderidae																							
Aphredoderus sayanus	pirate perch		X	4.9	6.3	38	66			1				4	4			1	6			X	X
Mugilidae																							
Mugil curema	white mullet *																						X
Mugil cephalus	striped mullet		X					2	51	12	5							59			X	X	X
Atherinopsidae																							
Labidesthes sicculus	brook silverside		X				7								1			1	1 (I)	X		X	X
Menidia beryllina	inland silverside		X															7		X	X	X	X

Species List - Fish San Jacinto River			Ref. 1 TSU	Ref. 2 1997 % Abundance		Reference 3 USGS 1997-98 # Collected									Ref. 4 1998	Ref. 5 TPWD Rare		Ref. 6 1996	Ref. 7 2000	Ref. 8 69-72	Ref.9 UT - TNHC		
Scientific Name	Common Name	TPWD draft focal species list 2009-08-12	San Jacinto River Basin	W. Fork San Jacinto River	E. Fork San Jacinto River	E. Fork San Jacinto River	W. Fork San Jacinto River	Garners Bayou	Greens Bayou	Buffalo Bayou	Cedar Bayou	Dickenson Bayou	White Oak Bayou	Luce Bayou	Upper Basin	Upper SJR Basin	Harris County	Lower San Jacinto Riber Basin	Upper San Jacinto River Basin	San Jacinto - Lake Houston Subbasin	San Jacinto River Basin pre-1940	San Jacinto River Basin 1940-1972	San Jacinto River Basin 1973+
Fundulidae																							
Adinia xenica	diamond killifish																					X	
Fundulus chrysotus	golden topminnow		X	<0.1	0		2												6	X		X	X
Fundulus blairae	western starhead topminnow		X																				X
Fundulus dispar	starhead topminnow																					X	X
Fundulus grandis	Gulf killifish		X															1		X	X	X	X
Fundulus notti	starhead topminnow																			X			
Fundulus notatus	blackstripe topminnow		X			62	100				1			1	9				34	X		X	X
Fundulus olivaceus	blackspotted topminnow		X	10.2	8.8															X		X	X
Fundulus pulvereus	bayou topminnow																					X	
Lucania parva	rainwater killifish		X																			X	
Poeciliidae																							
Gambusia affinis	western mosquitofish		X	37.7	33.4										12				296	X		X	X
Gambusia sp	mosquitofish					15	222	34	14	2	31	3	44	8									
Poecilia latipinna	sailfin molly		X				4	26	15				25									X	X
Cyprinodontidae																							
Cyprinodon variegatus	sheepshead minnow		X																	X		X	X
Moronidae																							
Morone chrysops	white bass		X				1											12		X			
Morone mississippiensis	yellow bass		X															1		X		X	
Morone saxatilis	striped bass		X				4																
Centrarchidae																							
Centrarchus macropterus	flier		X																	X		X	
Lepomis auritus	redbreast sunfish		X			7	25	4															
Lepomis cyanellus	green sunfish		X	0.8	1	11	104	10	5	4	2	4	34		2				3	X		X	X
Lepomis gulosus	warmouth		X	1.4	1.4	26	66	2		8	11	1	1	3	3				8	X		X	X
Lepomis humilis	orangespotted sunfish		X			4	15			203	1												

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		TPWD draft focal species list 2009-08-12	**San Jacinto River Basin**	**W. Fork San Jacinto River**	**E. Fork San Jacinto River**	**E. Fork San Jacinto River**	**W. Fork San Jacinto River**	**Garners Bayou**	**Greens Bayou**	**Buffalo Bayou**	**Cedar Bayou**	**Dickenson Bayou**	**White Oak Bayou**	**Luce Bayou**	**Upper Basin**	**Upper SJR Basin**	**Harris County**	**Lower San Jacinto Riber Basin**	**Upper San Jacinto River Basin**	**San Jacinto - Lake Houston Subbasin**	**San Jacinto River Basin pre-1940**	**San Jacinto River Basin 1940-1972**	**San Jacinto River Basin 1973+**
Scientific Name	**Common Name**																						
Lepomis macrochirus	bluegill		X	2.5	1.5	74	356	6	8	29	40		6	1	32			41	35	X		X	X
Lepomis marginatus	dollar sunfish		X	1	0.2	5													6	X		X	X
Lepomis megalotis	longear sunfish	X	X	9.1	6.8	344	1170	8	76	42	100	2	64	9	172			21	89	X		X	X
Lepomis microlophus	redear sunfish		X	<0.1	0		6								3					X		X	X
Lepomis miniatus	redspotted sunfish.		X																			X	X
Lepomis punctatus	spotted sunfish			2.2	2.6	5	6				2				1				11	X			
Lepomis symmetricus	bantam sunfish		X																	X		X	
Micropterus punctulatus	spotted bass		X	<0.1	<0.1		1													X		X	X
Micropterus salmoides	largemouth bass	X	X	0.8	0.3	20	163		12	14	4		23		15			30		X		X	X
Pomoxis annularis	white crappie		X	<0.1	0	2	34			3								15	1	X		X	X
Pomoxis nigromaculatus	black crappie		X			1												11		X		X	X
Percidae																							
Ammocrypta vivax	scaly sand darter		X																	X		X	X
Etheostoma chlorosoma	bluntnose darter		X	0.8	1		4													X		X	X
Etheostoma gracile	slough darter		X	0.6	0.8		1				2								1	X		X	X
Etheostoma parvipinne	goldstripe darter	X	X	1.4	0.4														6 (I)	X		X	
Etheostoma proeliare	cypress darter		X																			X	
Etheostoma spectabile	orangethroat darter		X																				
Percina caprodes	logperch																			X		X	X
Percina macrolepida	bigscale logperch		X				15															X	X
Percina maculata	blackside darter																						X
Percina sciera	dusky darter	X	X	0.3 (I)	1.2 (I)	38	46								20					X		X	X

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		TPWD draft focal species list 2009-08-12	**San Jacinto River Basin**	**W. Fork San Jacinto River**	**E. Fork San Jacinto River**	**E. Fork San Jacinto River**	**W. Fork San Jacinto River**	**Garners Bayou**	**Greens Bayou**	**Buffalo Bayou**	**Cedar Bayou**	**Dickenson Bayou**	**White Oak Bayou**	**Luce Bayou**	**Upper Basin**	**Upper SJR Basin**	**Harris County**	**Lower San Jacinto Riber Basin**	**Upper San Jacinto River Basin**	**San Jacinto - Lake Houston Subbasin**	**San Jacinto River Basin pre-1940**	**San Jacinto River Basin 1940-1972**	**San Jacinto River Basin 1973+**
Scientific Name	**Common Name**																						
Sciaenidae																							
Aplodinotus grunniens	freshwater drum	X	X	0	<0.1	8	18			1					1					X		X	X
Cynoscion nebulosus	spotted sea trout *																				X		
Leiostomus xanthurus	spot *																					X	X
Micropogonias undulatus	atlantic croaker																	1				X	
Elassomatidae																							
Elassoma zonatum	banded pygmy sunfish		X	0.4	2.6	1														X		X	X
Cichlidae																							
Cichlasoma cyanoguttatum	Rio Grande cichlid		X					9	7				8										X
Oreochromis aureus	blue tilapia (introduced)																						X
Eleotridae																							
Dormitator maculatus	pacific sleeper																					X	X

(1) Freshwater Fishes of the San Jacinto River Drainage
Texas Freshwater Fishes, Department of Biology,
Texas State University
(http://www.bio.txstate.edu/~tbonner/txfishes/)

(2) Spatial Variation of Headwater Fish Assemblages Explained by Hydrologic Variabiity and Upstream Effects of Impoundment.
Matthew E. Herbert and Frances P. Gelwick. Copeia, 2003, pp. 273-284.
(I) Intolerant
During 1997, fishes were sampled quarterly as follows: 8 February to 2 March, 30 April to 3 June, 11 August to 22 August, and 5 Noverber to 23 November. Sampling periods were during seasonal baseflow to avoid short-term displacement of fishes furing spates (Paloumpis, 1958) and for greater efficiency and consistency of effort. For West Fork streams directly entering Lake Conroe, sites were sufficiently upstream such that flowing stream conditons were present throughout the site.
Study sites were on first to fourth order streams of the East (9 sites) and West Forks (12 sites) and were typical of sandy, coastal streams in the southeastern United States (Felley, 1992). All sites were within the Sam Houston National Forest,and land cover was predominantly loblolly pine (Pinus taeda).

(3) Fish, Benthic Macroinvertebrate, and Stream Habitat Data From the Houston-Galveston Area Council Service Area, Texas, 1997-98
Moring, Bruce, et al. 1998. USGS Report 98-658
(http://pubs.usgs.gov/of/1998/ofr98-658/)
West Fork SJR includes: Spring Cr., Lake Cr., Panther Cr., Sandy Cr., Willow Cr., Walnut Cr., Cypress Cr.
East Fork SJR includes: Caney Cr., Spring Branch Cr.

(4) A Study of Freshwater Mussels (Pelecypoda: Unionidae), Fish, and Associsted Ecological Factors in Lake Creek, Montgomery County, Texas
Stephen P. Ansley, 1998 Thesis, Southwest Texas State University
COPYRIGHT 1998
Site 1 - 1.5 km north of the junction of FM 1488 and FM 2978 at
N 30 09' 07.6" latitude and W 95 20' 49.4" longitude
Site 2 - 2.7 km north of the junction of FM 1488 and FM 149 at
N 30 09' 53.2" latitude and W 95 25' 18.7" longitude

(5) Texas Parks and Wildlife Dept. Annotated County Lists of Rare Species
Last Revision 5/4/2009 5:54:00 PM
http://gis.tpwd.state.tx.us/TpwEndangeredSpecies/DesktopDefault.aspx
X - Species Present
T - Species on the Texas Threatened List

(6) Fish Populations in the Major Tributaries of the Houston Ship Channel.
Segments 1001. 1006' 1007' 1013' 1017
Mark Luedke, June 1994. Texas Natural Resource Conservation Commission
The San Jacinto River was surveyed at two sites, Banana Bend and HWY 90. The Banana Bend and HWY 90 sites are 12.2 and 15.3 miles, respectively, upstream from the mouth of the San Jacinto River. Both sampling sites are in Segment 1001. Little or no water flows over the Lake Houston dam during critical low flow conditions, so the Jan Jacinto River above the dam has not been considered part of the Houston Ship Channel System (Kirkpatrick 1987). The average flow near the sites surveyed was not determined by the USGS because of tidal influences.

(7) The effects of Timber Harvesting on Stream Water Quality in the Sam Houston National Forest: A Physicochemical, Benthic Macroinvertebrate, and Fish Analysis.
Charles Dewey Stoffels, Stephen F. Austin State University, August 2000
(I) - Intolerant

(8) A Study of Aquatic Quality and Soci-Economic Uses of San Jacinto River Watershed
Sam Houston State University. Huntsville, Texas 1973. Under NSF Grant GY-10760
The Study area was the San Jacinto Watershed, Lake Houston Subbasin from May 14, 1973 to August 3, 1973.

