Colorado and Lavaca Rivers and Matagorda and Lavaca Bays Basin and Bay Expert Science Team

Environmental Flow Regime Recommendations Report

Final Submission to the Colorado and Lavaca Rivers and Matagorda and Lavaca Bays Basin and Bay Area Stakeholder Committee, Environmental Flows Advisory Group, and Texas Commission on Environmental Quality

March 1, 2011

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Colorado and Lavaca Rivers and Matagorda and Lavaca Bays

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March 2011

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

Patrick Brzozowski, Chairman,
Colorado and Lavaca Rivers and Matagorda and Lavaca Bays Basin and Bay Area Stakeholder Committee

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

For your consideration, the Colorado and Lavaca Rivers and Matagorda and Lavaca Bays Basin and Bay Expert Science Team (Colorado-Lavaca BBEST) hereby submits its final report pursuant to its charge under Senate Bill 3 (89th R, 2007), including environmental flow recommendations with rationales. The Colorado-Lavaca BBEST members have reached consensus on the presentation of the recommendations submitted in this document.

Respectfully submitted,

Dave Buzan

David Buzan

Colorado-Lavaca Bay/Basin Expert Science Team. 2011. Environmental Flow Regime Recommendations Report. Produced by the Colorado and Lavaca Rivers and Matagorda and Lavaca Bays Basin and Bay Expert Science Team for the Colorado and Lavaca Rivers and Matagorda and Lavaca Bays Basin and Bay Stakeholder Committee. Austin, TX. 497 p. http://www.tceq.texas.gov/permitting/water_supply/water_rights/eflows/colorado-lavaca-bbsc.

This report was edited for style and formatted by the Texas Water Resources Institute.

Environmental Flow Regime Recommendations

Road Map to the Report

Healthy aquatic ecosystems require variability in flow (Section 1). The Colorado-Lavaca Basin and Bay Expert Science Team reached consensus on environmental flow regime at 21 stream sites in the Colorado and Lavaca River basins in January 2011 (Section 1). The BBEST considered all available scientific data in formulating these recommendations. Recent, detailed scientifically accepted studies had developed environmental flow regimes at some sites selected for evaluation by the BBEST. After thorough review and discussion, those recommendations were adopted by the BBEST.

Intense BBEST review of historic flows, aerial photography, soils, riparian vegetation, wetlands, water quality, and biology identified relationships between flow and aquatic ecology for the remaining water bodies (Section. 2). Rapid assessments of fish habitat-flow relationships based on channel measurements and fish biology were conducted for selected sites (Section 3.7). Relationships between flow and stream channel maintenance were evaluated at 3 representative sites (Section 3.10).

Historic flows were analyzed using HEFR (Hydrology-based Environmental Flow Regime) to create draft environmental flow regimes (Sections 3.1-3.6). Review of rapid assessment based habitat-flow relationships and other information showed preliminary HEFR flows vary in amounts and over seasons that support a sound ecological environment. Environmental flow regimes for streams were compared to flow regimes for estuaries to ensure they were compatible (Section 4). Based on their review of available data, the BBEST concluded it was appropriateto use HEFR flows to build the BBEST's recommended environmental flow regimes.

Preliminary modeling evaluated relationships between environmental flow regimes and possible future water availability (Section 5). Suggestions were developed to guide implementation of these environmental flow regimes (Section 6). Future work was identified to support the evaluation of the recommended environmental flow regimes in these basins (Section 7). Results of the BBEST analyses and recommendations were published and provided to the Colorado-Lavaca Bay/Basin stakeholders and the TCEQ on March 1, 2011.

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Acronyms

ac-ft – acre-feet (volume of water equal to an acre covered to a depth of 1 foot)

BBASC

BBEST

CCM – Comparative Cross Section Methodology

cfs – cubic feet per second

EMB – East Matagorda Bay

ENSO – El Nino/Southern Oscillation

EPA – U. S. Environmental Protection Agency

FINS – Freshwater Inflow Needs Study

fps – feet per second

GIWW – Gulf Intracoastal Water Way

HECRAS – Hydrologic Engineering Centers River Analysis System

HEFR – Hydrology-Based Environmental Flow Regime

HSC – Habitat Suitability Criteria

LCRA – Lower Colorado River Authority

LSWP – LCRA-San Antonio Water System Project

MBHE – Matagorda Bay Health Evaluation (Section 2.7)

NRCS – Natural Resources Conservation Service

NWS – National Weather Service

PDO – Pacific Decadal Oscillation

ppt – parts per thousand, a measure of salinity. Ex. 1 ppt means 1 part salt in 1,000 parts water

SAC – Texas Environmental Flows Science Advisory Committee

SB2 – Senate Bill 2

SB3 – Senate Bill 3

TCEQ – Texas Commission on Environmental Quality

TESCP – Texas Ecological Systems Classification Program (Section 3.8)

TIFP – Texas Instream Flow Program

TPWD – Texas Parks and Wildlife Department

TWDB – Texas Water Development Board

TxRR – Texas Rainfall-Runoff model

USFWS – United States Fish and Wildlife Service

USGS – United States Geological Survey

WAM – Water Availability Model

WUA – Weighted useable area

Technical Terminology

Facultative (wet) – Plants that usually occur in wetlands, sometimes found outside of wetlands

Focal species – Focus of the biological overlays. Species that, when their ecological requirements are met, will provide broad protection for most biological components of the ecosystem

Guilds – A group of species (or habitat) containing similar characteristics

Habitat Suitability Criteria – refers to a relationship that quantifies how 'suitable' a range of depths, velocities, or substrates are for some target organism

Microhabitat – In rivers it refers to the small scale differences in depth, velocity, cover or substrate

Mesohabitat – In rivers it refers to geomorphic level units such as pools, rapids, and runs

Mussel – freshwater clam

Obligate (wet) – plants that are almost always found in wetlands

Palustrine – freshwater marsh

Pool – a part of the stream that is deeper than other parts of the stream and where the water is not visibly flowing downstream

Regulated Flow – those flows output by the WAM which would be physically present at a location if viewed in the real world. WAM regulated flows are comprised of the inflows already allocated to downstream water rights or instream flow requirements, any remaining portion of the inflows that are still available for appropriation and reservoir releases traveling to downstream diversion points or to meet instream flow requirements. WAM regulated flows are used as a basis for evaluating instream flow compliance with the BBEST recommended flow regimes.

Riffle – a fast flowing part of the stream where rippled waves are formed

Riparian zone – vegetated area on each bank of a stream

Run – a part of the stream that is deeper than a riffle, with water visibly flowing without forming rippled waves

TxBlend – Hydrodynamic model used by the TWDB to predict flow patterns and salinity in bays.

TxRR – Model used by the TWDB to calculate the volume of rainfall that flows off a watershed. Used to calculate flows from areas that do not have USGS flow gages.

WAM – The TCEQ Water Availability Modeling System is comprised of generalized computer modeling software, input files representing a specific level of surface water right utilization for each river basin in Texas, geospatial data for each river basin, and other relevant data base files. WAMs are used to simulate the priority-order based allocation of surface water by water rights through a repetition of a period of naturalized hydrology.

Weighted useable area – refers to an amount of available habitat that is weighted by how suitable it is for a target organism based on the attributes of the habitat

1. Introduction

1.1 Colorado-Lavaca BBEST

In accordance with Senate Bill 3 (SB 3), the Colorado-Lavaca BBASC (TCEQ 2010a) appointed ten members to serve on the Colorado-Lavaca BBEST. The official name of the science team includes only the Colorado and Lavaca rivers. However, the science team's area of study also included the drainages for the Navidad River, Tres Palacios Creek, and Garcitas Creek. Hereafter, the Colorada-Lavaca BBEST will be referred to as the BBEST. The names and professional affiliations of the BBEST members are listed in the Table 1.1.

In addition to the appointed BBEST members, the TCEQ, TPWD, and TWDB provided agency staff to support the BBEST's activities and research. The BBEST members wish to acknowledge the effort and considerable support provided by the state agency staff members. Their contributions were vital to the data collection and scientific analyses presented in this report. In addition to the state agency staff, the BBEST members wish to acknowledge members of the BBASC, SAC, NGOs, and the public who attended the BBEST meetings and offered helpful advice and insights that contributed to the development of this report.

Table 1.1 BBEST Members

BBEST Member	Professional Affiliation
David Buzan Chair	PBS&J
Bryan P. Cook Vice Chair	Lower Colorado River Authority
Melissa M. Fontenot	BIO-WEST, Inc.
Thom Hardy, Ph.D.	Texas State University
Richard J. Hoffpauir, Ph.D.	Richard Hoffpauir Consulting
Kirk Kennedy, P.G.	Kennedy Resource Company
Okla W. Thornton, Jr.	Colorado River Municipal Water District
Joseph F. Trungale, P.E.	Trungale Engineering & Science
Catherine Wakefield	Wharton County Junior College
Steven P. Watters, P.W.S	Freese and Nichols, Inc.

The first meeting of the BBEST was held in conjunction with a meeting of the BBASC on March 31, 2010. Thereafter, the BBEST held public meetings monthly through February, 2011. BBEST meetings were held in Austin, Texas, primarily at the headquarters of the Lower Colorado River Authority. In addition to meetings of the entire BBEST, several smaller workgroups of BBEST members met as needed to study specific aspects of the environmental flow analysis. BBEST members coordinated a field trip to gather data in the upper reaches of the Colorado River Basin, a meeting of riparian ecologists to obtain guidance on evaluating relationships between flow and riparian vegetation, and a meeting of experts on Matagorda and Lavaca bays to gather information about bay health. Some BBEST members also participated in a stream cross-section and sediment survey at BBEST-selected sites sponsored by the TWDB.

1.2 Sound Ecological Environment

SB 3 defines an environmental flow regime as:

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

SB 3 does not define a sound ecological environment. However, SAC guidance (SAC 2009a) identifies the characteristics expected of a sound ecological environment and the instream and freshwater inflow components of an environmental flow regime that support these characteristics. The BBEST reached consensus on the following description of the state of the riverine, riparian, and estuarine environments in the river basins that are the focus of this report. The BBEST also reached consensus on the components of the environmental flow regime that will maintain a sound ecological environment in these basins.

Streams and estuaries in the Colorado, Lavaca and Navidad river basins have changed in a variety of ways for the past 100 years. Causes of those changes have been natural and man-made. Precipitation patterns extended drought periods at times and high flow periods during other times. Manmade changes include reservoir construction, diversions, wastewater and irrigation return flows, increased impervious cover, and livestock grazing. Man-made changes have also included introduction of invasive species like grass carp, Asian clam, and saltcedar. Although effects of these changes on aquatic ecosystems may vary between systems, it is reasonable to say all water bodies selected for analysis by the BBEST have been affected to some degree.

However, the BBEST has reviewed data for these water bodies and believes they have acceptably sound ecological environments in terms of flow regimes. In this context, an acceptably sound ecological environment has flow regimes that support existing biological communities in rivers, riparian, bay and estuary habitats. The BBEST did not find information indicating human modifications of flow regimes had substantially degraded these biological communities.

There are many definitions of sound ecological environment. All definitions involve subjective interpretation of both language and intent. The flow regimes developed by the BBEST are intended to support an acceptably sound ecological environment by:

- Providing seasonally varying flows that mimic, to the extent practical, natural flow regimes
- Supporting the existing variety of habitats
- Supporting existing longitudinal and floodplain connectivity to support aquatic and flow-dependent riparian communities
- Maintaining aquatic life uses designated in the Texas Surface Water Quality Standards,
- Providing a flow regime that maintains the existing dynamic equilibrium of erosion, transport, and deposition of sediments in upland river and stream channels and maintains sediment delivery to coastal wetlands and deltas

1.3 Flow Regime Components

Natural flow regimes are a response to rainfall-runoff events over undisturbed lands and riparian connections. As such, statistical measures of the hydrographs of natural flow regimes will reveal variability in stream flow over time. The variability of a natural flow regime may be characterized by stream flow magnitude and flow event frequency, duration and rate of change. Stream flow variability of a natural flow regime supports riverine and estuarine ecosystem function from biological, chemical and structural perspectives.