(9) DRAFT Hendrickson spreadsheet Trinity&SanJacinto_forGeorgeGuillen.xls

MUSSELS

Species List - Mollusks and Invertebrate San Jacinto River			Ref. 3 USGS 97-98										Ref. 4 1998	Ref. 5 Rare		Ref. 7 2000	Ref.10 TPWD	
Scientific Name	Common Name	TPWD draft focal species list 2009-08-12	Buffalo Bayou	Caney Creek	Cypress Creek	East Fork SJR	West Fork SJR	Lake Creek	East Sandy Creek	Luce Bayou	White Oak Bayou	Willow Creek	Upper Basin	Upper Basin	Harris Co.	Upper basin	San Jacinto River	Code
Unionidae																		
Amblema plicata	threeridge																X	
Anodonta suborbiculata	flat floater																*	
Arkansia wheeleri	Ouachita rock-pocketbook																	1-FE
Fusconaia lananensis	triangle pigtoe																X	2-SC
Glebula rotundata	round pearlshell																X	
Lampsilis bracteata	Texas fatmucket																	5-SC
Lampsilis hydiana	Louisiana fatmucket																X	
Lasmigona complanata	white heelsplitter																	SC
Leptodea fragilis	fragile papershell																X	
Ligumia subrostrata	pond mussel																X	
Megalonaias nervosa	washboard																X	
Obliquaria reflexa	threehorn wartyback																X	
Obovaria jacksoniana	southern hickorynut																X	5-SC
Pleurobema riddellii	Louisiana pigtoe)																X	2-SC
Popenaias popeii	Texas hornshell																	3,7-FC
Potamilus amphichaenus	Texas heelsplitter																	2-SC
Potamilus metnecktayi	Salina mucket																	2-SC
Potamilus ohiensis	pink papershell																X	
Potamilus purpuratus	bleufer																X	
Pyganodon grandis	giant floater																X	
Quadrula aurea (golden orb)	golden orb																	5-SC
Quadrula couchiana	Rio Grande monkeyface																	4-SC
Quadrula houstonensis	smooth pimpleback																	5-SC
Quadrula mortoni	western pimpleback																5-X	
Quadrula nobilis	gulf mapleleaf																O	
Quadrula nodulata	wartyback																	SC
Quadrula petrina	Texas pimpleback																	5-SC
Quadrula pustulosa	pimpleback																X	
Quincuncina mitchelli	false spike																	4-SC
Strophitus undulatus	creeper																O	SC
Toxolasma parvus	lilliput																X	
Toxolasma texasiensis	Texas lilliput																X	
Truncilla cognata	Mexican fawnsfoot																	2-SC
Truncilla macrodon	Texas fawnsfoot																	5-SC
Truncilla truncata	deertoe																X	
Uniomerus declivis	tapered pondhorn																X	
Uniomerus tetralasmus	pondhorn																X	
Utterbackia imbecillis	paper pondshell																X	
Arcidens confragosus	rock pocketbook	X												X	X		X	5-SC
Tritogonia verrucosa	pistolgrip													X	X		X	

Species List - Mollusks and Invertebrate **San Jacinto River**			**Ref. 3** USGS 97-98										**Ref. 4** 1998	**Ref. 5** **Rare**		**Ref. 7** 2000	**Ref.10** TPWD	
		TPWD draft focal species list 2009-08-12	**Buffalo Bayou**	**Caney Creek**	**Cypress Creek**	**East Fork SJR**	**West Fork SJR**	**Lake Creek**	**East Sandy Creek**	**Luce Bayou**	**White Oak Bayou**	**Willow Creek**	**Upper Basin**	**Upper Basin**	**Harris Co.**	**Upper basin**	**San Jacinto River**	**Code**
Scientific Name	**Common Name**																	
Truncilla donaciformis	fawnsfoot													X			X	SC
Villosa lienosa	little spectaclecase													X	X		X	
Lampsilis satura	sandbank pocketbook													X	X		X	2-SC
Fusconaia askewi	Texas pigtoe												2	X	X		X	2,3-SC
Fusconaia flava	Wabash pigtoe	X												X	X		X	
Plectomerus dombevanus	mudskipper, bankclimber												4				X	
Lampsilis teres	yellow sandshell	X											2				X	
Quadrula apiculata	southern mapleleaf												36				X	
Uniomerus sp.																X		
Corbiculidae																		
Corbicula sp																X		
Sphaeriidae (No Genus species in Ref. 3)			14	0	29	22	12	209	0	7	1	1						
Sphaerium fluminea.			14	29	0	0	0	1	4	0	0	1						
Sphaerium sp.																X		
INVERTEBRATE																		
Macrobrachium ohione	Ohio shrimp	X																

(3) Fish, Benthic Macroinvertebrate, and Stream Habitat Data From the Houston-Galveston Area Council Service Area, Texas, 1997-98

Moring, Bruce, et al. 1998. USGS Report 98-658

(4) A Study of Freshwater Mussels (Pelecypoda: Unionidae), Fish, and Associsted Ecological Factors in Lake Creek, Montgomery County, Texas
Stephen P. Ansley, 1998 Thesis, Southwest Texas State University
COPYRIGHT 1998
Site 1 - 1.5 km north of the junction of FM 1488 and FM 2978 at
N 30 09' 07.6" latitude and W 95 20' 49.4" longitude

(5) Texas Parks and Wildlife Dept. Annotated County Lists of Rare Species
Last Revision 5/4/2009 5:54:00 PM
http://gis.tpwd.state.tx.us/TpwEndangeredSpecies/DesktopDefault.aspx
X - Species Present
T - Species on the Texas Threatened List

(7) The Effects of Timber Harvesting on Stream Water Quality in the Sam Houston National Forest: A Physicochemical, Benthic Macroinvertebrate, and Fish Analysis.
Charles Dewey Stoffels, Stephen F. Austin State University, August 2000

10 TPWD (Marsha May), Texas Mussel Distribution Chart.
TWAP-SC = Species of Concern, TPWD Texas Wildlife Action Plan 2005
[1] Federal Endangered Species (FE)
[2] State Rank (S1) - Critically imperiled, extremely rare, very vulnerable to extirpation, 5 or fewer occurrences
[3] State Rank (S2) - Imperiled in state, very rare, vulnerable to extirpation, 6 to 20 occurrences
[4] State Rank (SH) - Of historical occurrence in state. May be rediscovered.
[5] State Rank (S?) - Not ranked to date
[7] Federal Candidate Species (FC)
* - Introduced

0 - Historical occurrence

Appendix C – Focus Species Lists

Draft List of Focus Species for Trinity and San Jacinto River Basins

This draft list was transmitted electronically from John Botros (TPWD) to Tim Osting (Espey Consultants, Inc.) on August 12, 2009. Highlighted notations were added, from the TSU/Bonner website, USGS and other references as noted.

MODIFIED Draft List of Focus Species for Trinity and San Jacinto River Basins

Trinity River Basin

Fishes

- *Polyodon spathula* (paddlefish) – species of concern; inhabits medium to large river systems usually in pool / backwater areas; uses gravel beds and swift water areas to spawn
    a. "Large river populations make extensive spawning migrations in the spring (Russell 1986; Paukert and Fisher 2000); their movement on these occasions associated with pools during high water."
    b. "only increased and prolonged river flow will attract fish onto the gravel beds; flow must be able to maintain a 3-5 m rise in the river for about 10-14 days (Russell 1986; Pitman 1992)".
    c. "Usually in swiftly flowing water over large gravel bars (Purkett 1961; 1963)."
- *Atractosteus spatula* (alligator gar) – species of concern; inhabits large river systems; dependent upon backwater / floodplain habitats for reproduction; piscivore
- *Notropis atrocaudalis* (blackspot shiner) – species of concern; inhabits small to moderate sized tributary streams
- *Notropis shumardi* (silverband shiner) - species of concern; flow sensitive species
- *Ictalurus furcatus* (blue catfish) – large river species with adults inhabiting the main river and juveniles being found in tributaries; sportfish
- *Morone chrysops* (white bass) – inhabits main stem river, migratory; sportfish
- *Lepomis megalotis* (longear sunfish) – inhabits both main stem and tributaries in pool and backwater areas; nest builder; invertivore
- *Micropterus salmoides* (largemouth bass) – inhabits both main stem and tributaries in pool and backwater areas; nest builder; piscivore; sportfish
- *Percina sciera* (dusky darter) – inhabits main stem and tributaries in run and riffle areas; flow sensitive; benthic invertivore
- *Aplodinotus grunniens* (freshwater drum) – large river species; mussel glochidia host species

Invertebrates

- *Lampsilis teres* (yellow sandshell) - intolerant of drought and dewatering; actively follow flood flow onto land, then retreat back as flows return to channel
- *Tritogonia verrucosa* (pistolgrip) – typical of oxygen rich riffles and runs
- *Fusconaia flava* (Wabash pigtoe) – especially intolerant of changing stream environments
- *Macrobrachium ohione* (Ohio shrimp) – inhabits main stem rivers; migratory species

San Jacinto River Basin

Fishes

- ***Lepisosteus oculatus*** (spotted gar) – ubiquitous in SJ basin; floodplain connectivity required for reproduction; piscivore
    a. BBEST recommended considering this as a focus species
    b. Limited habitat data exists coincident with catch data: velocity, secchi disc
    c. May be less tolerant of turbidity than other gar and tend to be more associated with aquatic vegetation (Lee and Wiley 1980; Pfliger 1997; Ross 2001).
    d. Spawn in shallow water among rooted aquatic vegetation (Lee and Wiley 1980; Tyler and Granger 1984; Love 2004).
    e. Spotted gar prefer shallow open waters, usually 3 - 5 m deep, as well as stagnant backwater. Spotted gars are rarely found in areas that do not include some form of brush covering. (Snedden, Kelso, and Rutherford, 1999)
- ***Lythrurus fumeus*** (ribbon shiner) – inhabits small and medium sized coastal plain streams; mesohabitats and substrate preferences variable
    a. Limited habitat data exists coincident with catch data: velocity, secchi disc
    b. Quiet pools or backwaters with weak flow preferred. Extremely tolerant of turbidity and other ecological factors characteristic of creeks and ditches flowing through agricultural areas (Snelson 1973).
    c. In the East and West Forks of the San Jacinto River, Texas, this species was associated with streams having higher and temporally less variable baseflow, but greater spatial variability of depth (Herbert and Gelwick 2003).
    d. Tolerant of turbidity and associated ecological factors characteristic of creeks flowing through agricultural areas. Prefers clear, vegetated pools with little current over sand (Smith, P. W. 1979. The fishes of Illinois. Univ. Illinois Press, Urbana. 314 pp).
- ***Hybopsis amnis*** (pallid shiner) – inhabits medium to larger streams; intolerant of excessive turbidity; year class strength linked to stream discharge
    a. BBEST recommended removing this species from consideration as focal
    b. Quiet waters over sand-silty bottoms, intolerant of heavy siltation and pollutants (Clemmer 1980).
    c. Turbidity limits and velocity limit information is available
    d. Floodplain access is important for successful spawning or survival of young fish (Kwak 1991).
- ***Notropis atrocaudalis*** (blackspot shiner) - species of concern; inhabits small to moderate sized tributary streams
    a. Limited habitat data exists coincident with catch data: velocity
    b. In runs and pools over all types of substrates, generally avoiding areas of backwater and swiftest currents. In Banita Creek, TX, N. atrocaudalis were found at mean depths ranging from 0.19 to 0.29 m, and mean current velocities ranging from 0.13 to 0.30 m/s (Bean et al., unpublished data).
- ***Erimyzon oblongus*** (creek chubsucker) - State threatened species; fluvial specialist; inhabits main stem and tributaries
    a. BBEST recommended removing this species from consideration as focal
    b. Limited habitat data exists coincident with catch data: velocity at location of spawning
    c. The creek chubsucker is highly sensitive to siltation and pollution. In Ohio, dead creek chubsuckers have been found with silt packed gills (Trautman 1981).
    d. Adult creek chubsuckers move upstream to spawn in the early spring. (Trautman 1981, Becker 1983).

e. Populations apparently declining in streams subject to siltation (Wall and Gilbert 1980).
f. Occupies small rivers and creeks often highly vegetated (Wall and Gilbert 1980).
g. Infrequent occurrence; greater number of museum specimens pre-73.

- ***Moxostoma poecilurum*** (blacktail redhorse) - inhabits main stem and tributaries; sandy to rocky substrates
  a. Limited habitat data exists coincident with catch data: velocity, secchi disc, D.O.
  b. During frequent but brief periods of flooding, blacktail redhorses move onto the inundated floodplain (Slack 1996; Ross 2001). Tolerates brackish water; specimen collected from Escambia River, Florida where salinity was 4.5 ppt at the surface and 24.4 ppt near the bottom (Bailey et al. 1954).
  c. Specimens from Village Creek, Texas, captured in channel pools; however, none were collected in winter and spring due to high stream discharges. (Moriarty and Winemiller 1997).
- ***Noturus nocturnus*** (freckled madtom) – flow sensitive life cycle; medium to large sized systems
  a. BBEST recommended use of this as a focal species
  b. Limited habitat data exists coincident with catch data: velocity, secchi disc, D.O.
  c. Inhabits clear to moderately turbid streams of medium to larges size having permanent flow and low to moderate gradients (Rhode 1980).
  d. N. nocturnus is an intolerant species sensitive to environmental conditions and typically first to disappear following a disturbance; fluvial specialist having narrow range of habitat use.
  e. In South Sulpher River, Texas, species associated with higher velocities and with riffle-habitat types and shallower depths that occurred during the low flow range (Morgan 2002).
- ***Pylodictis olivaris*** (flathead catfish) – long lived species; strong ties to floodplain connectivity; sportfish
  a. BBEST recommended use of this as a focal species
  b. Limited habitat data exists coincident with catch data: velocity, secchi disc, D.O.
  c. No floodplain connectivity references/data found.
  d. Life cycle: Young-of-the-year live in rubble bottomed riffles until between 2 and 4 inches in length
  e. Poor overall health and certain environmental conditions such as drought or flood can reduce flatheads' ability to spawn. (TPWD)
  f. Pflieger (1975) stated that the flathead catfish inhabits a variety of streams types, but avoids streams with high gradients or intermittent flow. The term "high gradient" was not defined.
  g. Adults are usually found associated with submerged logs or other cover (Pflieger 1975; Smith 1979).
  h. In Texas, Gholson (1975) reported that flathead catfish were most abundant near rocks, shoals, log jams, brush tops, ledges, submerged trees, and other structures that afford cover and also are associated with current.
  i. HSI Models: Flathead Catfish. USFWS Biological Report 82(10.152) September 1987
- ***Lepomis megalotis*** (longear sunfish) - inhabits both main stem and tributaries in pool and backwater areas; nest builder; invertivore.
  a. Limited habitat data exists coincident with catch data: velocity, secchi disc, D.O.
  b. Spawning occurs in shallow water with gravel bottom, and little current (Bietz 1981; Hubbs and Cooper 1935; Hankinson 1919).
  c. Abundant in clear, small upland streams with rocky bottoms and permanent or semi-permanent flows (Robison and Buchanan 1988).

- ***Micropterus salmoides*** (largemouth bass) – inhabits both main stem and tributaries in pool and backwater areas; nest builder; piscivore; sportfish
    a. Limited habitat data exists coincident with catch data: velocity, secchi disc, D.O.
    b. Growth seems to be poor for fish in salinities of over 4 ppt (Peterson 1991); fish cannot survive for an extended period in salinities greater than 12 ppt (Meador and Kelso 1990).
- ***Etheostoma parvipinne*** (goldstripe darter) - inhabits both main stem and tributaries in run mesohabitats; flow sensitive
    a. Occurrence data available
    b. In Texas, occupies small first-order creeks (Hubbs et al 1991). Species prefers small streams and feeder streams of low to moderate gradient (Rohde 1980).
    c. With in the East Fork of the San Jacinto River, Texas, Herbert and Gelwick (2003) found species to be associated with shallow water and higher conductivities
    d. Smiley et al. (2006) sampled 14 first-order streams in north-central Mississippi (streams did not contain aquatic vegetation), and found that species abundance was positively correlated with increasing percentage canopy cover, increasing water temperature and decreasing dissolved oxygen levels, increasing percentage sand and decreasing percentage clay substrate.
    e. A population was documented by Abdul (1987) in a small cattle pond in east Texas that was characterized by low pH (mean 3.7, range 2.9-4.0) and no buffering capacity (0 alkalinity); Etheostoma parvipinne was the only fish species present in the stream pond, and Robbins et al. (2003) reported that a reproducing population was still present as of August 2000.
    f. Smiley et al. (2006) report common occurrence of species in small streams having sand substrates, shallow water depths, and slow water velocities.
- ***Percina sciera*** (dusky darter) – inhabits main stem and tributaries in run and riffle areas; flow sensitive; benthic invertivore
    a. Limited habitat data exists coincident with catch data: velocity, secchi disc, D.O.
    b. Considered pollution intolerant species (United States Environmental Protection Agency 1983; Kleinsasser and Linam 1987; Linam and Kleinsasser 1987a).
- ***Aplodinotus grunniens*** (freshwater drum) – large river species; mussel glochidia host species
    a. Limited habitat data exists coincident with catch data: velocity, secchi disc, D.O.
    b. Individuals have been observed to become distressed when water temperatures exceed 25.6°C, and when dissolved oxygen concentrations remain low over an extended period (Priegel 1967b).

<u>Invertebrates</u>

- *Lampsilis teres* (yellow sandshell) - intolerant of drought and dewatering; actively follow flood flow onto land, then retreat back as flows return to channel
- *Tritogonia verrucosa* (pistolgrip) – typical of oxygen rich riffles and runs
- *Fusconaia flava* (Wabash pigtoe) – especially intolerant of changing stream environments
- *Quadrula apiculata* (Southern mapleleaf) – generalist but sensitive to dewatering (USFWS, Cherrish Stevens/Dr. Howells, personal communication 2009).
- *Macrobrachium ohione* (Ohio shrimp) – inhabits main stem rivers; migratory species

Appendix D – Data sources

SUMMARY OF RELEVANT DATA SOURCES

SUMMARY OF RELEVANT DATA SOURCES
SAN JACINTO RIVER BASIN
San Jacinto River Authority – www.sjra.net

Objective 1.3: Existing Hydrologic Data Sets

USGS NWIS (National Water Information System) –
Daily-averaged stream flow records
(see spreadsheet for listing of all records in basin)
Real-time flow records
Peak flow
Streamflow
http://waterdata.usgs.gov/tx/nwis/current/?type=flow
Lakes
http://waterdata.usgs.gov/tx/nwis/current/?type=lake
Instantaneous Data Archive (IDA) - Historical 15-minute flow records
http://ida.water.usgs.gov/ida/index.cfm?ncd=48

USGS – National Hydrography Dataset (NHD), geospatial information
http://nhd.usgs.gov/data.html

NWS – Flood forecasting and flood magnitude (etc., overbank) notations
http://www.weather.gov/ahps/forecasts.php
http://ahps.srh.noaa.gov/ahps2/forecasts.php?wfo=hgx&view=1,1,1,1,1,1,1,1&toggles=10,7,8,2,9,15,6
Example: Forecast and Action Stage information for Spring Creek near Spring, TX
http://ahps.srh.noaa.gov/ahps2/hydrograph.php?wfo=hgx&gage=spnt2&view=1,1,1,1,1,1,1,1

TCOON – Galveston Bay tide data
http://lighthouse.tamucc.edu/TCOON/HomePage

TWDB - Coastal Hydrology (TxRR)
http://midgewater.twdb.state.tx.us/bays_estuaries/hydrologypage.html
GIS - http://www.twdb.state.tx.us/mapping/index.asp

Objective 1.5: Existing Biological Data

TSU – Texas Freshwater Fishes (Tim Bonner's Field Guide)
http://www.bio.txstate.edu/~tbonner/txfishes/
San Jacinto basin
http://www.bio.txstate.edu/~tbonner/txfishes/San%20Jacinto.htm

TPWD – Rare, Threatened and Endangered Species of Texas, by County
http://gis.tpwd.state.tx.us/TpwEndangeredSpecies/DesktopDefault.aspx
Ecologically Significant Stream Segements
http://www.tpwd.state.tx.us/landwater/water/environconcerns/water_quality/sigsegs/

EPA - Texas Ecoregions
http://www.epa.gov/wed/pages/ecoregions/tx_eco.htm

USFWS – Endangered Species: Listed, Proposed and Candidate Species
http://www.fws.gov/endangered/wildlife.html

EARDC – List of Reports and Studies (biology, WQ and spring flow)
http://www.eardc.txstate.edu/EARDC%20Reports-Studies.html

Objective 1.6: Existing Physical Processes Data

TWDB – Historical suspended sediment load (tons/day) data at station 08070000 E. Fork San Jacinto River near Cleveland, TX. (see spreadsheet)

TNRIS –
Digital Data - Aerial Photos, DRGs, Basin (HUC) boundaries,
http://www.tnris.org/datadownload/download.jsp
StratMap – Hypsography/DEMs (Topography)
http://www.tnris.org/StratMap.aspx?layer=122

UT BEG – GAT
http://www.beg.utexas.edu/mainweb/services/15minquads.htm

USGS – National Land Cover Database (NLCD)
http://www.mrlc.gov/

NOAA –Coastal Change Analysis Program (C-CAP)
http://www.csc.noaa.gov/crs/lca/gulfcoast.html

NRCS – SSURGO soils data
http://soils.usda.gov/survey/geography/ssurgo/

USACE – Galveston District Library
http://www.swg.usace.army.mil/Library/default.asp

Objective 1.7: Existing Water Quality Data

TCEQ – Stream segments and monitoring stations
GIS - http://www.tceq.state.tx.us/implementation/water/tmdl/atlas.html
Maps - http://www.tceq.state.tx.us/comm_exec/forms_pubs/pubs/gi/gi-316/index.html
http://www.tceq.state.tx.us/files/basin18-20-GuadSanAntNuec.pdf_4447615.pdf
Surface Water Quality Monitoring System (SWQMS)
http://www.tceq.state.tx.us/compliance/monitoring/crp/data/samplequery.html

TWDB –
Estuarine Hydrographic Surveys (Galveston Bay)
http://midgewater.twdb.state.tx.us/bays_estuaries/surveypage.html
Estuary Monitoring Program – Datasonde Data
http://midgewater.twdb.state.tx.us/bays_estuaries/sondpage.html

USGS – Real-time water quality data for Texas
http://waterdata.usgs.gov/tx/nwis/current/?type=quality

Appendix **E – USGS data**

SUMMARY TABLE OF HISTORICAL AND CURRENT USGS GAUGING STATIONS IN THE SAN JACINTO AND COASTAL BASINS

USGS stream gaging stations in the San Jacinto and San Jacinto coastal basins

Site Code	Site Name	Value Count	Start Date	End Date	County	Latitude	Longitude
08075605	Berry Bayou at Nevada St, Houston, TX	814	10/01/2006	07/28/2009	Harris	29.65662003	-95.22910309
08075730	Vince Bayou at Pasadena, TX	13598	10/01/1971	07/28/2009	Harris	29.69467354	-95.21632385
08076700	Greens Bayou at Ley Rd, Houston, TX	1717	12/02/1971	07/28/2009	Harris	29.83716965	-95.23326874
08076997	Clear Ck at Mykawa St nr Pearland, TX	814	10/01/2006	07/28/2009	Harris	29.59689903	-95.29743958
08067500	Cedar Bayou nr Crosby, TX	9911	10/01/1971	07/28/2009	Liberty	29.97271919	-94.98576355
08067525	Goose Ck at Baytown, TX	814	10/01/2006	07/28/2009	Harris	29.77078247	-94.99964905
08067610	Lk Conroe Outflow Weir nr Conroe, TX	5113	10/01/1973	09/30/1989	Montgomery	30.35659599	-95.5605011
08067650	W Fk San Jacinto Rv bl Lk Conroe nr Conroe, TX	8817	10/18/1973	07/28/2009	Montgomery	30.34215355	-95.54299927
08067700	Caney Ck nr Dobbin, TX	914	04/01/1963	09/30/1965	Montgomery	30.35381889	-95.80995178
08067900	Lake Ck nr Conroe, TX	731	10/01/2002	09/30/2004	Montgomery	30.25354576	-95.57883453
08068000	W Fk San Jacinto Rv nr Conroe, TX	26578	05/01/1924	07/28/2009	Montgomery	30.24465752	-95.45716095
08068090	W Fk San Jacinto Rv abv Lk Houston nr Porter, TX	8986	05/01/1984	07/28/2009	Montgomery	30.08605194	-95.29993439
08068275	Spring Ck nr Tomball, TX	3370	10/01/1999	07/28/2009	Montgomery	30.1199398	-95.64605713
08068325	Willow Ck nr Tomball, TX	796	10/01/2006	07/28/2009	Harris	30.10549545	-95.54660797
08068390	Bear Br at Research Blvd, The Woodlands, TX	3618	01/27/1999	07/28/2009	Montgomery	30.19055557	-95.49111176
08068400	Panther Br at Gosling Rd, The Woodlands, TX	4379	08/01/1974	07/28/2009	Montgomery	30.19215965	-95.48382568
08068450	Panther Br nr Spring, TX	5015	04/01/1972	07/28/2009	Montgomery	30.13105011	-95.48133087
08068500	Spring Ck nr Spring, TX	25449	04/01/1939	07/28/2009	Montgomery	30.11049461	-95.43632507
08068720	Cypress Ck at Katy-Hockley Rd nr Hockley, TX	12073	06/01/1975	07/28/2009	Harris	29.95022392	-95.80828094
08068740	Cypress Ck at House-Hahl Rd nr Cypress, TX	12259	06/01/1975	07/28/2009	Harris	29.95911217	-95.71772766
08068780	Little Cypress Ck nr Cypress, TX	7889	05/01/1982	07/28/2009	Harris	30.01605415	-95.69744873
08068800	Cypress Ck at Grant Rd nr Cypress, TX	6293	10/01/1982	07/28/2009	Harris	29.97355652	-95.59855652
08068900	Cypress Ck at Stuebner-Airline Rd nr Westfield,	731	10/01/1987	09/30/1989	Harris	30.00661087	-95.5118866
08069000	Cypress Ck nr Westfield, TX	23551	07/01/1944	07/28/2009	Harris	30.03577614	-95.42882538
08069500	W Fk San Jacinto Rv nr Humble, TX	9496	10/01/1928	09/30/1954	Harris	30.02716446	-95.25798798
08070000	E Fk San Jacinto Rv nr Cleveland, TX	25439	05/01/1939	07/28/2009	Liberty	30.33659744	-95.10410309
08070200	E Fk San Jacinto Rv nr New Caney, TX	8986	05/01/1984	07/28/2009	Montgomery	30.14549255	-95.12437439
08070500	Caney Ck nr Splendora, TX	23733	01/01/1944	07/28/2009	Montgomery	30.25965881	-95.30243683
08071000	Peach Ck at Splendora, TX	15948	10/01/1943	07/28/2009	Montgomery	30.2327137	-95.1682663
08071280	Luce Bayou abv Lk Houston nr Huffman, TX	8975	05/01/1984	07/28/2009	Liberty	30.1096611	-95.05992889
08071500	San Jacinto Rv nr Huffman, TX	6209	10/01/1936	09/30/1953	Harris	29.99466324	-95.13354492