Some segments of the Colorado, Lavaca and Navidad river basins do not exhibit characteristics of a purely natural flow regime. Land use and riparian development, as described in section 1.2, have contributed to changes in the response of stream flow to rainfall-runoff events. However, the BBEST recognized that the existing riverine and estuarine environments are ecologically sound. As such, the BBEST chose to develop environmental flow regimes that support the existing flow variability and the existing variety of ecological needs for water.

Senate Bill 2 of the 77th Texas Legislature, enacted in 2001, created the TIFP. The TIFP is a joint effort of TCEQ, TPWD and TWDB with the purpose to "perform scientific and engineering studies to determine flow conditions necessary to support a sound ecological environment in the river basins of Texas" (TWDB, 2008a). The TIFP identified 4 basic instream flow components that support a sound ecological environment. Those flow components are provided in Table 1.2. The BBEST adopted the same flow components for its instream flow regime recommendations. In addition to the flow components identified by the TIFP, the BBEST identified 2 other flow components for inclusion in the flow regime for each stream. Additional detail on the BBEST's quantification of the instream flow components is provided in section 3.3 of this report. Estuarine flow components are described separately in section 2.6 – 2.8.

Table 1.2 Example components of an instream flow regime and supported processes. (Reproduced from TWDB, 2008a with additions by the BBEST)

Component	Hydrology	Geomorphology	Biology	Water quality
No-flow periods	Flow ceases between perennial pools		Generally stressful for fish communities but may provide opportunities for certain macroinvertebrates, reptiles and amphibians to increase population sizes.	Temperatures rise and oxygen levels decrease. These conditions sometimes cause fish kills.
Subsistence flows	Infrequent, low flows	Increase deposition of fine and organic particles	Provide restricted aquatic habitat; limit connectivity	Elevate temperature and constituent concentrations Maintain adequate levels of dissolved oxygen
Base flows	Average flow conditions, including variability	Maintain soil moisture and groundwater table Maintain a diversity of habitats	Provide suitable aquatic habitat, Provide connectivity along channel corridor	Provide suitable in-channel water quality
High flow pulses	In-channel, short duration, high flows	Maintain channel and substrate characteristics; Prevent encroachment of riparian vegetation	Serve as recruitment events for organisms; Provide connectivity to near-channel water bodies	Restore in-channel water quality after prolonged low flow periods
Overbank flows	Infrequent, high flows that exceed the channel	Provide lateral channel movement and floodplain maintenance; Recharge floodplain water table; Form new habitats; Flush organic material into channel; Deposit nutrients in floodplain	Provide new life phase cues for organisms; Maintain diversity of riparian vegetation; Provide conditions for seedling development; Provide connectivity to floodplain	Restore water quality in floodplain water bodies
Channel Maintenance	For most streams, channel maintenance occurs mostly during pulse and overbank flows	Long-term maintenance of existing channel morphology	Maintains foundation for physical habitat features in stream	Water quality conditions like those during pulse and overbank flows

1.3.1. No-flow periods

Streams in the more arid reaches of the upper Colorado River basin and some streams with relatively small watersheds experience periods without flow. Although these streams may experience periods with no flow, the information reviewed indicates these streams maintain perennial pools with characteristic aquatic communities. It is expected that reductions in flow that create more frequent or longer periods of no-flow would negatively affect the ecological condition of these streams and might threaten the existence of some perennial pools during dry conditions.

1.3.2. Subsistence Flows

Subsistence flow is the lowest flow magnitude in the recommended flow regime of the BBEST. Natural hydrologic variability may reduce flows occasionally below the subsistence magnitude, however. Subsistence flows are considered a minimum threshold for maintaining adequate water quality and limited habitat. Extended periods of subsistence flow or successive periods of subsistence flow may impair or interrupt the typical ecological functions of a riverine or estuarine system.

1.3.3 Base Flows

The term base flow in this report refers to flow magnitudes above the subsistence flow level and typically below the lowest magnitude within the high flow pulse categories. Unlike traditional definitions of base flow which link these flows to periods between storms or ground water contribution, the BBEST recommendations for base flows are based on flow magnitudes that support a specific range within the spectrum of ecological functions. In that sense, the base flow recommendations in this report may be more specifically referred to as ecological base flows. Rainfall-runoff timing or sources of contribution are not considered.

In the broadest context, base flows provide for the average or typical ecological functions in the riparian environment. Variability within the average or typical spectrum of ecological function is expected in a sound ecological environment. Base flows characteristic of dry periods maintain and provide for greater abundance of riffle and shallow run habitat that connect shallow pools. Base flows characteristic of above average rainfall will favor habitats such as deep pools and fast runs. Due to expected natural variability within the range of average flow conditions that allows for a variety of habitat, the BBEST recommends three levels of base flow within the flow regimes that support a sound ecological environment.

1.3.4 High Flow Pulse Events

High flow pulses are episodic events of flow usually above the highest base flow magnitude. The terms pulse flow, pulse and pulse event are used interchangeably within this report to refer to high flow pulses. The terms seasonal pulse or annual pulse are used when referring to a specific return period for the respective pulse flow events. Unless otherwise indicated, the more generalized use of high flow pulse may refer to either seasonally or annually recurring high flow pulses.

High flow pulses are a direct result of stream flow response to rainfall runoff events and typically last less than a month. While base flow conditions can persist for many weeks or an entire season, pulse flows typically occur as discrete events marked by a rapid rise in stream flow rate followed by a gradual decline in stream flow rate over days or weeks as base flow conditions are reestablished.

High flow pulses provide a variety of important ecological functions. Water surface elevation may increase during a pulse flow event sufficient to connect the main stream channel to portions of the riparian zone or floodplain that are typically inaccessible during base flow conditions, such as back-waters and oxbows. Main stream connectivity to off-channel habitat allows aquatic organisms to move in and out of those habitats. Normal cueing of the reproductive cycle of aquatic organisms may be dependent on the seasonal timing and magnitude of pulse flow events. Riparian vegetation may benefit from pulse flow events via seed germination and transportation. Sediment movement from channel substrate increases with stream velocity. Increased water surface elevation allows greater wetted perimeter and potential for sediment transport from those portions of the riparian zone that are typically inaccessible due to location or vegetative coverage.

In order to provide variability of ecological functions, the BBEST is recommending up to 5 levels of pulse flow events. The pulse flow event recommendations are categorized as either seasonal events or annual events. Seasonal events are smaller in magnitude, duration and total volume than the annual events but are recommended to occur more frequently. Seasonal events provide flows to support a broad range of biological functions. Geomorphic functions may also be supported by seasonal pulse recommendations. Annual events may occur at any time of the year and are larger than seasonal pulses in terms of magnitude, duration and total volume. Annual pulse events may cross over into the category of overbank flows. As pulse flow event recommendations increase in terms of magnitude, duration and total volume, the ecological function may shift from biological to geomorphic depending on the site specific structure of the channel and the biological community present.

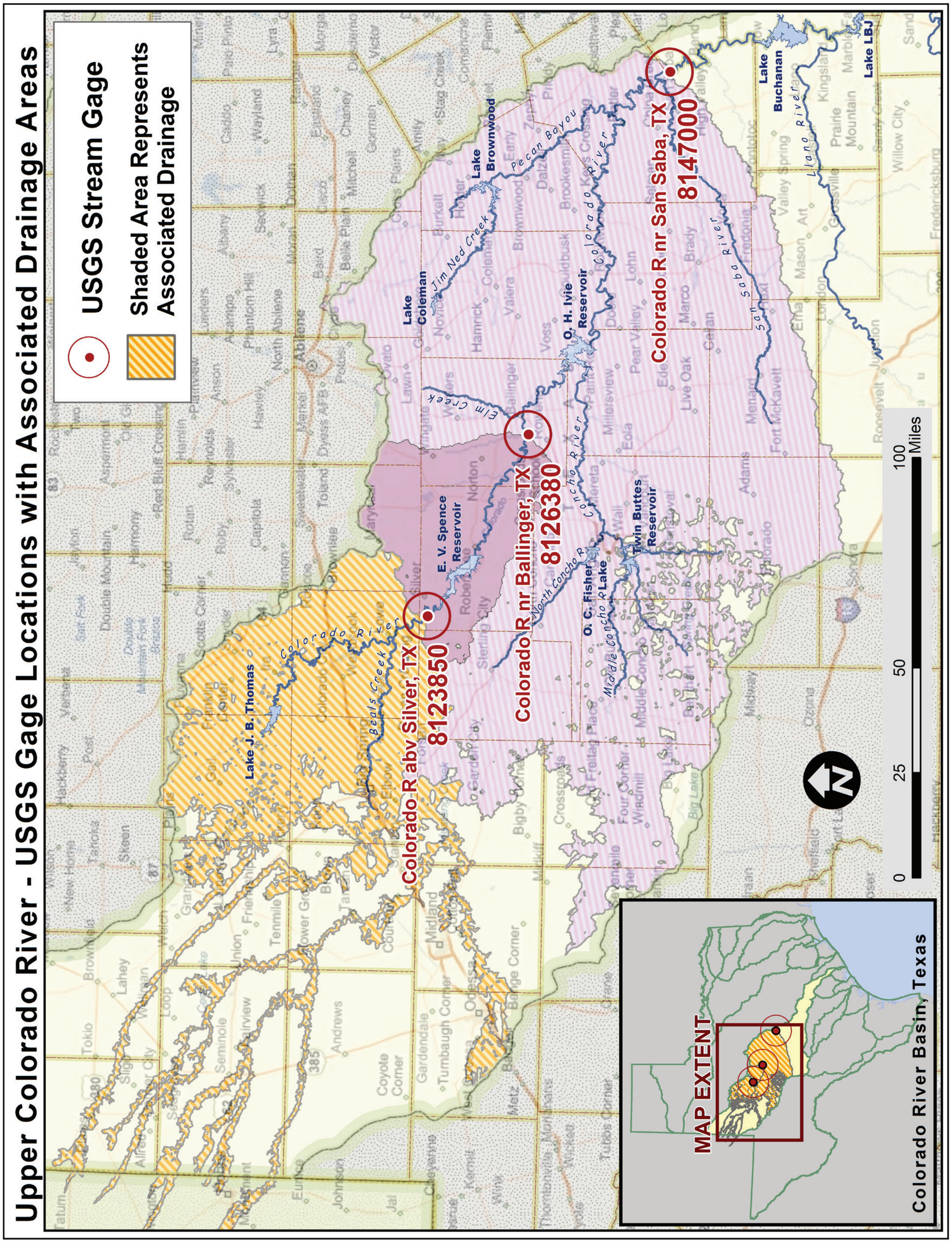
1.3.5 Overbank Flow Events

Overbank flows are defined by the BBEST as those rates of flow which result in water surface elevations which exceed the NWS flood stage. Overbanking events are less common than high pulse flow events, yet are expected to provide ecological functions that support a sound ecological environment such as clearing large or accumulated in-channel debris, allowing access to the flood plain for organisms and seeds, and providing energy for the upper range of geomorphic activity. Root systems in the off channel riparian zone are also directly connected to the water table during overbanking events as the stream surface rises over the flood plain. This periodic flooding fosters growth of facultative and obligate wetland plants living in the riparian zone and floodplain while at the same time controlling invasive dry land species. In the recommended flow regimes for each location, the high flow pulse recommendations which may result in water surface elevations in excess of the NWS flood stage are indicated as overbank flows.

1.3.6 Channel Maintenance Flow Events

Flows which move sediment and maintain existing channel morphology are typically high pulse and overbank flows. A flow regime that replicates the magnitudes and variability of the historic flow regime is most likely to maintain a channel in dynamic equilibrium. Review of flow regimes developed from historic hydrology as in this case has indicated that the developed flow regime usually does not capture enough of the flow in the historic flow regime to ensure maintenance of the existing channel. Although not quantified at this point in time, any substantial reduction in the existing long-term flow magnitude and duration may cause loss of existing channel morphology.