Site Code	Site Name	Value Count	Start Date	End Date	County	Latitude	Longitude
08072300	Buffalo Bayou nr Katy, TX	11498	07/01/1977	07/28/2009	Fort Bend	29.74328613	-95.8068924
08072730	Bear Ck nr Barker, TX	11498	07/01/1977	07/28/2009	Harris	29.83078194	-95.68688965
08072760	Langham Ck at W Little York Rd nr Addicks, TX	3766	07/01/1977	07/28/2009	Harris	29.86717033	-95.64661407
08073500	Buffalo Bayou nr Addicks, TX	23124	09/01/1945	07/28/2009	Harris	29.76189613	-95.60578156
08073600	Buffalo Bayou at W Belt Dr, Houston, TX	13628	09/01/1971	07/28/2009	Harris	29.7621727	-95.557724
08073700	Buffalo Bayou at Piney Point, TX	13463	10/01/1963	07/28/2009	Harris	29.74689674	-95.52355194
08074000	Buffalo Bayou at Houston, TX	15238	06/01/1936	07/28/2009	Harris	29.76022911	-95.40855408
08074020	Whiteoak Bayou at Alabonson Rd, Houston, TX	3326	10/01/1999	07/28/2009	Harris	29.87078094	-95.48049927
08074150	Cole Ck at Deihl Rd, Houston, TX	8191	05/01/1964	02/11/2004	Harris	29.85133743	-95.48799896
08074250	Brickhouse Gully at Costa Rica St, Houston, TX	6373	09/01/1964	02/11/2004	Harris	29.82800484	-95.46938324
08074500	Whiteoak Bayou at Houston, TX	26510	05/25/1936	07/28/2009	Harris	29.7752285	-95.39716339
08074760	Brays Bayou at Alief, TX	814	10/01/2006	07/28/2009	Harris	29.7091198	-95.58300018
08074800	Keegans Bayou at Roark Rd nr Houston, TX	6373	09/01/1964	02/11/2004	Harris	29.65662193	-95.56216431
08074810	Brays Bayou at Gessner Dr, Houston, TX	2640	10/01/2001	07/28/2009	Harris	29.6727314	-95.52827454
08075000	Brays Bayou at Houston, TX	26510	05/25/1936	07/28/2009	Harris	29.69717407	-95.41216278
08075400	Sims Bayou at Hiram Clarke St, Houston, TX	14090	08/18/1964	07/28/2009	Harris	29.61884308	-95.44605255
08075500	Sims Bayou at Houston, TX	15707	10/01/1952	09/01/2001	Harris	29.67439651	-95.28938293
08075763	Hunting Bayou at Hoffman St, Houston, TX	806	10/01/2006	07/28/2009	Harris	29.80883789	-95.31327057
08075770	Hunting Bayou at IH 610, Houston, TX	16306	05/01/1964	07/28/2009	Harris	29.79328156	-95.26799011
08075900	Greens Bayou nr US Hwy 75 nr Houston, TX	10569	08/03/1965	07/28/2009	Harris	29.9568882	-95.41799164
08076000	Greens Bayou nr Houston, TX	20537	10/01/1952	07/28/2009	Harris	29.91827774	-95.30687714
08076180	Garners Bayou nr Humble, TX	5780	02/25/1986	07/28/2009	Harris	29.93438911	-95.23410034
08076500	Halls Bayou at Houston, TX	17974	10/01/1952	07/28/2009	Harris	29.86189079	-95.33493805
08077000	Clear Ck nr Pearland, TX	15958	08/01/1944	09/04/1994	Brazoria	29.59745407	-95.28660583
08078000	Chocolate Bayou nr Alvin, TX	18189	03/01/1959	07/28/2009	Brazoria	29.36940384	-95.32077026

Appendix **F – SAC/BBEST presentation**

San Jacinto River Basin Ecological Overlay Drill-down

Tim Osting
Espey Consultants, Inc.
2009-09-09 (SAC)
2009-09-10 (BBEST)

1

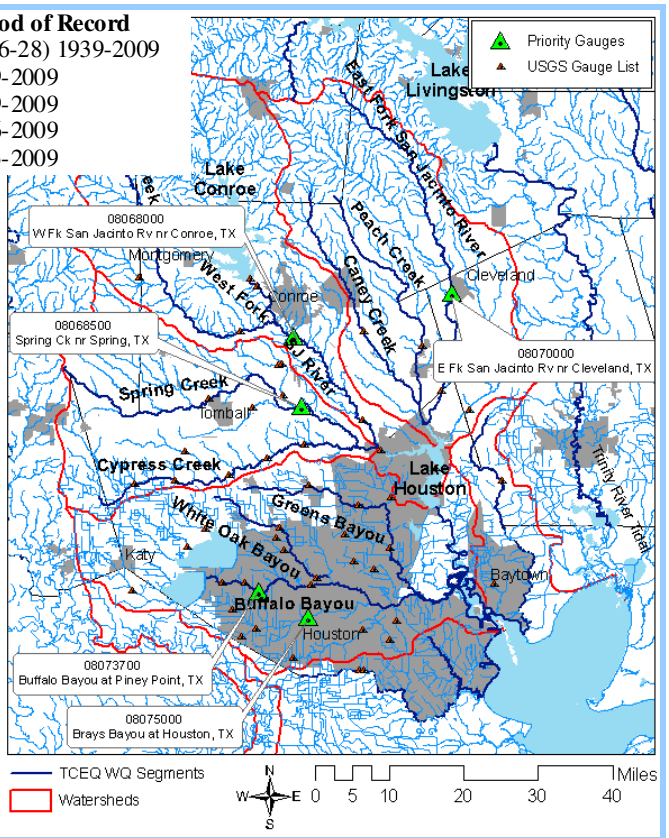
Deliverables

- Matrix of fish and mussel species
  - Focal components
- Report
  - Short list of focal fish and mussel species
  - Relationships between "flow" and…
    - …Focal species and biological components
    - …Physical processes
    - …Water quality
    - …Nutrient and sediment loading

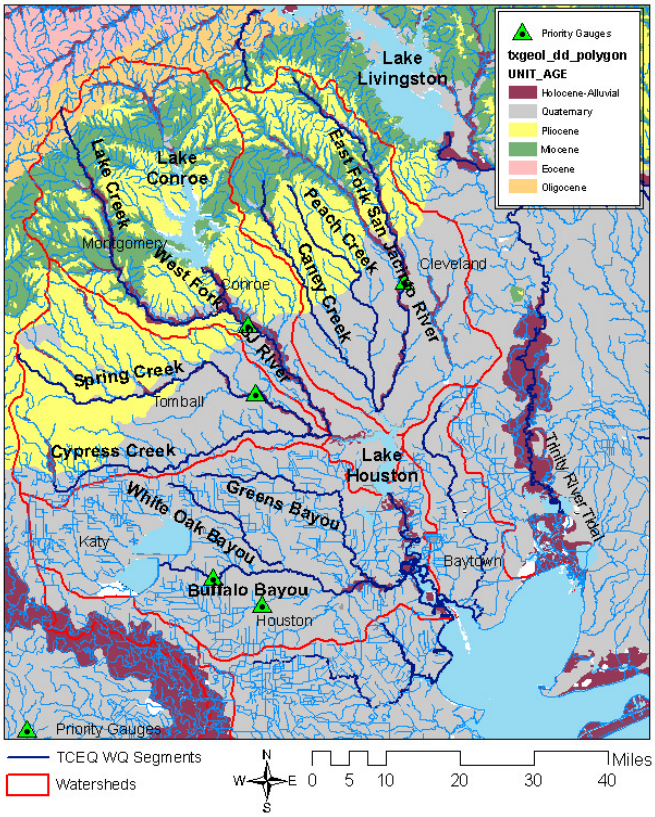
2

Name	Period of Record
W. Fork San Jacinto near Conroe, TX	(1926-28) 1939-2009
E. Fork San Jacinto near Cleveland, TX	1939-2009
Spring Creek near Spring, TX	1939-2009
Brays Bayou near at Houston, TX	1936-2009
Buffalo Bayou at Piney Point, TX	1963-2009

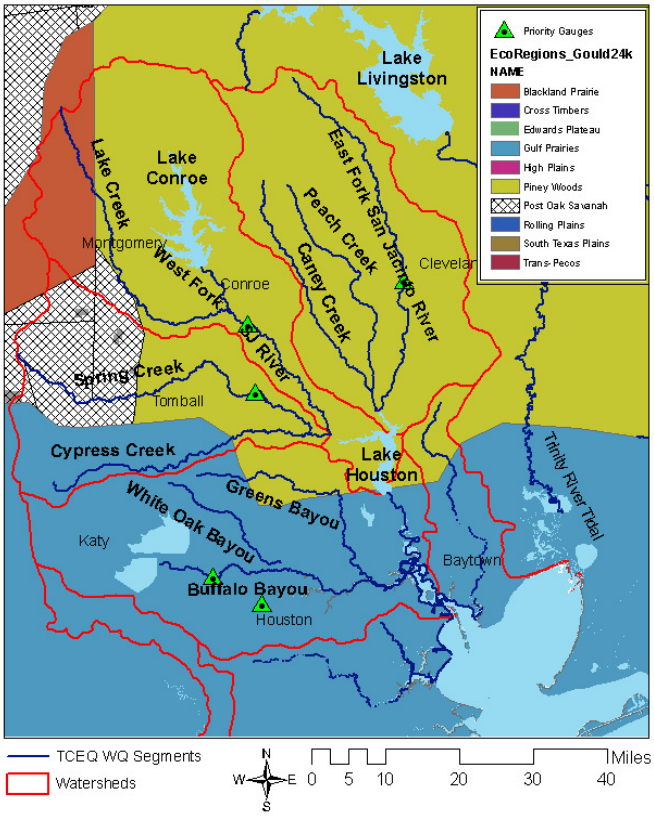
SJR – Priority gauges



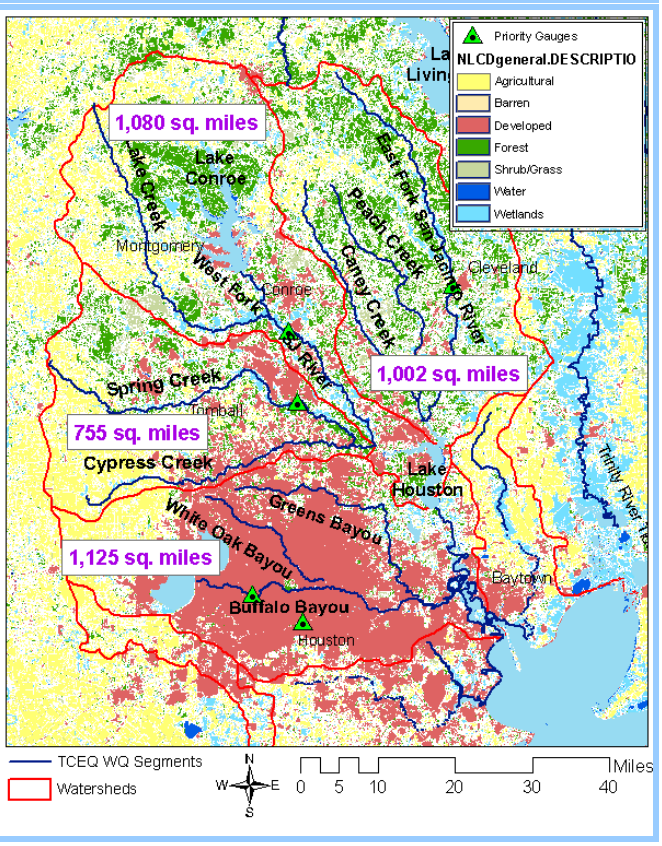
SJR – Geology



SJR – Ecoregions



SJR – Land Use Land Cover



SJR – Land Use Land Cover

	Spring Creek	West Fork SJR	East Fork SJR	Lower-SJR
Water	0.5%	4.8%	0.5%	2.2%
Developed	24.8%	14.6%	10.9%	65.4%
Barren	0.5%	0.4%	0.1%	0.5%
Forest	23.6%	32.1%	44.0%	7.3%
Shrub/Grass	11.1%	13.5%	18.2%	4.1%
Agricultural	31.0%	20.0%	8.3%	13.3%
Wetlands	8.5%	14.6%	17.9%	7.1%
Total Area (sq. mi.)	755	1,080	1,002	1,125

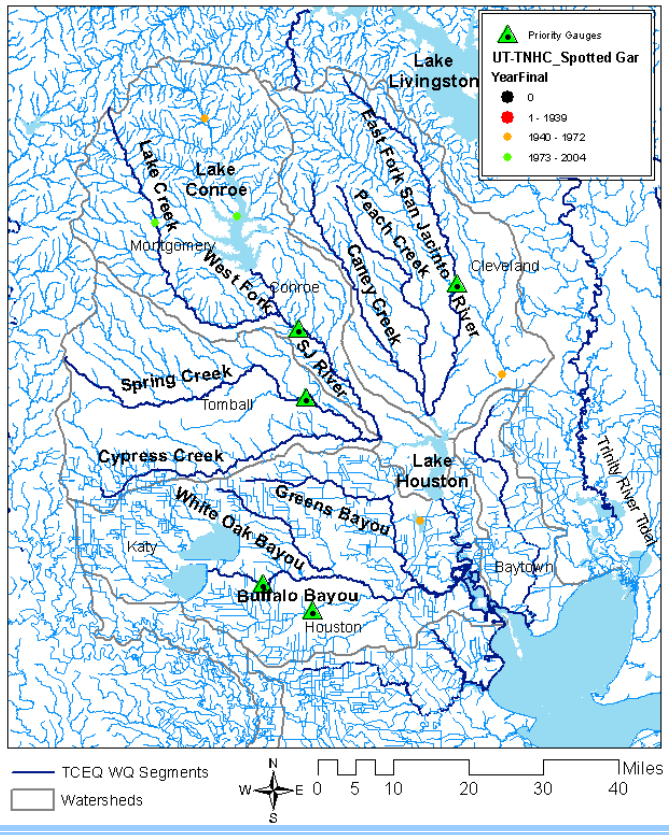
7

Matrix of fish and mussel species

- Fish and Mussel species matrix
  - Fish species – geographic occurrence
    - TSU – Hassan-Williams and Bonner website
    - Six other references
    - TPWD draft focal species
    - TPWD rare and threatened species
    - UT TNHC - Hendrickson
  - Mussel species – geographic occurrence
    - TPWD draft focal species
    - TPWD Marsha May (includes Burlakova's data)
    - Three other references
    - USFWS, Dr. Howells

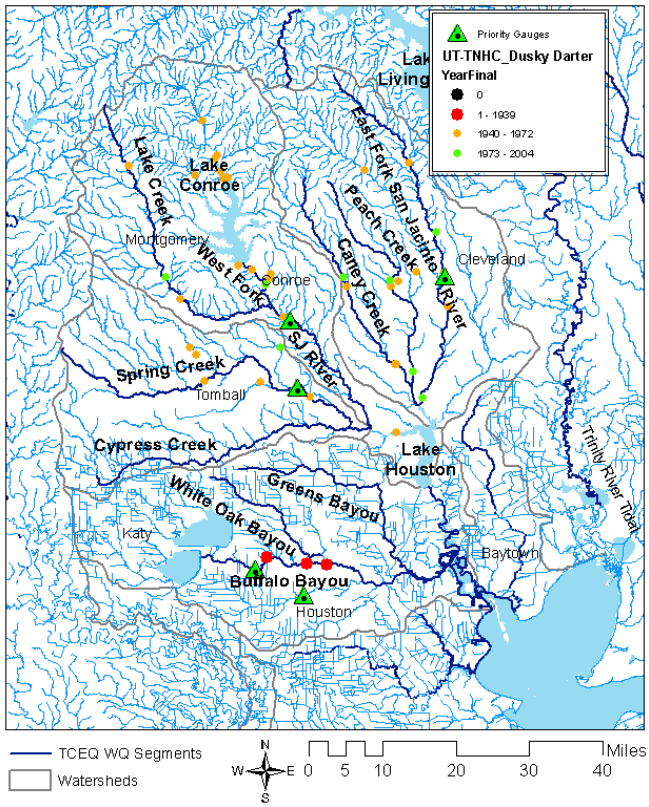
8

Spotted Gar (draft TNHC)



10

Dusky darter (draft TNHC)



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Focal mussel and invertebrate species

Species List - Mollusks and Invertebrate San Jacinto River			Ref. 3 USGS 97-98										Ref. 4 1998	Ref. 5 Rare		Ref. 7 2000	Ref.10 TPWD	
		TPWD draft focal species list 2009-08-12	Buffalo Bayou	Caney Creek	Cypress Creek	East Fork SJR	West Fork SJR	Lake Creek	East Sandy Creek	Luce Bayou	White Oak Bayou	Willow Creek	Upper Basin	Upper Basin	Harris Co.	Upper basin	San Jacinto River	Code
Scientific Name	**Common Name**																	
Tritogonia verrucosa	pistolgrip													X	X		X	
Fusconaia askewi	Texas pigtoe												2	X	X		X	2,3-SC
Lampsilis teres	yellow sandshell	X											2				X	
Quadrula apiculata	southern mapleleaf												36				X	
INVERTEBRATE																		
Macrobrachium ohione	Ohio shrimp	X																

12

Focal component discussion

- **Challenges in using the focal species information**
  - **Considering available time-frame, resources and existing information**

- What is a focal biological component?
  - Focal species or guilds
  - Considers competing needs of guilds or species
  - Parameter sensitive to flow variation
  - Parameter indicating ecosystem status
  - Habitat condition affecting a focal species
  - A specific flow condition, in a specific location, during a specific time of year, affecting a focal species?
    - High flow pulse
    - Baseflow in August

13

Flow components

Overbank Flows	Overbank flows are infrequent, high magnitude flow events that produce water levels that exceed channel banks and result in water entering the floodplain. A primary objective is to maintain riparian areas associated with riverine systems, eg, transport sediments and nutrients to riparian arease, recharge floodplain aquifers, and provide suitable conditions for seedlings.
High Flow Pulses	High flow pulses are short duration, high magnitude (but still within channel) flow events that occur during or immediately following reainfall events. They serve to maintain important physical habitat features and connectivity along a stream channel.
Base Flows (cfs)	Base flows represent the range of "average" or "normal" flow conditions in the absense of significant precipitation or runoff events. Base flows provide instream habitat conditions needed to maintain the diversity of biological communities in streams and rivers.
Subsistence Flows (cfs)	Subsistence flows are low flows that occur during times of drought or under very dry conditions

Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Winter			Spring			Summer					

From SAC 2009 Hydrologic methods report

that cites TIFP 2008, NRC 2005 14

Fish focal component summary

<u>Flow Components</u>

Overbank flows

Spotted gar – spring overbank habitats may be beneficial for spawning

Flow pulses

Pallid shiner – turbidity intolerance >45 NTU (adults) and >85 NTU (juveniles)

Largemouth bass – fry are intolerant to velocity >27cm/s

Base flows

Freckled madtom – habitat utilization is largely gravelly riffles

Flathead catfish – young of year require rubble-bottom riffles July – Fall

Dusky darter – spawn over gravel riffles 30-90cm deep February through June

Subsistence flows

Freshwater drum – intolerant of temp. >25.6`C and extended periods of low DO

Largemouth bass – salinity intolerant > 12ppt

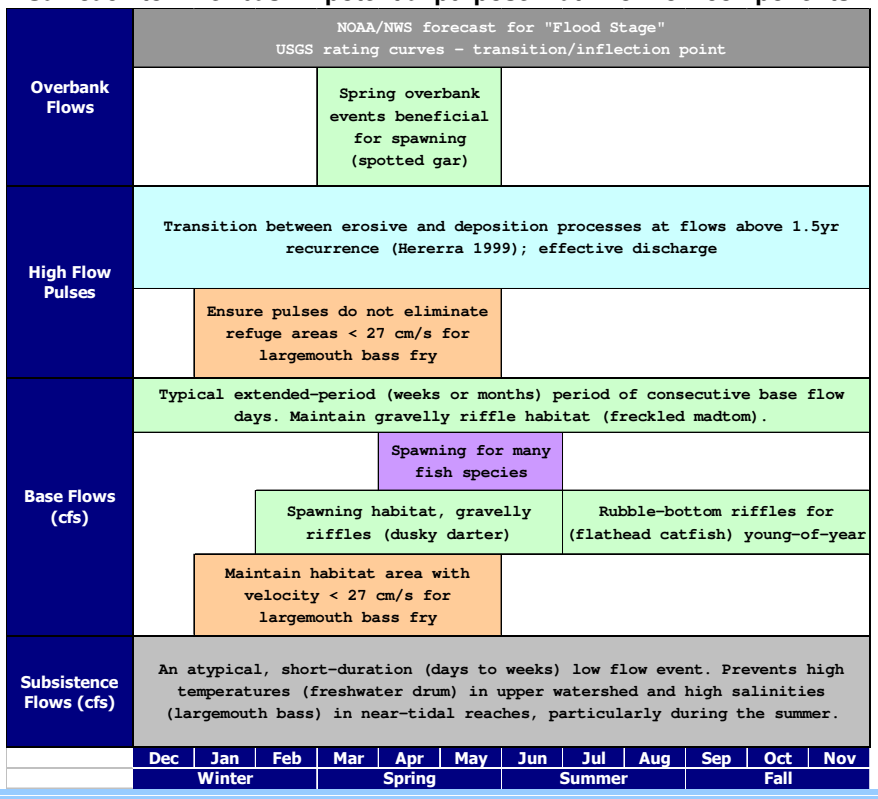
<u>Seasonality</u>

Maintenance of spawning habitats important between **April** and **June** for most species.