1.4 Recommended Environmental Flow Regimes



Colorado River above Silver, USGS Gage 08123850, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1957-2009	7 periods Max duration: 31 days	45 periods Max duration: 110 days	35 periods Max duration: 56 days	16 periods Max duration: 70 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	2 cfs	2 cfs	1 cfs	1 cfs
Base Medium	4 cfs	5 cfs	3 cfs	4 cfs
Base High	7 cfs	12 cfs	8 cfs	10 cfs
2 Pulses per season	Trigger: 18 cfs Volume: 120 af Duration: 11 days	Trigger: 600 cfs Volume: 2,500 af Duration: 9 days	Trigger: 100 cfs Volume: 350 af Duration: 6 days	Trigger: 100 cfs Volume: 400 af Duration: 6 days
1 Pulse per season	Trigger: 42 cfs Volume: 300 af Duration: 15 days	Trigger: 1,800 cfs Volume: 7,900 af Duration: 11 days	Trigger: 330 cfs Volume: 1,400 af Duration: 9 days	Trigger: 430 cfs Volume: 1,800 af Duration: 9 days
1 Pulse per year	Trigger: 3,000 cfs Volume: 13,600 af Duration: 17 days			
1 Pulse per 2 years	Trigger: 4,500 cfs Volume: 20,400 af Duration: 18 days			
1 Pulse per 5 years (Overbank)	Trigger: 8,100 cfs Volume: 36,700 af Duration: 21 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

af = acre-feet

Colorado River near Ballinger, USGS Gage 08126380, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1908-2009	14 periods Max duration: 86 days	41 periods Max duration: 83 days	32 periods Max duration: 107 days	13 periods Max duration: 69 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	4 cfs	3 cfs	2 cfs	4 cfs
Base Medium	9 cfs	9 cfs	6 cfs	9 cfs
Base High	14 cfs	19 cfs	14 cfs	17 cfs
2 Pulses per season	Trigger: 27 cfs Volume: 180 af Duration: 11 days	Trigger: 1,300 cfs Volume: 5,300 af Duration: 9 days	Trigger: 130 cfs Volume: 490 af Duration: 6 days	Trigger: 250 cfs Volume: 950 af Duration: 8 days
1 Pulse per season	Trigger: 96 cfs Volume: 660 af Duration: 17 days	Trigger: 3,200 cfs Volume: 13,700 af Duration: 10 days	Trigger: 630 cfs Volume: 2,600 af Duration: 9 days	Trigger: 1,500 cfs Volume: 5,700 af Duration: 10 days
1 Pulse per year	Trigger: 4,500 cfs Volume: 18,300 af Duration: 13 days			
1 Pulse per 2 years (Overbank)	Trigger: 7,400 cfs Volume: 29,800 af Duration: 14 days			
1 Pulse per 5 years (Overbank)	Trigger: 12,300 cfs Volume: 49,000 af Duration: 15 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			
cfs = cubic feet per second af = acre-feet				

Colorado River near San Saba,USGS Gage 08147000, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1923-2009	0 periods Max duration: 0 days	0 periods Max duration: 0 days	4 periods Max duration: 24 days	0 periods Max duration: 0 days
Subsistence	50 cfs	50 cfs	30 cfs	30 cfs
Base Low	95 cfs	120 cfs	72 cfs	95 cfs
Base Medium	150 cfs	190 cfs	120 cfs	150 cfs
Base High	210 cfs	360 cfs	210 cfs	210 cfs
2 Pulses per season	Trigger: 520 cfs Volume: 3,100 af Duration: 9 days	Trigger: 5,800 cfs Volume: 31,300 af Duration: 9 days	Trigger: 510 cfs Volume: 1,900 af Duration: 4 days	Trigger: 890 cfs Volume: 3,500 af Duration: 6 days
1 Pulse per season	Trigger: 1,600 cfs Volume: 11,100 af Duration: 15 days	Trigger: 11,000 cfs Volume: 70,200 af Duration: 13 days	Trigger: 1,400 cfs Volume: 6,500 af Duration: 7 days	Trigger: 3,800 cfs Volume: 19,200 af Duration: 12 days
1 Pulse per year	Trigger: 18,900 cfs Volume: 129,100 af Duration: 23 days			
1 Pulse per 2 years	Trigger: 30,400 cfs Volume: 222,200 af Duration: 28 days			
1 Pulse per 5 years	Trigger: 39,600 cfs Volume: 300,500 af Duration: 31 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
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cfs = cubic feet per second

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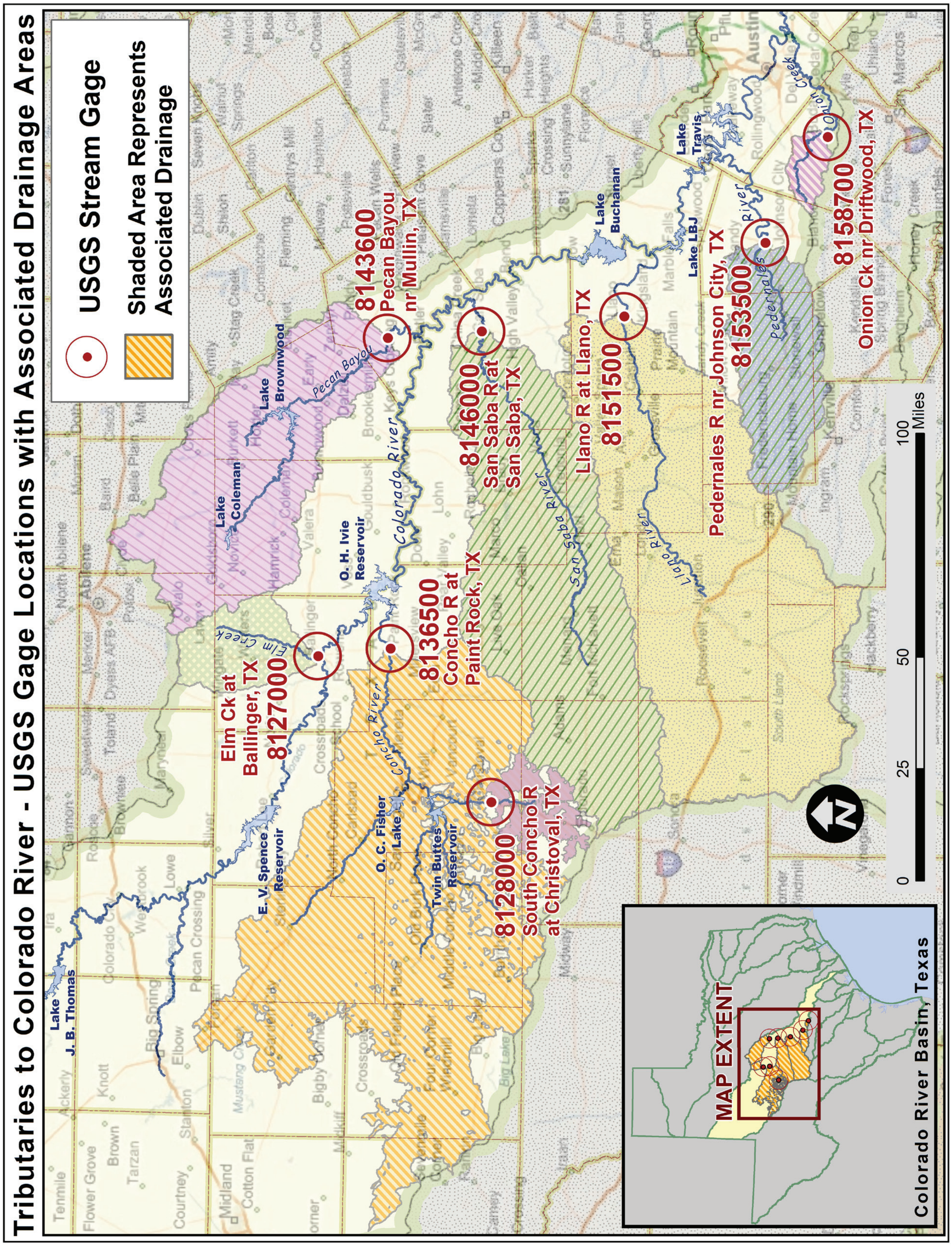

Tributaries to Colorado River - USGS Gage Locations with Associated Drainage Areas
USGS Stream Gage
Shaded Area Represents Associated Drainage
8128000 South Concho R at Christoval, TX
Elm Ck at Ballinger, TX 8127000
8136500 Concho R at Paint Rock, TX
8146000 San Saba R at San Saba, TX
8143600 Pecan Bayou nr Mullin, TX
Llano R at Llano, TX 8151500
Pedernales R nr Johnson City, TX 8153500
8158700 Onion Ck nr Driftwood, TX
Lake J. B. Thomas
E. V. Spence Reservoir
O. C. Fisher Lake
Twin Buttes Reservoir
O. H. Ivie Reservoir
Lake Coleman
Lake Brownwood
Lake Buchanan
Lake LBJ
Lake Travis
Colorado River
Concho River
Elm Creek
Pecan Bayou
San Saba River
Llano River
Pedernales River
Onion Creek
0 25 50 100 Miles
MAP EXTENT
Colorado River Basin, Texas

Elm Creek at Ballinger, USGS Gage 08127000, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1933-2009	Average number of days each year with no flow = 130			
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	1 cfs	1 cfs	1 cfs	1 cfs
Base Medium	1 cfs	1 cfs	1 cfs	1 cfs
Base High	4 cfs	5 cfs	1 cfs	1 cfs
2 Pulses per season	Trigger: 10 cfs Volume: 71 af Duration: 10 days	Trigger: 380 cfs Volume: 1,400 af Duration: 10 days	Trigger: 6 cfs Volume: 25 af Duration: 6 days	Trigger: 10 cfs Volume: 46 af Duration: 9 days
1 Pulse per season	Trigger: 40 cfs Volume: 270 af Duration: 16 days	Trigger: 1,000 cfs Volume: 3,800 af Duration: 12 days	Trigger: 74 cfs Volume: 300 af Duration: 10 days	Trigger: 190 cfs Volume: 850 af Duration: 15 days
1 Pulse per year	Trigger: 1,900 cfs Volume: 7,200 af Duration: 18 days			
1 Pulse per 2 years	Trigger: 3,500 cfs Volume: 13,100 af Duration: 20 days			
1 Pulse per 5 years (Overbank)	Trigger: 6,300 cfs Volume: 22,700 af Duration: 22 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second ,

af = acre-feet

Concho River at Paint Rock, USGS Gage 08136500, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1916-2009	5 periods Max duration: 42 days	40 periods Max duration: 78 days	40 periods Max duration: 316 days	18 periods Max duration: 154 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	8 cfs	4 cfs	1 cfs	5 cfs
Base Medium	20 cfs	14 cfs	4 cfs	16 cfs
Base High	36 cfs	27 cfs	12 cfs	29 cfs
2 Pulses per season	Trigger: 61 cfs Volume: 400 af Duration: 10 days	Trigger: 500 cfs Volume: 2,000 af Duration: 8 days	Trigger: 32 cfs Volume: 140 af Duration: 6 days	Trigger: 74 cfs Volume: 330 af Duration: 7 days
1 Pulse per season	Trigger: 160 cfs Volume: 1,200 af Duration: 16 days	Trigger: 1,400 cfs Volume: 5,700 af Duration: 11 days	Trigger: 110 cfs Volume: 520 af Duration: 8 days	Trigger: 300 cfs Volume: 1,300 af Duration: 10 days
1 Pulse per year	Trigger: 3,000 cfs Volume: 13,500 af Duration: 19 days			
1 Pulse per 2 years	Trigger: 5,200 cfs Volume: 23,400 af Duration: 23 days			
1 Pulse per 5 years	Trigger: 12,300 cfs Volume: 55,300 af Duration: 29 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

af = acre-feet

South Concho River at Christoval, USGS Gage 08128000, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1931-1994	0 days with no flow during period of record			
Subsistence	2 cfs	3 cfs	2 cfs	2 cfs
Base Low	9 cfs	9 cfs	7 cfs	7 cfs
Base Medium	15 cfs	15 cfs	12 cfs	12 cfs
Base High	22 cfs	22 cfs	22 cfs	22 cfs
2 Pulses per season	Not applicable	Not applicable	Not applicable	Not applicable
1 Pulse per season	Not applicable	Not applicable	Not applicable	Trigger: 45 cfs Volume: 190 af Duration: 7 days
1 Pulse per year	Trigger: 420 cfs Volume: 1,400 af Duration: 9 days			
1 Pulse per 2 years	Trigger: 930 cfs Volume: 2,800 af Duration: 10 days			
1 Pulse per 5 years	Trigger: 2,600 cfs Volume: 6,800 af Duration: 11 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