Bass spawn earlier – late winter to early spring at temperatures between 16 and 22`C

15

San Jacinto River basin - potential purpose matrix of flow components



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Flow component discussion

- General species information may support utility of flow components
- Site-specific information does not support choice of specific flow values

17

Biology overlay

- TDWR 1981 and TDWR 1983
  - W Fork San Jacinto River
  - intensive surveys from winter 1979 and summer 1981
  - Stream substrate sand; some areas of gravel riffles
- TPWD 1986 – Fisheries status reports
  - Characterize the fisheries as in good condition
- USGS least-impacted sites/reaches

18

USGS-HGAC study

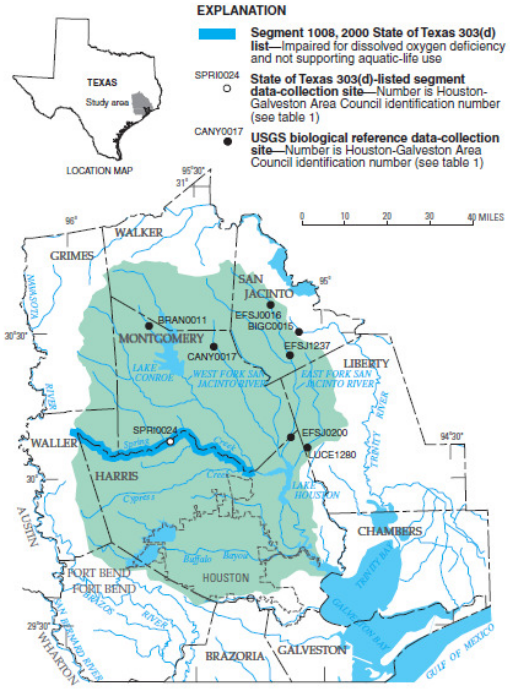

Figure 1. San Jacinto River Basin and data-collection sites.

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Hydrology overlay

Table 1 - TCEQ 7Q2 values for SJR basin gauges

Segment	Site Code	Site Name	Start Year	End Year	7Q2 (ft3/s)
902	08067500	Cedar Bayou nr Crosby, TX	1972	1996	0.3
1003	08070200	E Fk San Jacinto Rv nr New Caney, TX	1984	1996	22.6
1003	**08070000**	**E Fk San Jacinto Rv nr Cleveland, TX**	**1973**	**1996**	**18.2**
1004	08068090	W Fk San Jacinto Rv abv Lk Houston nr Porter, TX	1984	1996	26.6
1004	**08068000**	**W Fk San Jacinto Rv nr Conroe, TX**	**1974**	**1996**	**20.3**
1004	08067650	W Fk San Jacinto Rv bl Lk Conroe nr Conroe, TX	1975	1989	0.1*
1004	08067610	Lk Conroe Outflow Weir nr Conroe, TX	1974	1989	0.1*
1008	**08068500**	**Spring Ck nr Spring, TX**	**1975**	**1996**	**15.4**
1009	08069000	Cypress Ck nr Westfield, TX	1979	1996	17.6
1009	08068800	Cypress Ck at Grant Rd nr Cypress, TX	1983	1996	1.2
1009	08068740	Cypress Ck at House-Hahl Rd nr Cypress, TX	1976	1996	0.2
1009	08068720	Cypress Ck at Katy-Hockley Rd nr Hockley, TX	1976	1996	0.1*
1010	08070500	Caney Ck nr Splendora, TX	1973	1996	14.2
1011	08071000	Peach Ck at Splendora, TX	1960	1977	7.2
1014	08074000	Buffalo Bayou at Houston, TX	1962	1975	25.4
1014	**08073700**	**Buffalo Bayou at Piney Point, TX**	**1985**	**1996**	**50.6**
1014	08073600	Buffalo Bayou at W Belt Dr, Houston, TX	1980	1996	43.3
1014	08073500	Buffalo Bayou nr Addicks, TX	1980	1996	23
1015	08067900	Lake Ck nr Conroe, TX	1969	1989	2.8
1016	08076000	Greens Bayou nr Houston, TX	1980	1996	20.7
1016	08075900	Greens Bayou nr US Hwy 75 nr Houston, TX	1981	1996	11.8
1017	08074500	Whiteoak Bayou at Houston, TX	1980	1996	29.1
1102	08077000	Clear Ck nr Pearland, TX	1963	1992	0.5
1108	08078000	Chocolate Bayou nr Alvin, TX	1966	1996	1.5

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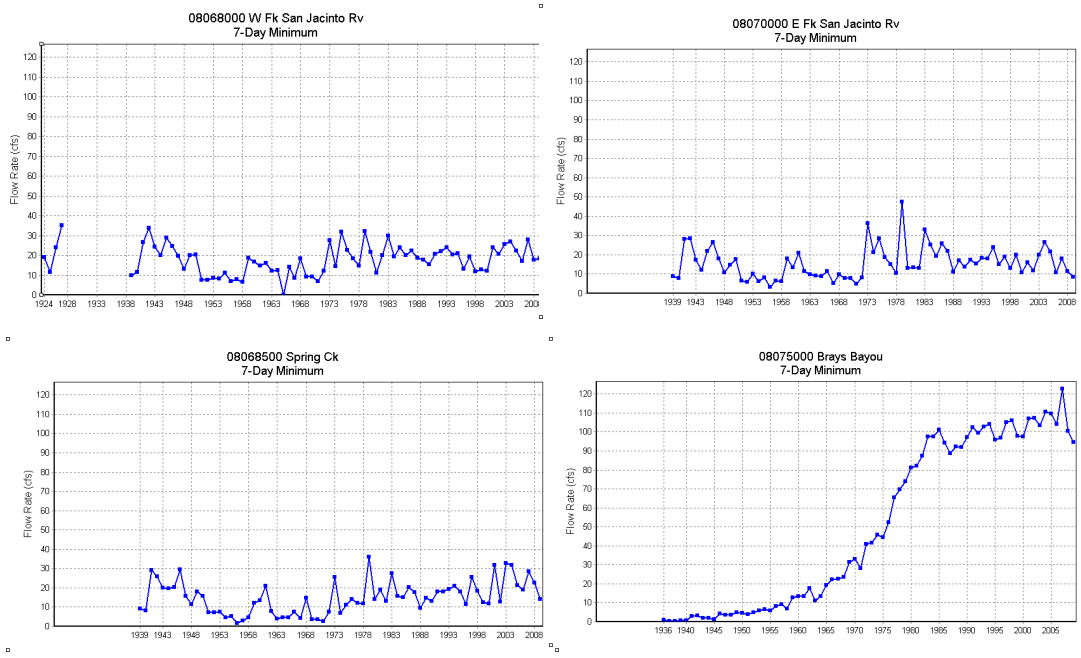
Hydrology overlay



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Physical Processes overlay

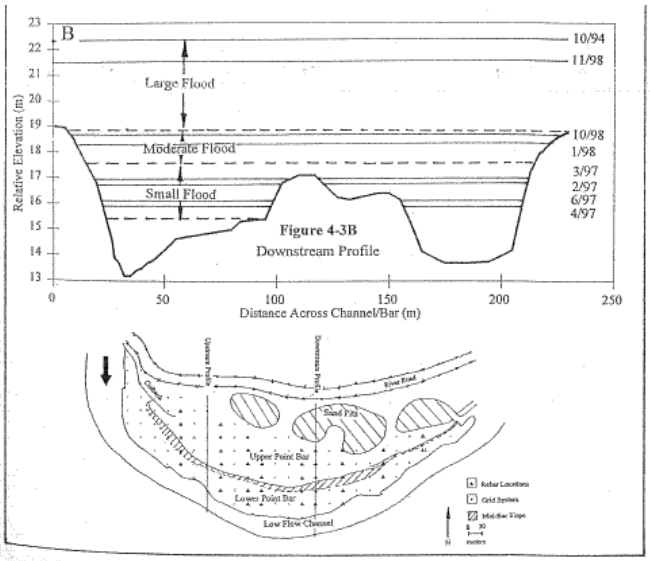

Figure 3-4: Upstream (A) and Downstream (B) Profiles across Hallett point bar showing high stage of five flood events.

Herrera, Roxana. 1999. Morphology and stratigraphy of a coarse-grained point bar on the West Fork San Jacinto River : Montgomery County, Texas. University of Houston, MS Thesis.

- 08068000 USGS West Fork SJR at Conroe
- Small flood <1.5 year Recurrence Interval (RI)
  - ~7,000 cfs
  - Erosion processes
- Medium flood 1.5 to 4 year RI
  - Deposition
- Large flood >4 year RI
  - 18,000 cfs
  - Deposition

Sinuosity=1.3; width:depth=35; slope=0.0009; grain-size (qualitative)

cross-section and mapping measurements following a number of flood events

22

Physical processes overlay

- USDA 1952
  - Bedload component estimated at 20-25% of total sediment load
- SJRA 1981 (LP168)
  - Suspended sediment load estimated
    - E Fork SJR – 363,200 lb/day
    - W Fork SJR – 189,800 lb/day
- TDWR 1981
  - E Fork SJR – 0.037 ac-ft/sq. mile/year
  - Captured by Lake Houston

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Water quality overlay

- Intensive surveys:
  - Winter 1979
  - Summer 1981
- Cursory inspection of available TCEQ-SWQM data

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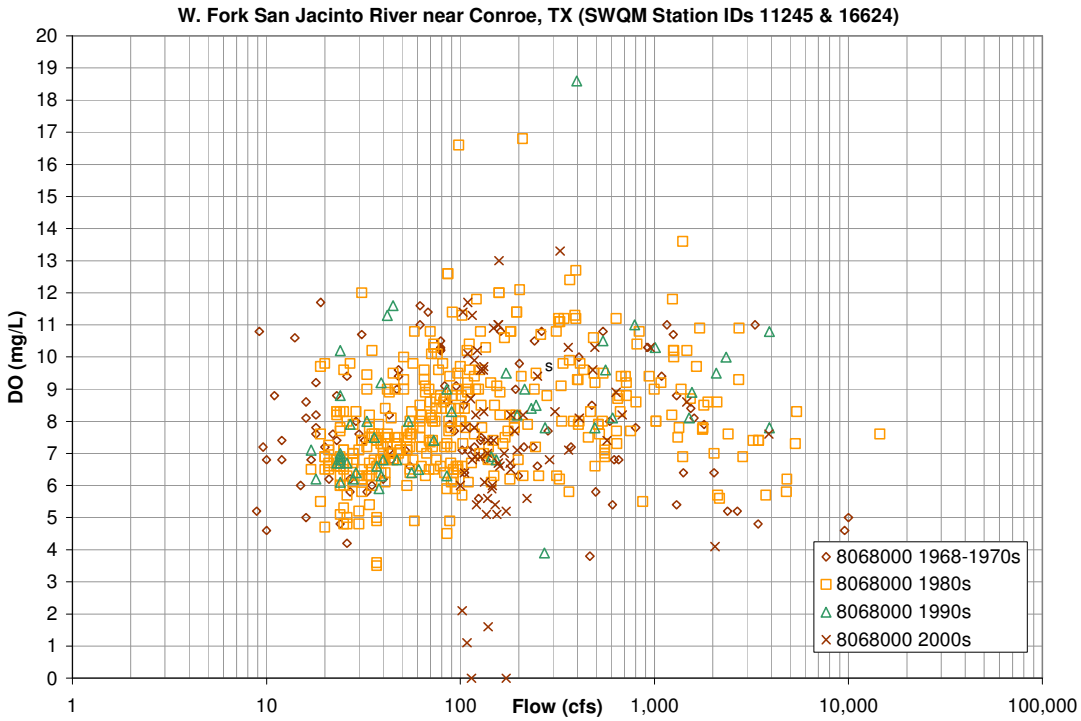

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Sediment and nutrient loading

- USDA 1952
  - Net 10% decrease in bay volume 1898-1937 because of decreased depths in delta areas
- Longley et al. 1994
  - Net increase in depth 1968-1977
  - Subsidence
  - Lake Houston completed 1953
- TDWR 1981 (LP113) – Nutrient loadings based upon 1970-1977 data
- Longley et al. 2001
    - Nutrient budget

26

Questions

- Process
  - TWDB accepting comments
    - Jorge Izaguirre
    - Ruben Solis
  - September 14, 2009 - Final comments transmitted to SJRA-EC team
  - September 21, 2009 - Final report due

- tosting at espeyconsultants.com
- 512.326.5659

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Appendix G – TWDB comments

COMMENTS FROM TWDB AND SAC

Tim Osting

From: Jorge Izaguirre [Jorge.Izaguirre@twdb.state.tx.us]
Sent: Thursday, September 17, 2009 2:06 PM
To: Tim Osting; rkelling@sjra.net; Ruben Solis
Cc: Carla Guthrie; Mark Wentzel; Nolan Raphelt
Subject: Re: Fwd: RE: SB3 SAC San Jacinto River basin EcologicalOverlayDraft for distribution

Attachments: 20090904_SJR_Fish_Mussel_Matrix.xls; 20090904_SJR_EcoOverlay_DRAFTd.pdf; 0900010980_SJRA.pdf

20090904_SJR_Fish_Mussel_Matri... 20090904_SJR_EcoOverlay_DRAFTd... 0900010980_SJRA.pdf (1 MB)

Tim,

FYI (see email below).