af = acre-feet

Pecan Bayou near Mullin, USGS Gage 08143600, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1968-2009	0 periods Max duration: 0 days	2 periods Max duration: 69 days	7 periods Max duration: 54 days	1 periods Max duration: 9 days
Subsistence	2 cfs	2 cfs	2 cfs	2 cfs
Base Low	3 cfs	3 cfs	2 cfs	3 cfs
Base Medium	7 cfs	9 cfs	4 cfs	7 cfs
Base High	12 cfs	19 cfs	8 cfs	12 cfs
2 Pulses per season	Trigger: 52 cfs Volume: 230 af Duration: 7 days	Trigger: 710 cfs Volume: 3,600 af Duration: 10 days	Trigger: 21 cfs Volume: 73 af Duration: 4 days	Trigger: 36 cfs Volume: 110 af Duration: 3 days
1 Pulse per season	Trigger: 250 cfs Volume: 1,500 af Duration: 14 days	Trigger: 2,100 cfs Volume: 13,200 af Duration: 17 days	Trigger: 100 cfs Volume: 440 af Duration: 7 days	Trigger: 250 cfs Volume: 1,200 af Duration: 9 days
1 Pulse per year	Trigger: 3,500 cfs Volume: 25,800 af Duration: 26 days			
1 Pulse per 2 years	Trigger: 6,700 cfs Volume: 54,100 af Duration: 33 days			
1 Pulse per 5 years	Trigger: 13,900 cfs Volume: 124,900 af Duration: 43 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

af = acre-feet

San Saba River at San Saba, USGS Gage 08146000, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1916-1992	0 periods Max duration: 0 days	2 periods Max duration: 3 days	13 periods Max duration: 46 days	0 periods Max duration: 0 days
Subsistence	29 cfs	22 cfs	22 cfs	22 cfs
Base Low	56 cfs	56 cfs	32 cfs	40 cfs
Base Medium	81 cfs	81 cfs	46 cfs	64 cfs
Base High	110 cfs	110 cfs	62 cfs	87 cfs
2 Pulses per season	Trigger: 150 cfs Volume: 980 af Duration: 14 days	Trigger: 810 cfs Volume: 3,600 af Duration: 9 days	Not applicable	Trigger: 150 cfs Volume: 600 af Duration: 8 days
1 Pulse per season	Trigger: 330 cfs Volume: 2,300 af Duration: 18 days	Trigger: 2,000 cfs Volume: 9,200 af Duration: 12 days	Trigger: 210 cfs Volume: 1,100 af Duration: 9 days	Trigger: 500 cfs Volume: 2,300 af Duration: 12 days
1 Pulse per year	Trigger: 5,500 cfs Volume: 27,400 af Duration: 21 days			
1 Pulse per 2 years	Trigger: 9,000 cfs Volume: 45,300 af Duration: 24 days			
1 per 5 years (Overbank)	Trigger: 14,900 cfs Volume: 75,500 af Duration: 27 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

af = acre-feet

Llano River at Llano, USGS Gage 08151500, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1923-2009	0 periods Max duration: 0 days	2 periods Max duration: 67 days	5 periods Max duration: 31 days	0 periods Max duration: 0 days
Subsistence	55 cfs	55 cfs	55 cfs	55 cfs
Base Low	100 cfs	100 cfs	67 cfs	87 cfs
Base Medium	150 cfs	150 cfs	92 cfs	120 cfs
Base High	190 cfs	190 cfs	130 cfs	190 cfs
2 Pulses per season	Trigger: 390 cfs Volume: 2,500 af Duration: 13 days	Trigger: 1,800 cfs Volume: 8,500 af Duration: 10 days	Not applicable	Trigger: 370 cfs Volume: 1,600 af Duration: 8 days
1 Pulse per season	Trigger: 1,100 cfs Volume: 6,800 af Duration: 16 days	Trigger: 4,800 cfs Volume: 23,200 af Duration: 13 days	Trigger: 560 cfs Volume: 2,600 af Duration: 9 days	Trigger: 1,400 cfs Volume: 6,300 af Duration: 11 days
1 Pulse per year	Trigger: 9,100 cfs Volume: 46,100 af Duration: 18 days			
1 Pulse per 2 years (Overbank)	Trigger: 17,400 cfs Volume: 89,300 af Duration: 22 days			
1 Pulse per 5 years (Overbank)	Trigger: 41,100 cfs Volume: 214,000 af Duration: 27 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

af = acre-feet

Pedernales River near Johnson City, USGS Gage 08153500, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1939-2009	0 periods Max duration: 0 days	3 periods Max duration: 37 days	15 periods Max duration: 88 days	3 periods Max duration: 33 days
Subsistence	7 cfs	4 cfs	4 cfs	4 cfs
Base Low	23 cfs	29 cfs	16 cfs	16 cfs
Base Medium	45 cfs	60 cfs	29 cfs	29 cfs
Base High	80 cfs	110 cfs	49 cfs	49 cfs
2 Pulses per season	Trigger: 270 cfs Volume: 1,300 af Duration: 9 days	Trigger: 1,700 cfs Volume: 6,300 af Duration: 8 days	Not Applicable	Trigger: 160 cfs Volume: 620 af Duration: 6 days
1 Pulse per season	Trigger: 860 cfs Volume: 4,700 af Duration: 15 days	Trigger: 3,700 cfs Volume: 14,400 af Duration: 10 days	Trigger: 290 cfs Volume: 1,100 af Duration: 7 days	Trigger: 860 cfs Volume: 3,000 af Duration: 8 days
1 Pulse per year	Trigger: 7,000 cfs Volume: 28,400 af Duration: 15 days			
1 Pulse per 2 years	Trigger: 10,900 cfs Volume: 44,600 af Duration: 17 days			
1 Pulse per 5 years	Trigger: 26,300 cfs Volume: 107,900 af Duration: 21 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

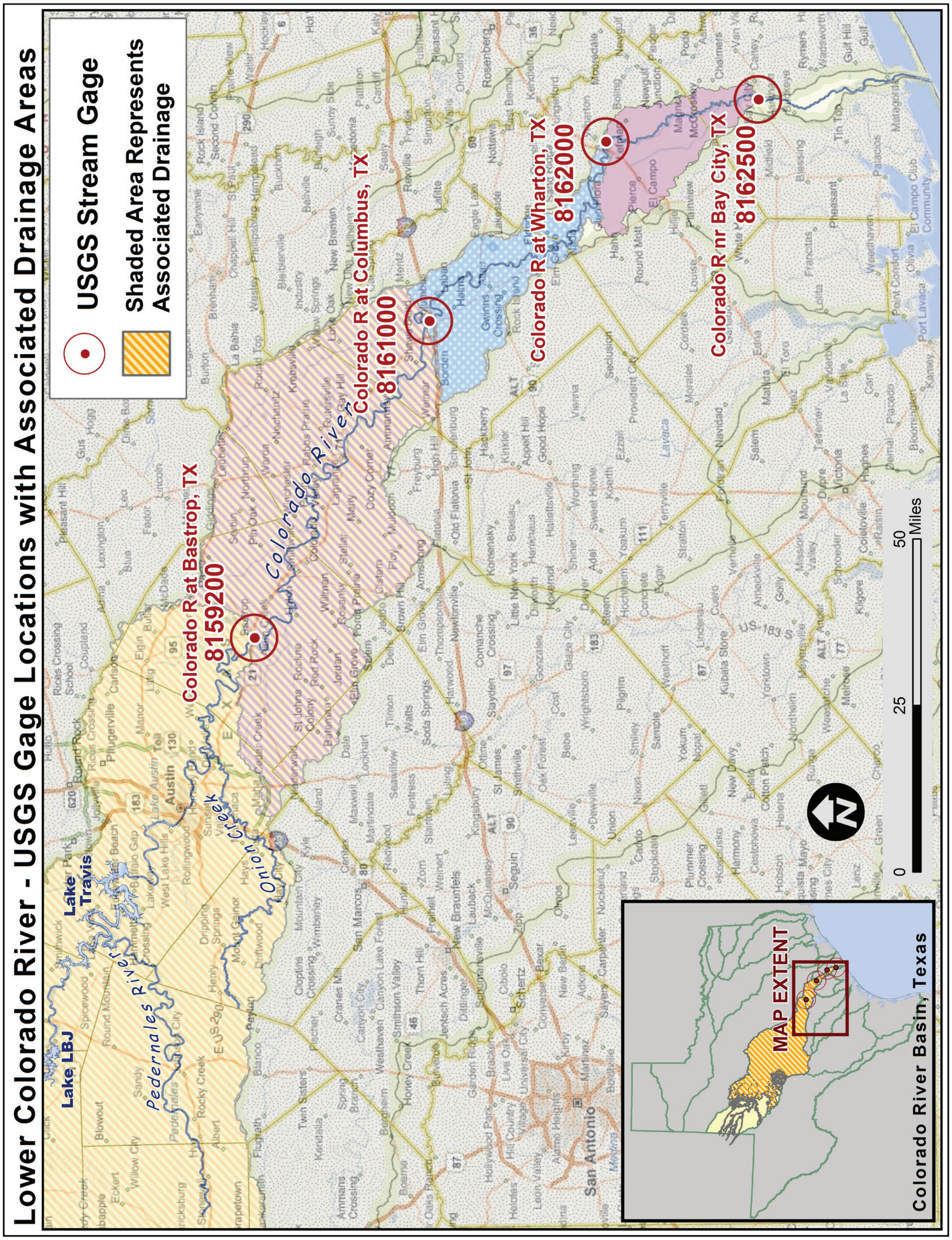
af = acre-feet

Onion Creek near Driftwood, USGS Gage 08158700, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1992-2010	0 periods Max duration: 0 days	4 periods Max duration: 245 days	3 periods Max duration: 453 days	1 periods Max duration: 182 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	2 cfs	4 cfs	1 cfs	1 cfs
Base Medium	6 cfs	12 cfs	3 cfs	3 cfs
Base High	26 cfs	34 cfs	7 cfs	7 cfs
2 Pulses per season	Not applicable	Trigger: 200 cfs Volume: 1,100 af Duration: 11 days	Not applicable	Trigger: 18 cfs Volume: 70 af Duration: 5 days
1 Pulse per season	Trigger: 170 cfs Volume: 1,900 af Duration: 20 days	Trigger: 620 cfs Volume: 3,700 af Duration: 19 days	Not applicable	Trigger: 120 cfs Volume: 560 af Duration: 11 days
1 Pulse per year	Trigger: 1,200 cfs Volume: 8,700 af Duration: 34 days			
1 Pulse per 2 years	Trigger: 2,400 cfs Volume: 18,900 af Duration: 45 days			
1 Pulse per 5 years	Trigger: 3,600 cfs Volume: 29,600 af Duration: 53 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

af = acre-feet


Lower Colorado River - USGS Gage Locations with Associated Drainage Areas
USGS Stream Gage
Shaded Area Represents Associated Drainage
Colorado R at Bastrop, TX
8159200
Colorado R at Columbus, TX
8161000
Colorado R at Wharton, TX
8162000
Colorado R nr Bay City, TX
8162500
Colorado River
Pedernales River
Onion Creek
Lake LBJ
Lake Travis
Austin
San Antonio
0
25
50
Miles
MAP EXTENT
Colorado River Basin, Texas

Colorado River at Bastrop, USGS Gage 08159200, Recommended Environmental Flow Regime