Here are some comments:

From Carla Guthrie:
For Osting and SJRA draft report: Report looks outstanding given the time constraints on the project. Only comment is that the Executive Summary paragraph #4 uses TSF rather than TSJ for the Trinity-San Jacinto acronym.

From me:
Page 2:
3.0 Overlay .... has ERROR! BOOKMARK NOT DEFINED.

Also, as a reminder, please review section 2 of Exhibit C on the contract (attached 0900010980_SJRA.pdf). This section outlines the final deliverables.

Thanks,

Jorge

>>> Ruben Solis 9/17/2009 1:12 PM >>>
FYI - the SAC has no additional comments. - Ruben

>>> "rbrandes" <rbrandes@trcsolutions.com> 9/17/2009 1:11 PM >>>
Ruben, don't know of any comments so I guess go with it.
------Original Message------
From: Ruben Solis
To: Bob TR Brandes
Cc: Tim Osting
Subject: Fwd: RE: SB3 SAC San Jacinto River basin Ecological OverlayDraft for distribution
Sent: Sep 17, 2009 8:27 AM

Bob,

Bob Huston is out - wondering if we'll be getting any comments from the SAC on the San Jacinto River Basin Ecological Overlay draft report provided by Tim Osting. The final is due on Monday, and he's trying to wrap up his edits.

Thanks.

- Ruben

>>> "Tim Osting" <tosting@espeyconsultants.com> 9/16/2009 10:50 AM >>>

1

Ruben,
I've not received a response from Mr. Huston except yesterday's auto-response below. Dr. Espey suggested possibly contacting Fred Manhart if you think it is necessary.

I've not received any specific comments from SAC. Except Weirsema discussed during the SAC meeting use of caution related to habitat suitability given regional differences; he used as an example temperature preferences developed from data in northern US states. To date, no comments affecting the final report have been provided to me.

Tim

-----Original Message-----
From: Robert Huston
Sent: Tuesday, September 15, 2009 10:51 AM
To: Tim Osting
Subject: Out of Office AutoReply: SB3 SAC San Jacinto River basin Ecological Overlay Draft for distribution

I am out of the office until Monday, September 21st. Should you need to contact me in case of emergency, please leave me a voice mail on my cell phone (512)913-4554. Thanks, Bob Huston

Sent via BlackBerry by AT&T

Species List - Fish
San Jacinto River

Scientific Name	Common Name	TPWD draft focal species list 2009-08-12	Ref. 1 TSU San Jacinto River Basin	Ref. 2 1997 % Abundance W. Fork San Jacinto River	Ref. 2 1997 % Abundance E. Fork San Jacinto River	Reference 3 USGS 1997-98 # Collected E. Fork San Jacinto River	Reference 3 USGS 1997-98 # Collected W. Fork San Jacinto River	Reference 3 USGS 1997-98 # Collected Garners Bayou	Reference 3 USGS 1997-98 # Collected Greens Bayou	Reference 3 USGS 1997-98 # Collected Buffalo Bayou	Reference 3 USGS 1997-98 # Collected Cedar Bayou	Reference 3 USGS 1997-98 # Collected Dickenson Bayou	Reference 3 USGS 1997-98 # Collected White Oak Bayou	Reference 3 USGS 1997-98 # Collected Luce Bayou	Ref. 4 1998 Upper Basin	Ref. 5 TPWD Rare Upper SJR Basin	Ref. 5 TPWD Rare Harris County	Ref. 6 1996 Lower San Jacinto Riber Basin	Ref. 7 2000 Upper San Jacinto River Basin	Ref. 8 69-72 San Jacinto - Lake Houston Subbasin	Ref.9 UT - TNHC San Jacinto River Basin pre-1940	Ref.9 UT - TNHC San Jacinto River Basin 1940-1972	Ref.9 UT - TNHC San Jacinto River Basin 1973+
Lepisosteidae																							
Atractosteus spatula	alligator gar		X																				
Lepisosteus oculatus	spotted gar	X	X			8	13	1	13	25	2	2			1			4		X		X	X
Lepisosteus osseus	longnose gar		X			2	1			14										X			
Lepisosteus platostomus	shortnose gar						13													X			
Petromyzontidae																							
Ichthyomyzon castaneus	chestnut lamprey																						X
Ichthyomyxon gagei	southern brook lamprey		X	0	8.5															X		X	X
Amiidae																							
Amia calva	bowfin		X		<0.1					2													X
Anguillidae																							
Anguilla rostrata	American eel		X													X	X						
Clupeidae																							
Alosa chrysochloris	skipjack herring		X																				
Brevoortia patronus	gulf menhaden																				X		
Dorosoma cepedianum	gizzard shad		X			17	186	2	3	658					5			3	1	X		X	X
Dorosoma petenense	threadfin shad		X				8			1								496		X			X
Engraulidae																							
Anchoa mitchilli	bay anchovy																	10					X
Cyprinidae																							
Carassius auratus	goldfish		X																				
Ctenopharyngodon idella	grass carp		X				2			3								3					X
Cyprinella lutrensis	red shiner		X	0.6	0.1	9	472	25	355	6	19		60								X	X	X
Cyprinella venusta	blacktail shiner		X	3.9	1.4	234	665				3			6	82			1	5			X	X
Cyprinus carpio	common carp		X				5		5	10			1					4		X			X
Hybognathus nuchalis	Mississippi silvery minnow		X																			X	
Hybognathus placitus	plains minnow		X																				
Hybopsis amnis	pallid shiner	X	X				1															X	X
Luxilus chrysocephalus	striped shiner		X																	X			

Species List - Fish
San Jacinto River

			Ref. 1	Ref. 2		Reference 3									Ref. 4	Ref. 5		Ref. 6	Ref. 7	Ref. 8	Ref.9		
			TSU	1997		USGS 1997-98									1998	TPWD		1996	2000	69-72	UT - TNHC		
				% Abundance		# Collected										Rare							
		TPWD draft focal species list 2009-08-12	San Jacinto River Basin	W. Fork San Jacinto River	E. Fork San Jacinto River	E. Fork San Jacinto River	W. Fork San Jacinto River	Garners Bayou	Greens Bayou	Buffalo Bayou	Cedar Bayou	Dickenson Bayou	White Oak Bayou	Luce Bayou	Upper Basin	Upper SJR Basin	Harris County	Lower San Jacinto Riber Basin	Upper San Jacinto River Basin	San Jacinto - Lake Houston Subbasin	San Jacinto River Basin pre-1940	San Jacinto River Basin 1940-1972	San Jacinto River Basin 1973+
Lythrurus fumeus	ribbon shiner	X	X	9.2	4.3														13	X		X	X
Lythrurus umbratilis	redfin shiner		X	1.3	4.3														1	X		X	X
Macrhybopsis aestivalis	speckled chub						1																
Macrhybopsis hyostoma	shoal chub		X																				
Notemigonus crysoleucas	golden shiner		X	0.4	0.1															X		X	X
Notropis amabilis	Texas shiner		X																	X			
Notropis atherinoides	emerald shiner																		8	x			X
Notropis atrocaudalis	blackspot shiner	X	X	3.9	4.9		4												33	X		X	X
Notropis blennius	river shiner					1																	
Notropis buchanani	ghost shiner		X																	X			
Notropis potteri	chub shiner		X																			X	
Notropis sabinae	Sabine shiner		X																	X			X
Notropis shumardi	silverband shiner		X																				
Notropis stramineus	sand shiner						8								10								
Notropis texanus	weed shiner		X																				
Notropis volucellus	mimic shiner		X	<0.1	0															X		X	X
Opsopoeodus emiliae	pugnose minnow		X	0.1	0.1	1	2													X	X	X	X
Phenacobius mirabilis	suckermouth minnow																			X			
Pimephales promelas	fathead minnow		X				1				3											X	
Pimephales vigilax	bullhead minnow		X	2.9	<0.1	85	851	52	117	207	29		365		96				53	X		X	X
Semotilus atromaculatus	creek chub		X																				
Catostomidae																							
Carpiodes carpio	river carpsucker		X			2	33													X		X	X
Cycleptus elongatus	blue sucker		X													XT							
Erimyzon oblongus	creek chubsucker	X	X	0.7 (I)	1.5 (I)											X T	X T		2	X		X	
Erimyzon sucetta	lake chubsucker		X	0.2	0															X		X	X
Ictiobus bubalus	smallmouth buffalo		X			1				5								6		X		X	
Minytrema melanops	spotted sucker		X	0.2	0.5		3				2									X		X	X
Moxostoma congestum	gray redhorse		X																				
Moxostoma poecilurum	blacktail redhorse	X	X	0	<0.1	43	11								9					X		X	X

Species List - Fish San Jacinto River			Ref. 1 TSU	Ref. 2 1997 % Abundance		Reference 3 USGS 1997-98 # Collected									Ref. 4 1998	Ref. 5 TPWD Rare		Ref. 6 1996	Ref. 7 2000	Ref. 8 69-72	Ref.9 UT - TNHC		
		TPWD draft focal species list 2009-08-12	San Jacinto River Basin	W. Fork San Jacinto River	E. Fork San Jacinto River	E. Fork San Jacinto River	W. Fork San Jacinto River	Garners Bayou	Greens Bayou	Buffalo Bayou	Cedar Bayou	Dickenson Bayou	White Oak Bayou	Luce Bayou	Upper Basin	Upper SJR Basin	Harris County	Lower San Jacinto Riber Basin	Upper San Jacinto River Basin	San Jacinto - Lake Houston Subbasin	San Jacinto River Basin pre-1940	San Jacinto River Basin 1940-1972	San Jacinto River Basin 1973+
Ictaluridae																							
Ameiurus melas	black bullhead		X	0.2	0.1		3												1	X		X	
Ameiurus natalis	yellow bullhead		X	1.6	3.6	4	6	3	1	4	4		2						38	X		X	X
Ictalurus furcatus	blue catfish		X			1				14								4		X			X
Ictalurus punctatus	channel catfish		X	<0.1	0.1	14	51		2	39	15				2			2		X		X	X
Noturus gyrinus	tadpole madtom		X	<0.1	0	6	33			1			2	1	2					X		X	X
Noturus nocturnus	freckled madtom	X	X	0.4	1.3	1	2								1					X		X	X
Pylodictis olivaris	flathead catfish	X	X			1	4				1							2		X		X	
Loricariidae																							
Pterygoplichthys disjunctivus	vermiculated sailfin catfish (I)																						X
Pterygoplichthys multiradiatus	plecostomus																						X
Esocidae																							
Esox americanus	redfin/grass pickerel		X	0.2	0.9	6	4							1					1	X		X	X
Salmonidae																							
Oncorhynchus mykiss	rainbow trout		X																				
Aphredoderidae																							
Aphredoderus sayanus	pirate perch		X	4.9	6.3	38	66			1				4	4			1	6			X	X
Mugilidae																							
Mugil curema	white mullet *																						X
Mugil cephalus	striped mullet		X					2	51	12	5							59			X	X	X
Atherinopsidae																							
Labidesthes sicculus	brook silverside		X				7								1			1	1 (I)	X		X	X
Menidia beryllina	inland silverside		X															7		X	X	X	X
Fundulidae																							
Adinia xenica	diamond killifish																					X	
Fundulus chrysotus	golden topminnow		X	<0.1	0		2												6	X		X	X
Fundulus blairae	western starhead topminnow		X																				X
Fundulus dispar	starhead topminnow																					X	X
Fundulus grandis	Gulf killifish		X															1		X	X	X	X
Fundulus notti	starhead topminnow																			X			