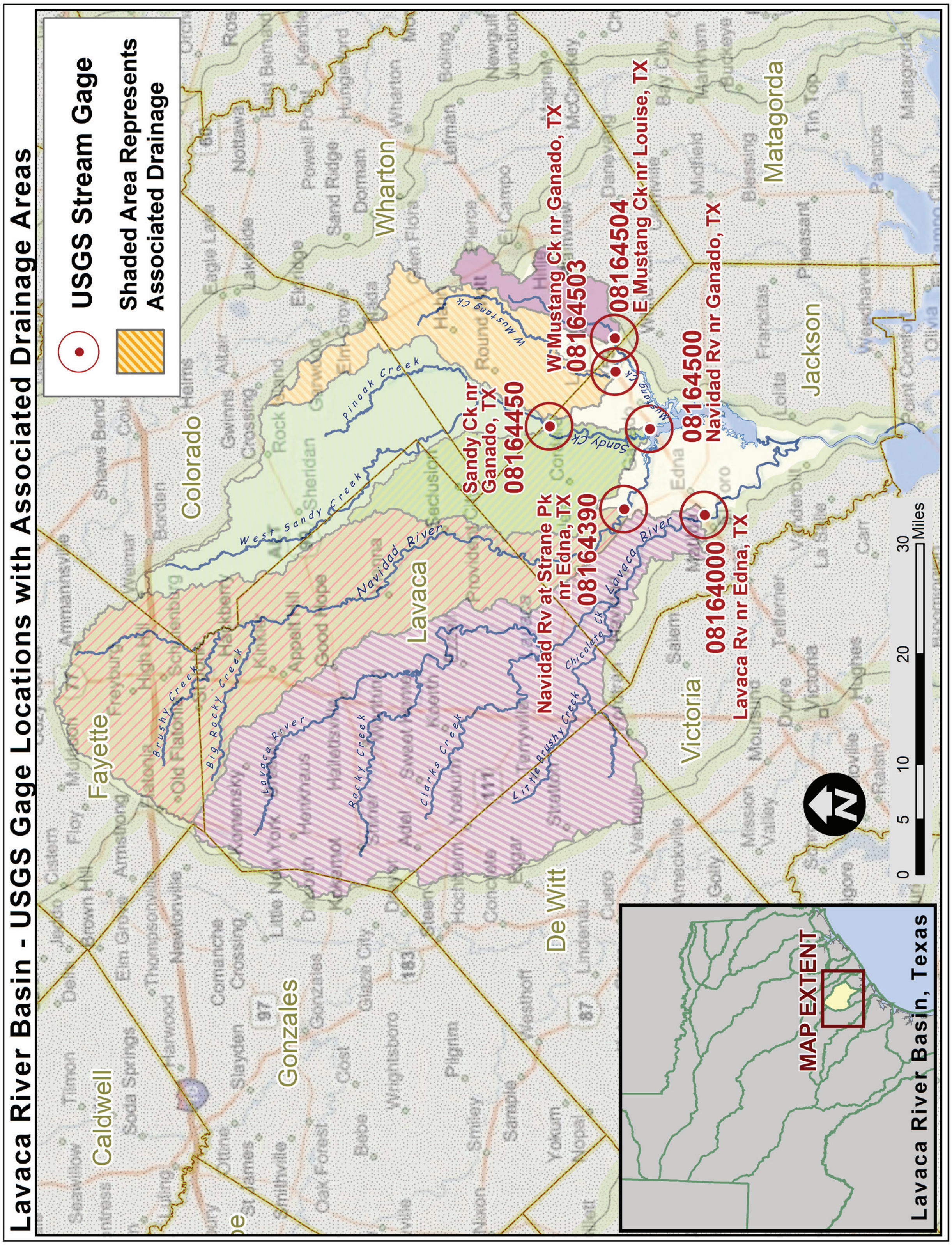
Flow	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Subsistence (cfs)	208	274	274	184	275	202	137	123	123	127	180	186
Base–Dry (cfs)	313	317	274	287	579	418	347	194	236	245	283	311
Base–Average (cfs)	433	497	497	635	824	733	610	381	423	433	424	450
Pulse flow–Base	Magnitude (2,000 to 3,000 cfs); Frequency (8-10 times annually); Duration (3-5 days)											
Pulse flow–High	Magnitude (8,000 cfs); Frequency (2 events in a 3-year period); Duration (2-3 days)											
Channel Maintenance	Magnitude (27,000 to 30,000 cfs); Frequency (1 event in 3 year period); Duration (3 days)											
Overbank	Magnitude (>30,000 cfs); Frequency and Duration (naturally driven)											

Colorado River at Columbus, USGS Gage 08161000, Recommended Environmental Flow Regime

Flow	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Subsistence (cfs)	340	375	375	299	425	534	342	190	279	190	202	301
Base–Dry (cfs)	487	590	525	554	966	967	570	310	405	356	480	464
Base–Average (cfs)	828	906	1036	1011	1397	1512	906	522	617	749	764	746
Pulse flow–Base	Magnitude (2,000 to 3,000 cfs); Frequency (8-10 times annually); Duration (3-5 days)											
Pulse flow–High	Magnitude (8,000 cfs); Frequency (2 events in a 3-year period); Duration (2-3 days)											
Channel Maintenance	Magnitude (27,000 to 30,000 cfs); Frequency (1 event in 3 -year period); Duration (3 days)											
Overbank	Magnitude (>30,000 cfs); Frequency and Duration (naturally driven)											

Colorado River at Columbus, USGS Gage 08161000, Recommended Environmental Flow Regime

Flow	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Subsistence (cfs)	315	303	204	270	304	371	212	107	188	147	173	202
Base–Dry (cfs)	492	597	531	561	985	984	577	314	410	360	486	470
Base–Average (cfs)	838	906	1036	1011	1397	1512	906	522	617	749	764	746
Pulse flow–Base	Magnitude (2,000 to 3,000 cfs); Frequency (8-10 times annually); Duration (3-5 days)											
Pulse flow–High	Magnitude (8,000 cfs); Frequency (2 events in a 3-year period); Duration (2-3 days)											
Channel Maintenance	Magnitude (27,000 to 30,000 cfs); Frequency (1 event in 3-year period); Duration (3 days)											
Overbank	Magnitude (>30,000 cfs); Frequency and Duration (naturally driven)											


Lavaca River Basin - USGS Gage Locations with Associated Drainage Areas
USGS Stream Gage
Shaded Area Represents Associated Drainage
Sandy Ck nr Ganado, TX 08164450
W Mustang Ck nr Ganado, TX 08164503
08164504 E Mustang Ck nr Louise, TX
08164500 Navidad Rv nr Ganado, TX
Navidad Rv at Strane Pk nr Edna, TX 08164390
08164000 Lavaca Rv nr Edna, TX
Fayette
Colorado
Wharton
Lavaca
Jackson
Matagorda
Victoria
De Witt
Gonzales
Caldwell
0 5 10 20 30 Miles
MAP EXTENT
Lavaca River Basin, Texas

Lavaca River near Edna, USGS Gage 08164000, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1938-2010	3 periods Max duration: 26 days	3 periods Max duration: 7 days	4 periods Max duration: 9 days	6 periods Max duration: 53 days
Subsistence	16 cfs	16 cfs	16 cfs	16 cfs
Base Low	30 cfs	30 cfs	20 cfs	20 cfs
Base Medium	55 cfs	55 cfs	33 cfs	33 cfs
Base High	94 cfs	94 cfs	48 cfs	58 cfs
2 Pulses per season	Trigger: 2,000 cfs Volume: 8,000 af Duration: 8 days	Trigger: 4,600 cfs Volume: 17,800 af Duration: 8 days	Trigger: 88 cfs Volume: 370 af Duration: 6 days	Trigger: 1,600 cfs Volume: 6,100 af Duration: 7 days
1 Pulse per season	Trigger: 4,500 cfs Volume: 18,400 af Duration: 10 days	Trigger: 6,800 cfs Volume: 26,600 af Duration: 8 days	Trigger: 420 cfs Volume: 1,800 af Duration: 9 days	Trigger: 4,500 cfs Volume: 18,000 af Duration: 9 days
1 Pulse per year (Overbank)	Trigger: 11,400 cfs Volume: 46,100 af Duration: 10 days			
1 Pulse per 2 years (Overbank)	Trigger: 15,700 cfs Volume: 64,100 af Duration: 11 days			
1 Pulse per 5 years (Overbank)	Trigger: 22,800 cfs Volume: 94,100 af Duration: 12 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

af = acre-feet

Navidad River at Strane Park near Edna, USGS Gage 08164390, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1996-2010	0 periods Max duration: 0 days	0 periods Max duration: 0 days	3 periods Max duration: 11 days	2 periods Max duration: 3 days
Subsistence	4 cfs	4 cfs	4 cfs	4 cfs
Base Low	14 cfs	18 cfs	24 cfs	17 cfs
Base Medium	35 cfs	35 cfs	47 cfs	35 cfs
Base High	71 cfs	71 cfs	84 cfs	71 cfs
2 Pulses per season	Trigger: 2,000 cfs Volume: 9,000 af Duration: 8 days	Trigger: 3,900 cfs Volume: 17,300 af Duration: 8 days	Trigger: 200 cfs Volume: 1,000 af Duration: 7 days	Trigger: 2,000 cfs Volume: 8,700 af Duration: 8 days
1 Pulse per season	Trigger: 3,800 cfs Volume: 17,000 af Duration: 9 days	Trigger: 4,900 cfs Volume: 22,100 af Duration: 8 days	Trigger: 610 cfs Volume: 3,400 af Duration: 9 days	Trigger: 3,800 cfs Volume: 18,800 af Duration: 10 days
1 Pulse per year (Overbank)	Trigger: 7,100 cfs Volume: 34,400 af Duration: 10 days			
1 Pulse per 2 years (Overbank)	Trigger: 10,200 cfs Volume: 50,000 af Duration: 11 days			
1 Pulse per 5 years (Overbank)	Trigger: 15,500 cfs Volume: 77,600 af Duration: 12 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

af = acre-feet

Sandy Creek near Ganado, USGS Gage 08164450, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1977-2010	4 periods Max duration: 9 days	8 periods Max duration: 20 days	3 periods Max duration: 11 days	0 periods Max duration: 0 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	5 cfs	5 cfs	9 cfs	9 cfs
Base Medium	14 cfs	14 cfs	21 cfs	21 cfs
Base High	30 cfs	30 cfs	39 cfs	39 cfs
2 Pulses per season	Trigger: 800 cfs Volume: 4,000 af Duration: 7 days	Trigger: 1,400 cfs Volume: 7,300 af Duration: 9 days	Trigger: 91 cfs Volume: 500 af Duration: 6 days	Trigger: 630 cfs Volume: 3,100 af Duration: 8 days
1 Pulse per season	Trigger: 1,800 cfs Volume: 10,000 af Duration: 10 days	Trigger: 3,100 cfs Volume: 17,800 af Duration: 11 days	Trigger: 260 cfs Volume: 1,600 af Duration: 9 days	Trigger: 1,800 cfs Volume: 9,200 af Duration: 10 days
1 Pulse per year	Trigger: 4,500 cfs Volume: 26,700 af Duration: 14 days			
1 Pulse per 2 years	Trigger: 5,800 cfs Volume: 35,400 af Duration: 15 days			
1 Pulse per 5 years (Overbank)	Trigger: 8,300 cfs Volume: 52,900 af Duration: 17 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

af = acre-feet

East Mustang Creek near Louise, USGS Gage 08164504, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1996-2010	10 periods Max duration: 83 days	17 periods Max duration: 20 days	14 periods Max duration: 53 days	17 periods Max duration: 42 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	1 cfs	1 cfs	2 cfs	1 cfs
Base Medium	2 cfs	3 cfs	5 cfs	3 cfs
Base High	6 cfs	6 cfs	8 cfs	8 cfs
2 Pulses per season	Trigger: 150 cfs Volume: 680 af Duration: 7 days	Trigger: 280 cfs Volume: 1,400 af Duration: 9 days	Trigger: 20 cfs Volume: 100 af Duration: 7 days	Trigger: 150 cfs Volume: 650 af Duration: 8 days
1 Pulse per season	Trigger: 340 cfs Volume: 1,700 af Duration: 10 days	Trigger: 550 cfs Volume: 3,000 af Duration: 11 days	Trigger: 60 cfs Volume: 310 af Duration: 9 days	Trigger: 430 cfs Volume: 2,100 af Duration: 10 days
1 Pulse per year	Trigger: 1,200 cfs Volume: 6,400 af Duration: 14 days			
1 Pulse per 2 years (Overbank)	Trigger: 1,500 cfs Volume: 8,600 af Duration: 16 days			
1 Pulse per 5 years (Overbank)	Trigger: 2,200 cfs Volume: 12,500 af Duration: 17 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology and sound ecological environment. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