Species List - Fish San Jacinto River			Ref. 1 TSU	Ref. 2 1997 % Abundance		Reference 3 USGS 1997-98 # Collected									Ref. 4 1998	Ref. 5 TPWD Rare		Ref. 6 1996	Ref. 7 2000	Ref. 8 69-72	Ref.9 UT - TNHC		
		TPWD draft focal species list 2009-08-12	San Jacinto River Basin	W. Fork San Jacinto River	E. Fork San Jacinto River	E. Fork San Jacinto River	W. Fork San Jacinto River	Garners Bayou	Greens Bayou	Buffalo Bayou	Cedar Bayou	Dickenson Bayou	White Oak Bayou	Luce Bayou	Upper Basin	Upper SJR Basin	Harris County	Lower San Jacinto Riber Basin	Upper San Jacinto River Basin	San Jacinto - Lake Houston Subbasin	San Jacinto River Basin pre-1940	San Jacinto River Basin 1940-1972	San Jacinto River Basin 1973+
Fundulus notatus	blackstripe topminnow		X			62	100				1			1	9				34	X		X	X
Fundulus olivaceus	blackspotted topminnow		X	10.2	8.8															X		X	X
Fundulus pulvereus	bayou topminnow																					X	
Lucania parva	rainwater killifish		X																			X	
Poeciliidae																							
Gambusia affinis	western mosquitofish		X	37.7	33.4										12				296	X		X	X
Gambusia sp	mosquitofish					15	222	34	14	2	31	3	44	8									
Poecilia latipinna	sailfin molly		X				4	26	15				25									X	X
Cyprinodontidae																							
Cyprinodon variegatus	sheepshead minnow		X																	X		X	X
Moronidae																							
Morone chrysops	white bass		X				1											12		X			
Morone mississippiensis	yellow bass		X															1		X		X	
Morone saxatilis	striped bass		X				4																
Centrarchidae																							
Centrarchus macropterus	flier		X																	X		X	
Lepomis auritus	redbreast sunfish		X			7	25	4															
Lepomis cyanellus	green sunfish		X	0.8	1	11	104	10	5	4	2	4	34		2				3	X		X	X
Lepomis gulosus	warmouth		X	1.4	1.4	26	66	2		8	11	1	1	3	3				8	X		X	X
Lepomis humilis	orangespotted sunfish		X			4	15			203	1												
Lepomis macrochirus	bluegill		X	2.5	1.5	74	356	6	8	29	40		6	1	32			41	35	X		X	X
Lepomis marginatus	dollar sunfish		X	1	0.2	5													6	X		X	X
Lepomis megalotis	longear sunfish	X	X	9.1	6.8	344	1170	8	76	42	100	2	64	9	172			21	89	X		X	X
Lepomis microlophus	redear sunfish		X	<0.1	0		6								3					X		X	X
Lepomis miniatus	redspotted sunfish.		X																			X	X
Lepomis punctatus	spotted sunfish			2.2	2.6	5	6				2				1				11	X			
Lepomis symmetricus	bantam sunfish		X																	X		X	
Micropterus punctulatus	spotted bass		X	<0.1	<0.1		1													X		X	X
Micropterus salmoides	largemouth bass	X	X	0.8	0.3	20	163		12	14	4		23		15			30		X		X	X
Pomoxis annularis	white crappie		X	<0.1	0	2	34			3								15	1	X		X	X

Species List - Fish San Jacinto River			Ref. 1 TSU	Ref. 2 1997 % Abundance		Reference 3 USGS 1997-98 # Collected									Ref. 4 1998	Ref. 5 TPWD Rare		Ref. 6 1996	Ref. 7 2000	Ref. 8 69-72	Ref.9 UT - TNHC		
		TPWD draft focal species list 2009-08-12	San Jacinto River Basin	W. Fork San Jacinto River	E. Fork San Jacinto River	E. Fork San Jacinto River	W. Fork San Jacinto River	Garners Bayou	Greens Bayou	Buffalo Bayou	Cedar Bayou	Dickenson Bayou	White Oak Bayou	Luce Bayou	Upper Basin	Upper SJR Basin	Harris County	Lower San Jacinto Riber Basin	Upper San Jacinto River Basin	San Jacinto - Lake Houston Subbasin	San Jacinto River Basin pre-1940	San Jacinto River Basin 1940-1972	San Jacinto River Basin 1973+
Pomoxis nigromaculatus	black crappie		X			1												11		X		X	X
Percidae																							
Ammocrypta vivax	scaly sand darter		X																	X		X	X
Etheostoma chlorosoma	bluntnose darter		X	0.8	1		4													X		X	X
Etheostoma gracile	slough darter		X	0.6	0.8		1				2								1	X		X	X
Etheostoma parvipinne	goldstripe darter	X	X	1.4	0.4														6 (I)	X		X	
Etheostoma proeliare	cypress darter		X																			X	
Etheostoma spectabile	orangethroat darter		X																				
Percina caprodes	logperch																			X		X	X
Percina macrolepida	bigscale logperch		X				15															X	X
Percina maculata	blackside darter																						X
Percina sciera	dusky darter	X	X	0.3 (I)	1.2 (I)	38	46								20					X		X	X
Sciaenidae																							
Aplodinotus grunniens	freshwater drum	X	X	0	<0.1	8	18			1					1					X		X	X
Cynoscion nebulosus	spotted sea trout *																				X		
Leiostomus xanthurus	spot *																					X	X
Micropogonias undulatus	atlantic croaker																	1				X	
Elassomatidae																							
Elassoma zonatum	banded pygmy sunfish		X	0.4	2.6	1														X		X	X
Cichlidae																							
Cichlasoma cyanoguttatum	Rio Grande cichlid		X					9	7				8										X
Oreochromis aureus	blue tilapia (introduced)																						X
Eleotridae																							
Dormitator maculatus	pacific sleeper																					X	X

(1) Freshwater Fishes of the San Jacinto River Drainage
Texas Freshwater Fishes, Department of Biology,

Species List - Fish San Jacinto River		Ref. 1	Ref. 2		Reference 3									Ref. 4	Ref. 5		Ref. 6	Ref. 7	Ref. 8	Ref.9		
		TSU	1997		USGS 1997-98									1998	TPWD		1996	2000	69-72	UT - TNHC		
			% Abundance		# Collected										Rare							
	TPWD draft focal species list 2009-08-12	San Jacinto River Basin	W. Fork San Jacinto River	E. Fork San Jacinto River	E. Fork San Jacinto River	W. Fork San Jacinto River	Garners Bayou	Greens Bayou	Buffalo Bayou	Cedar Bayou	Dickenson Bayou	White Oak Bayou	Luce Bayou	Upper Basin	Upper SJR Basin	Harris County	Lower San Jacinto Riber Basin	Upper San Jacinto River Basin	San Jacinto - Lake Houston Subbasin	San Jacinto River Basin pre-1940	San Jacinto River Basin 1940-1972	San Jacinto River Basin 1973+

Texas State University
(http://www.bio.txstate.edu/~tbonner/txfishes/)

(2) Spatial Variation of Headwater Fish Assemblages Explained by Hydrologic Variabiity and Upstream Effects of Impoundment.
Matthew E. Herbert and Frances P. Gelwick. Copeia, 2003, pp. 273-284.
(I) Intolerant
During 1997, fishes were sampled quarterly as follows: 8 February to 2 March, 30 April to 3 June, 11 August to 22 August, and 5 Noverber to 23 November. Sampling periods were during seasonal baseflow to avoid short-term displacement of fishes furing spates (Paloumpis, 1958) and for greater efficiency and consistency of effort. For West Fork streams directly entering Lake Conroe, sites were sufficiently upstream such that flowing stream conditons were present throughout the site.
Study sites were on first to fourth order streams of the East (9 sites) and West Forks (12 sites) and were typical of sandy, coastal streams in the southeastern United States (Felley, 1992). All sites were within the Sam Houston National Forest,and land cover was predominantly loblolly pine (Pinus taeda).

(3) Fish, Benthic Macroinvertebrate, and Stream Habitat Data From the Houston-Galveston Area Council Service Area, Texas, 1997-98
Moring, Bruce, et al. 1998. USGS Report 98-658
(http://pubs.usgs.gov/of/1998/ofr98-658/)
West Fork SJR includes: Spring Cr., Lake Cr., Panther Cr., Sandy Cr., Willow Cr., Walnut Cr., Cypress Cr.
East Fork SJR includes: Caney Cr., Spring Branch Cr.

(4) A Study of Freshwater Mussels (Pelecypoda: Unionidae), Fish, and Associsted Ecological Factors in Lake Creek, Montgomery County, Texas
Stephen P. Ansley, 1998 Thesis, Southwest Texas State University
COPYRIGHT 1998
Site 1 - 1.5 km north of the junction of FM 1488 and FM 2978 at

Species List - Fish San Jacinto River	TPWD draft focal species list 2009-08-12	Ref. 1	Ref. 2		Reference 3									Ref. 4	Ref. 5		Ref. 6	Ref. 7	Ref. 8	Ref.9		
		TSU	1997		USGS 1997-98									1998	TPWD		1996	2000	69-72	UT - TNHC		
			% Abundance		# Collected										Rare							
		San Jacinto River Basin	W. Fork San Jacinto River	E. Fork San Jacinto River	E. Fork San Jacinto River	W. Fork San Jacinto River	Garners Bayou	Greens Bayou	Buffalo Bayou	Cedar Bayou	Dickenson Bayou	White Oak Bayou	Luce Bayou	Upper Basin	Upper SJR Basin	Harris County	Lower San Jacinto Riber Basin	Upper San Jacinto River Basin	San Jacinto - Lake Houston Subbasin	San Jacinto River Basin pre-1940	San Jacinto River Basin 1940-1972	San Jacinto River Basin 1973+

N 30 09' 07.6" latitude and W 95 20' 49.4" longitude

Site 2 - 2.7 km north of the junction of FM 1488 and FM 149 at
N 30 09' 53.2" latitude and W 95 25' 18.7" longitude

(5) Texas Parks and Wildlife Dept. Annotated County Lists of Rare Species
Last Revision 5/4/2009 5:54:00 PM
http://gis.tpwd.state.tx.us/TpwEndangeredSpecies/DesktopDefault.aspx
X - Species Present
T - Species on the Texas Threatened List

(6) Fish Populations in the Major Tributaries of the Houston Ship Channel.
Segments 1001. 1006' 1007' 1013' 1017
Mark Luedke, June 1994. Texas Natural Resource Conservation Commission
The San Jacinto River was surveyed at two sites, Banana Bend and HWY 90. The Banana Bend and HWY 90 sites are 12.2 and 15.3 miles, respectively, upstream from the mouth of the San Jacinto River. Both sampling sites are in Segment 1001. Little or no water flows over the Lake Houston dam during critical low flow conditions, so the Jan Jacinto River above the dam has not been considered part of the Houston Ship Channel System (Kirkpatrick 1987). The average flow near the sites surveyed was not determined by the USGS because of tidal influences.

(7) The effects of Timber Harvesting on Stream Water Quality in the Sam Houston National Forest: A Physicochemical, Benthic Macroinvertebrate, and Fish Analysis.
Charles Dewey Stoffels, Stephen F. Austin State University, August 2000
(I) - Intolerant

(8) A Study of Aquatic Quality and Soci-Economic Uses of San Jacinto River Watershed
Sam Houston State University. Huntsville, Texas 1973. Under NSF Grant GY-10760
The Study area was the San Jacinto Watershed, Lake Houston Subbasin from May 14, 1973 to August 3, 1973.

(9) DRAFT Hendrickson spreadsheet Trinity&SanJacinto_forGeorgeGuillen.xls