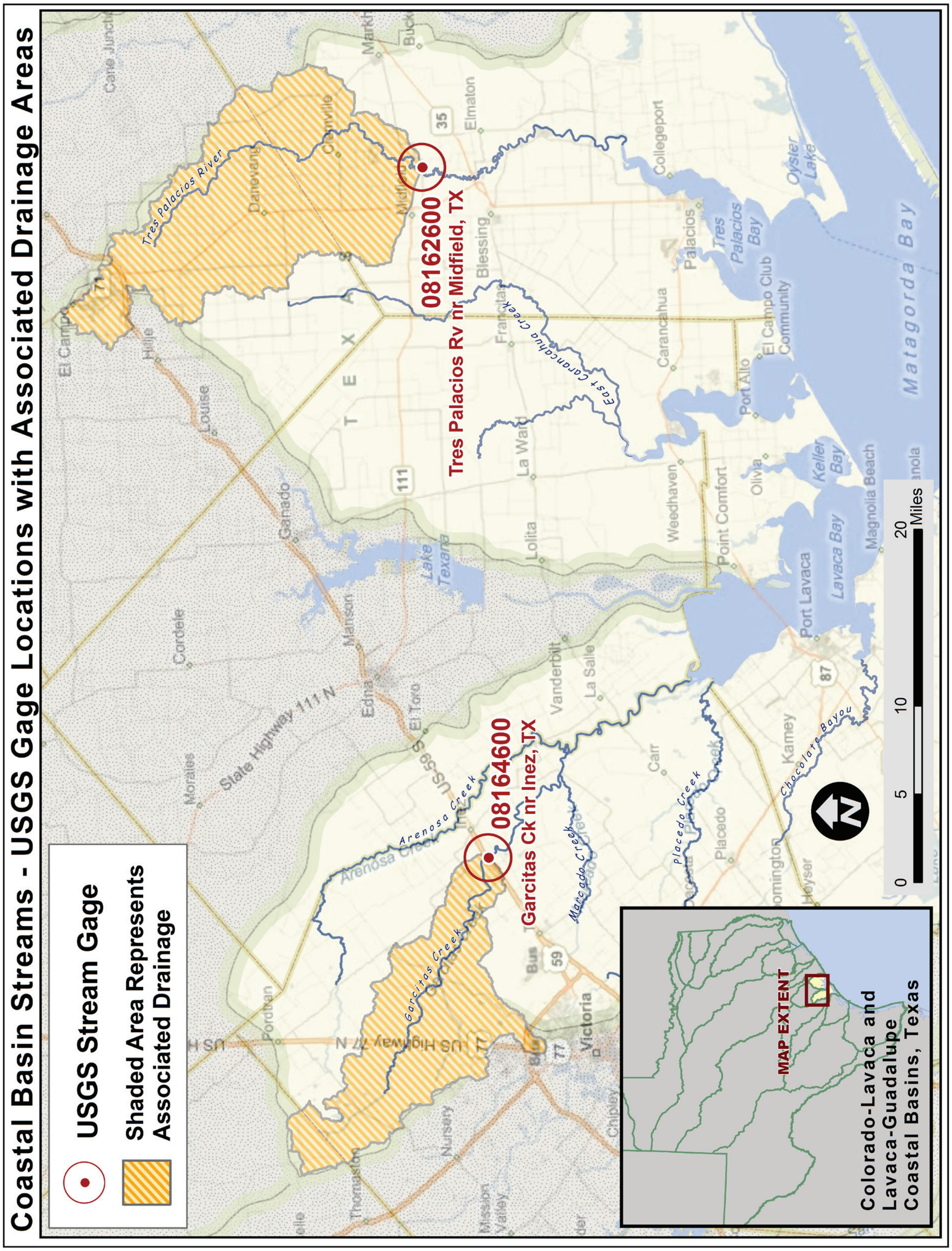
af = acre-feet

West Mustang Creek near Ganado, USGS Gage 08164503, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1977-2010	3 periods Max duration: 82 days	0 periods Max duration: 0 days	0 periods Max duration: 0 days	0 periods Max duration: 0 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	4 cfs	5 cfs	10 cfs	6 cfs
Base Medium	9 cfs	11 cfs	18 cfs	14 cfs
Base High	20 cfs	20 cfs	32 cfs	26 cfs
2 Pulses per season	Trigger: 470 cfs Volume: 2,400 af Duration: 7 days	Trigger: 810 cfs Volume: 4,400 af Duration: 8 days	Trigger: 75 cfs Volume: 420 af Duration: 6 days	Trigger: 470 cfs Volume: 2,200 af Duration: 8 days
1 Pulse per season	Trigger: 1,000 cfs Volume: 5,600 af Duration: 10 days	Trigger: 1,500 cfs Volume: 9,400 af Duration: 11 days	Trigger: 190 cfs Volume: 1,200 af Duration: 9 days	Trigger: 1,300 cfs Volume: 7,100 af Duration: 11 days
1 Pulse per year	Trigger: 2,800 cfs Volume: 17,800 af Duration: 15 days			
1 Pulse per 2 years	Trigger: 4,700 cfs Volume: 31,900 af Duration: 18 days			
1 Pulse per 5 years	Trigger: 6,700 cfs Volume: 46,900 af Duration: 21 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

af = acre-feet


Coastal Basin Streams - USGS Gage Locations with Associated Drainage Areas
USGS Stream Gage
Shaded Area Represents Associated Drainage
08162600
Tres Palacios Rv nr Midfield, TX
08164600
Garcitas Ck nr Inez, TX
Tres Palacios River
East Carancahua Creek
Arenosa Creek
Garcitas Creek
Marcado Creek
Placedo Creek
Chocolate Bayou
Lake Texana
Tres Palacios Bay
Matagorda Bay
Lavaca Bay
Keller Bay
Oyster Lake
State Highway 111 N
US Highway 77 N
0 5 10 20 Miles
MAP EXTENT
Colorado-Lavaca and Lavaca-Guadalupe Coastal Basins, Texas

Garcitas Creek near Inez, USGS Gage 08164600, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1970-2010	0 periods Max duration: 0 days	13 periods Max duration: 59 days	5 periods Max duration: 190 days	7 periods Max duration: 34 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	2 cfs	2 cfs	1 cfs	1 cfs
Base Medium	4 cfs	4 cfs	2 cfs	2 cfs
Base High	7 cfs	7 cfs	3 cfs	5 cfs
2 Pulses per season	Trigger: 110 cfs Volume: 520 af Duration: 8 days	Trigger: 380 cfs Volume: 1,500 af Duration: 10 days	Trigger: 8 cfs Volume: 28 af Duration: 4 days	Trigger: 110 cfs Volume: 420 af Duration: 8 days
1 Pulse per season	Trigger: 410 cfs Volume: 1,800 af Duration: 12 days	Trigger: 1,100 cfs Volume: 4,400 af Duration: 13 days	Trigger: 36 cfs Volume: 150 af Duration: 8 days	Trigger: 510 cfs Volume: 2,000 af Duration: 11 days
1 Pulse per year	Trigger: 2,000 cfs Volume: 8,900 af Duration: 17 days			
1 Pulse per 2 years	Trigger: 3,100 cfs Volume: 13,600 af Duration: 19 days			
1 Pulse per 5 years (Overbank)	Trigger: 5,400 cfs Volume: 24,200 af Duration: 22 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

af = acre-feet

cfs = cubic feet per second

Tres Palacios Creek near Midfield, USGS Gage 08162600, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1970-2010	No periods of no flow			
Subsistence	7 cfs	7 cfs	7 cfs	7 cfs
Base Low	9 cfs	9 cfs	7 cfs	7 cfs
Base Medium	13 cfs	13 cfs	13 cfs	13 cfs
Base High	18 cfs	22 cfs	22 cfs	18 cfs
2 Pulses per season	Trigger: 650 cfs Volume: 2,500 af Duration: 8 days	Trigger: 1,200 cfs Volume: 4,400 af Duration: 8 days	Trigger: 75 cfs Volume: 360 af Duration: 7 days	Trigger: 800 cfs Volume: 3,200 af Duration: 8 days
1 Pulse per season	Trigger: 1,300 cfs Volume: 4,900 af Duration: 9 days	Trigger: 1,900 cfs Volume: 7,100 af Duration: 8 days	Trigger: 280 cfs Volume: 1,300 af Duration: 9 days	Trigger: 1,900 cfs Volume: 7,700 af Duration: 10 days
1 Pulse per year (Overbank)	Trigger: 3,500 cfs Volume: 13,800 af Duration: 10 days			
1 Pulse per 2 years (Overbank)	Trigger: 4,600 cfs Volume: 18,200 af Duration: 11 days			
1 Pulse per 5 years (Overbank)	Trigger: 6,700 cfs Volume: 26,100 af Duration: 11 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

af = acre-feet

Table 2.7.4. Recommended freshwater inflow regime for Matagorda Bay.

	Flow Volumes (acre-feet)			Achievement Guideline†
Threshold	Maintain 15,000 acre-feet per month			100%
Regime:	**Spring**	**Fall**	**Intervening**	
MBHE 1	114,000	81,000	105,000	90%*
MBHE 2	168,700	119,900	155,400	75%*
MBHE 3	246,200	175,000	226,800	60%*
MBHE 4	433,200	307,800	399,000	35%*
Long-term Volume and Variability	Average at least 1.4 to 1.5 million acre-feet per year‡			100%

†Achievement guidelines refer to the amount of time that the flow volumes should be met or exceeded. *Based on historical frequency of occurrence.

‡Recommend projected long-term annual average flow is maintained at a level of at least 1.4 to 1.5 million acre-feet, with a coefficient of variation (CV) value above 0.8.

Table 2.8.8 Recommended Lavaca Bay Freshwater Inflow regime (acre-feet) for gaged inflows from the Lavaca River, Lake Texana releases, and Garcitas Creek.

Freshwater Inflow Regime (Acre-Feet)				
Onset Month	**Subsistence**	**Base Low**	**Base Medium**	**Base High**
Spring February March April May	13,500 3 consecutive months	55,080 3 consecutive months	127,980 3 consecutive months	223,560 3 consecutive months
Fall August September October	9,600 3 consecutive months	39,168 3 consecutive months	91,080 3 consecutive months	158,976 3 consecutive months
Intervening Six Months	6,900 Total for 6 month period	28,152 Total for 6 month period	65,412 Total for 6 month period	114,264 Total for 6 month period

References

SAC (2009a). Methodologies for Establishing a Freshwater Inflow Regime for Texas Estuaries Within the Context of the Senate Bill 3 Environmental Flows Process. http://www.tceq.texas.gov/assets/public/permitting/watersupply/water_rights/eflows/fwi20090605.pdf

Texas Commission on Environmental Quality. 2010a. "Colorado and Lavaca Rivers and Matagorda and Lavaca Bays Basin and Bay Stakeholder Committee and Expert Science Team." http://www.tceq.texas.gov/permitting/water_supply/water_rights/eflows/colorado-lavaca-bbsc

TWDB. 2008a, Texas Instream Flow Studies: Technical Overview, TWDB Report 369. Austin, TX. May, 2008.

2. Detailed Summaries

2.1 Upper Colorado

2.1.1 Colorado River above Silver — USGS 08123850


Colorado River above Silver on September 2, 2010. Photo on left is towards upstream. Photo on right is towards downstream.


Colorado River at Pecan Crossing upstream of USGS gage above Silver on September 2, 2010. Photo on left is towards downstream. Photo on right is upstream on September 2, 2010.

General Area Description (Griffith et al. 2004, Linam et al. 2002, Parsons Engineering Science, Inc. 1999)

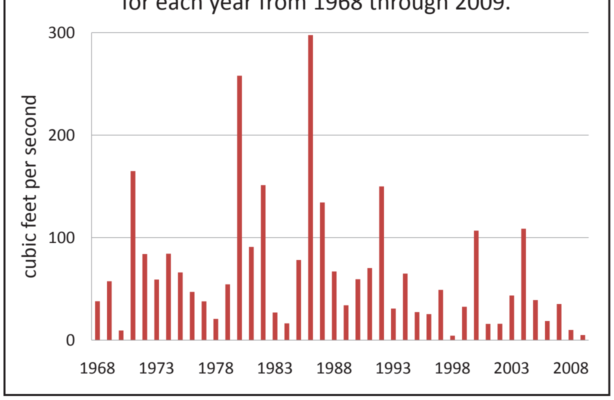
- 10 river miles upstream of E.V. Spence Reservoir and downstream of Lake J.B. Thomas
- TCEQ Water Quality Segment 1412
- Southwestern Tablelands, EPA Level III ecoregion
- Primary land use: grazing with relatively small amounts of crop land
- Sub-humid grassland and semiarid, irregular plains to tablelands with moderate to considerable relief
- Streams generally wide and shallow with substantial variation in flow

- Low velocities and frequent low flow combined with substantial exposure to direct sun, may contribute to harsh conditions for aquatic biota
- Potential natural vegetation: grama-buffalo grass with some mesquite-buffalo grass and juniper-scrub oak-midgrass savanna on escarpment bluffs
- Rainfall that accumulates in the draws and valleys in this watershed typically only flows a short distance before seeping into the ground or evaporating
- Groundwater contributes an insignificant amount to base flow
- About 756 river miles upstream from the river's mouth

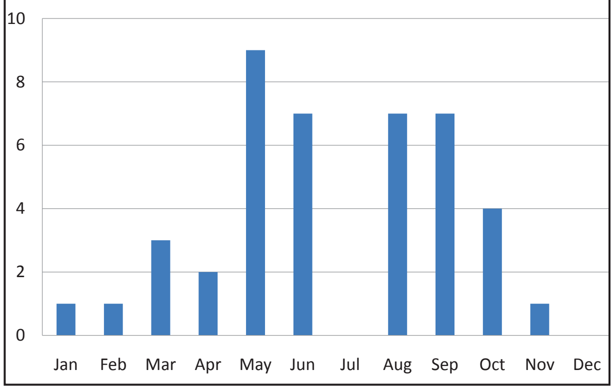
USGS Gage 08123850 Description

Coke County, Texas	Hydrologic Unit Code: 120800008	Latitude: 32°03'13", Longitude: 100°45'42" NAD27
Drainage area: 14,910 square miles	Contributing drainage area: 4,650 square miles	
Gage Datum: 1,907.66 feet above sea level NGVD29	Flood stage elevation (NOAA 2010): 15 ft above the USGS gage elevation	

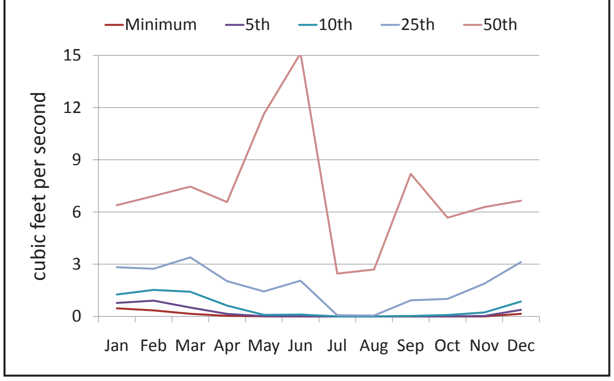
Summary of Historical USGS Flow Records at Colorado River above Silver



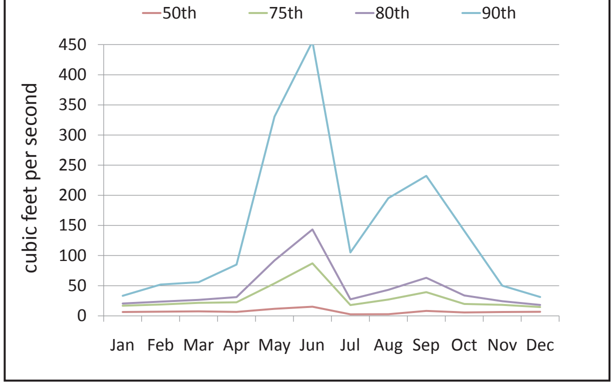
Colorado River above Silver daily average flow for each year from 1968 through 2009.



Colorado River above Silver number of peak flows in each month from 1968 through 2009.



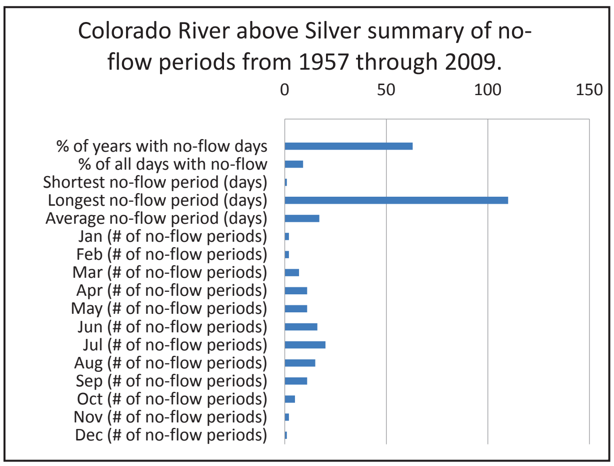
Colorado River above Silver low flow percentiles from 1968 through 2009.

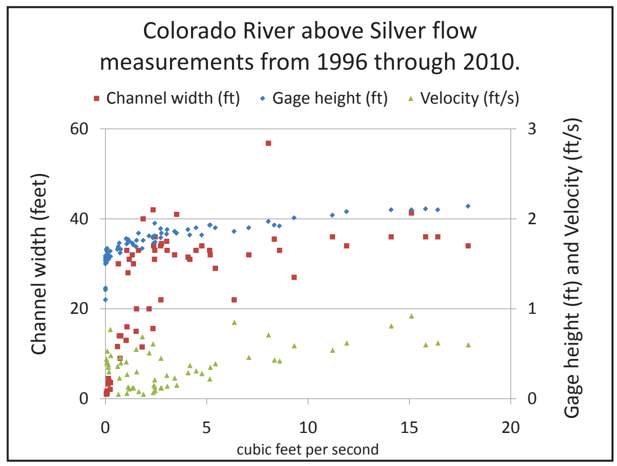


Colorado River above Silver high-flow percentiles from 1968 through 2009.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	114	371	1414	918	2196	2264	679	1675	2887	2601	907	190	1351
Minimum	0.5	0.3	0.1	0	0	0	0	0	0	0	0	0.2	0
Average	14	24	51	45	124	141	42	82	121	96	37	15	66
5th	1	1	1	0.1	0	0	0	0	0	0	0	0.4	0
10th	1	2	1	1	0.1	0.1	0	0	0	0.1	0.2	1	1
20th	2	2	3	1	1	1	0	0	0.4	1	1	3	1
25th	3	3	3	2	1	2	0.1	0.1	1	1	2	3	2
50th	6	7	7	7	12	15	2	3	8	6	6	7	7
75th	17	19	21	22	54	87	18	27	39	20	18	15	30
80th	20	24	27	31	92	143	27	43	63	34	24	18	46
90th	33	52	56	85	331	455	105	195	232	141	50	31	147
95th	65	143	143	255	935	772	376	615	683	538	171	71	397

Colorado River above Silver flow percentiles in cubic feet per second





Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases, two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5th, 25th, 50th, 75th, 80th, and 90th percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured.

Site Description

- Review of aerial photography with Google Earth
  - 10 river miles from USGS gage downstream to FM 2059
  - Flows for each aerial photography date
    - January 23, 1996: 2.8 cfs
    - October 21, 2005: 5.0 cfs, following a pulse on October 15, 2005 of 105 cfs
    - October 30, 2008: 1.5 cfs, following a pulse on October 17, 2008 of 52 cfs
  - Habitats
    - Long, straight, reaches of glides and pools with relatively few short riffles and runs, mouths of tributaries
    - 9 small islands
    - Riparian zone narrow and sparsely vegetated on both sides of river
    - River not very sinuous in this reach but does form one large bend
    - Bank height near USGS gage ranges from 15 to 25 ft above the water's surface
    - Split channels or oxbows not observed
    - No apparent dry reaches between pools on the three aerial photography dates
- Field Observations on September 2, 2010 at USGS gage site; USGS provisional flow of 0.0 cfs
  - Long, relatively straight pool of relatively constant width
  - Softshell turtles, diamond-back water snake, and belted kingfisher observed
  - Banks incised with widely scattered shrubs and trees, primarily black willow closest to the water, saltcedar along the shoreline, and hackberry higher on the bank; patches of spiny aster on bank midway between water and the top of the bank; Water turbid with a red clay color typical of the Colorado River in this reach
- Field observations on September 2, 2010 at Pecan Crossing about 15 river miles upstream of the USGS gage above Silver; Estimated flow less than 0.5 cfs
  - Red shiners (*Cyprinella lutrensis*), mosquitofish (*Gambusia*), Red River pupfish (*Cyprinodon rubrofluviatilis*), snails, riffle beetles, amphipods, and larval damselflies and larval flies observed
  - Filamentous green algae (*Chara* or *Nitella*) observed along with *Eleocharis* and unidentified macrophyte
  - Riparian zone sparsely vegetated with coastal Bermuda grass, switchgrass, and mesquite
  - Okla Thornton, Colorado River Municipal Water District, sampled this site over the past 20 years; and reports the site has had frequent no-flow periods but the pool upstream of the crossing has been perennial

Soil Types

Soil data were obtained from the Natural Resource Conservation Service for soil types adjacent to a 0.7-mile stretch of the river (NRCS 2010).

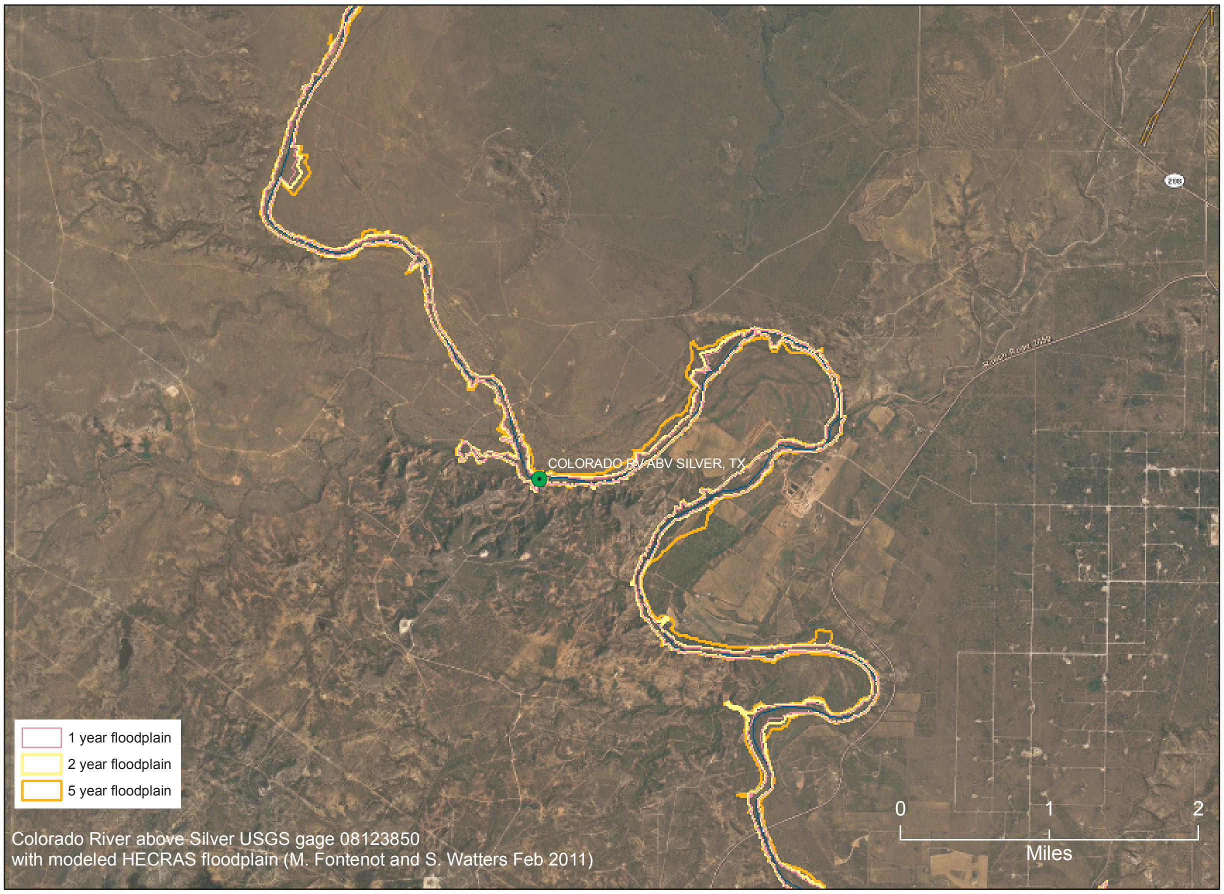
Soil	Setting	Slope %	Wetland Potential	Flood Frequency
Claremont silt loam	Draws on flood-plain steps	0-1	Well-drained	5-50 times per 100 years
Colorado loam	Flood plains on draws	0-1	Well-drained	More than 50 times per 100 years
Sagerton clay loam	Plains	0-1	Well-drained	Never
Yahola very fine sandy loam	Flood plains on river valleys	0-1	Well-drained	5-50 times per 100 years

Wetlands

National Wetland Inventory (USFWS 2010) data are not available for this reach of the river; however, visual review of aerial photography from three dates on Google Earth indicates few wetlands exist outside the river channel in this reach of the river.

Riparian/Flood Plain Vegetation

Texas Ecological Systems Classification of vegetation communities has not been completed for this area (German et al. 2009), so aerial photography and a site visit were used to review the riparian communities present along this reach. Black willow trees, which are frequently found growing in wetlands, were growing along the water's edge in some areas, and the dominant tree on the banks was non-native saltcedar. Wooded vegetation was scattered along the riverbanks. Additionally, HECRAS model results illustrating the area of inundation that occurs during a 1-year flow event, 2-year flow event, and 5-year flow event (shown in the HECRAS model map below) indicate that pulse events are relatively confined to the river channel. While the widely scattered black willow trees growing along the banks indicate a likely perennial water source, the more upland plant species located higher on the banks do not indicate there is frequent inundation or anoxic (wetland) soil conditions along this reach.



Sources: HECRAS derived 1, 2, and 5 year floodplain contours provided by BBEST members Melissa Fontenot and Steve Watters
Horizontal datum: NAD83
Contact: Lynne Hamlin, Water Resources Branch, TPWD lhamlin@tpwd.state.tx.us Feb. 2011
Disclaimer: While every attempt was made to present the information as accurately as possible, no claims are made to the completeness or accuracy of the information shown herein nor to its suitability for a particular use.
Scale and location are approximate.

HECRAS Model Results for the Colorado River above Silver

Biology

Source	Location	Biology	Observations
James 1989	Beals Creek, tributary to the Colorado River above Silver gage	Collected one larval crane fly and 5 species of fish (gizzard shad, mosquitofish, red shiner, longnose gar, and common carp)	Low diversity and numbers of aquatic biota attributed in part to elevated salinity and limited habitat
Meixner 1978	Colorado River downstream of USGS gage above Silver	Collected 5 species of benthic macroinvertebrates, including two types of snails, dipteran larvae, and aquatic oligochaetes	
TPWD 2010a	Colorado River	Concho water snake, a federally listed and proposed for delisting species of snake, may be present	Utilizes riffles and eats primarily fish
TPWD 2010b	Colorado River near Silver	April 20, 1980 - fish kill of 240 carp, 120 catfish, 40 sunfish, and 20 shiners July 1990 - fish kill of carp, catfish, sunfish, and minnows. Suspected oil field brine discharge into the river killed crappie, largemouth bass, gar, and flathead catfish upstream of Lake Spence Oil spill in 1997 killed fish. 10% were catfish and 90% were carp, shad, and minnows.	

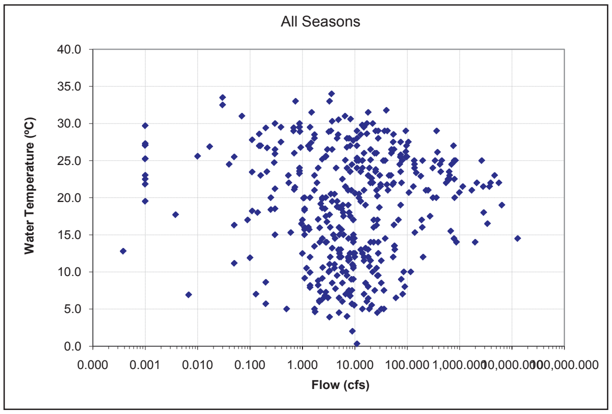
Water Quality

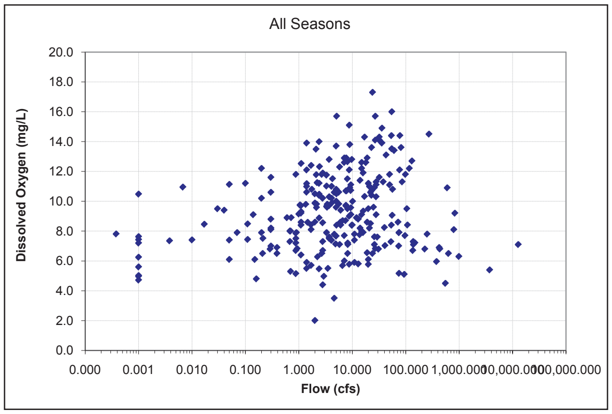
- The water quality period of record for this gage 8/30/1967 to 8/12/2009
- Relationships between flow and water quality parameters
  - Specific conductance decreases as flow increases.
  - pH increases with increasing flow.
  - NO2+NO3–Nitrogen increases with increasing flow.
  - Total phosphorus increases with increasing flow.
  - Chloride decreases with increasing flow.
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in the Water Quality Segment 1412, Colorado River below Lake J.B. Thomas. The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated high aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
  - The segment of river where this gage site is located is not listed on the 303(d) list.
- Relationships between temperature and flow
  - No correlation was observed between water temperature and flow.

- The highest temperature measured was 34.0 °C (flow: 0.03 cfs; dissolved oxygen: 9.5 mg/L).
- The lowest temperature measured was 0.3 °C (flow: 11 cfs; dissolved oxygen: not measured).
- The lowest flow measured was 0.0 cfs.
- The highest flow measured was 12,800 cfs (temperature: 14.5 °C; dissolved oxygen: 7.1 mg/L).

- Relationships between dissolved oxygen and flow
  - No correlation was observed between dissolved oxygen and flow.
  - The highest dissolved oxygen measurement was 17.3 mg/L (flow: 24 cfs; temperature: 7.5 °C).
  - The lowest dissolved oxygen was 2.0 mg/L (flow of 2 cfs; temperature: 17.1 °C).
  - The lowest flow was 0 cfs.
  - The highest flow was 12,800 cfs (temperature: 14.5 °C; dissolved oxygen: 7.1 mg/L).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - The maximum observed chloride was 4600 mg/L, which is below the TSWQS of 4740 mg/L.
  - The minimum and maximum pH were 6.5 and 9.7, which is slightly above the upper range of the TSWQS range of 6.5-9.0.
  - The highest observed instantaneous temperature was 34.0 °C, which is below the TSWQS of 35 °C.
  - The minimum observed dissolved oxygen concentration was 2.0 mg/L, which is below the TSWQS of 5.0 mg/L.

This reach of the Colorado River has relatively brackish water with specific conductance ranging from an annual average of 4,927 to 8,647 µS/cm (1975 to 2007) (USGS 2010). Extended periods of little-to-no flow and relatively high salinity levels may be two of several factors creating stressful conditions for biological communities. Toxic blooms of the brackish water, golden alga, *Prymnesium parvum*, have caused fish kills in this reach of the river (TPWD 2010b).





Geomorphology

Geomorphological analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77-93% of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows.

Flow interpretations

No-flow periods: About 9% of the days from 1957 through 2009 exhibited no flow. It is not known how change in the frequency and duration of no-flow periods will affect the health of the aquatic ecosystem. Increased frequency and duration of no-flow periods is not expected to improve ecosystem health.

Subsistence flows: River flows at or above 1.5 cfs (the 25th percentile flow from 1957 through 2009) at this gage appear to maintain perennial flow in this reach of the river based on review of aerial photography on Google Earth.

Base flows: Presence of turtles, water snakes, and belted kingfishers combined with a wetted channel observed at different flows on Google Earth indicate the existence of a perennial water body. Additionally, presence of at least 8 species of fish with a variety of spawning habits and physical habitat requirements indicates ecological value is provided by a variety of low flows.

Pulses and overbank flows: Soil types adjacent to the river indicate occasional flooding although the relatively widely scattered presence of typical riparian and floodplain vegetation like saltcedar, black willow, and hackberry trees indicates flooding is probably infrequent. Historical hydrology indicates pulses have occurred most frequently during the late spring and fall.

HEFR/Hydrological Analysis

	Winter	Spring	Summer	Fall
Overbank Flows	Qp: 8,100 cfs with Average Frequency 1 per 5 years Regressed Volume is 19,807 to 67,905 (36,674) Regressed Duration is 4 to 21 (9)			
High Flow Pulses	Qp: 4,524 cfs with Average Frequency 1 per 2 years Regressed Volume is 11,018 to 37,730 (20,389) Regressed Duration is 3 to 18 (8)			
	Qp: 3,032 cfs with Average Frequency 1 per year Regressed Volume is 7,366 to 25,205 (13,626) Regressed Duration is 3 to 17 (7)			
	Qp: 42 cfs with Average Frequency 1 per season Regressed Volume is 114 to 770 (296) Regressed Duration is 2 to 15 (5)	Qp: 1,810 cfs with Average Frequency 1 per season Regressed Volume is 4,878 to 12,676 (7,863) Regressed Duration is 3 to 11 (5)	Qp: 329 cfs with Average Frequency 1 per season Regressed Volume is 891 to 2,287 (1,428) Regressed Duration is 2 to 9 (5)	Qp: 433 cfs w Average Frequ 1 per seaso Regressed Vol is 1,203 to 2 (1,808) Regressed Dura is 2 to 9 (
	Qp: 18 cfs with Average Frequency 2 per season Regressed Volume is 48 to 326 (125) Regressed Duration is 1 to 11 (4)	Qp: 600 cfs with Average Frequency 2 per season Regressed Volume is 1,521 to 3,947 (2,450) Regressed Duration is 2 to 9 (4)	Qp: 91 cfs with Average Frequency 2 per season Regressed Volume is 220 to 564 (352) Regressed Duration is 2 to 6 (3)	Qp: 107 cfs w Average Frequ 2 per seaso Regressed Vol is 263 to 5 (395) Regressed Dura is 1 to 6 (
Base Flows (cfs)	7.1(43.4%)	12(41.9%)	7.7(37.9%)	10(41.0%)
	4.1(61.2%)	4.9(58.4%)	2.5(50.4%)	4.5(56.9%
	2(79.7%)	1.7(75.3%)	0.52(62.8%)	1.2(73.1%
Subsistence Flows (cfs)	0.2(95.0%)	0(100.0%)	0(100.0%)	0(100.0%)
	Nov, Dec, Jan, Feb	Mar, Apr, May, Jun	Jul, Aug	Sep, O
	Winter	Spring	Summer	Fall

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:
1. Period of Record used : 1/1/1957 to 12/31/2009.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 0 cfs.

Recommended Environmental Flow Regime

Colorado River above Silver, USGS Gage 08123850, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1957-2009	7 periods Max duration: 31 days	45 periods Max duration: 110 days	35 periods Max duration: 56 days	16 periods Max duration: 70 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	2 cfs	2 cfs	1 cfs	1 cfs
Base Medium	4 cfs	5 cfs	3 cfs	4 cfs
Base High	7 cfs	12 cfs	8 cfs	10 cfs
2 Pulses per season	Trigger: 18 cfs Volume: 120 af Duration: 11 days	Trigger: 600 cfs Volume: 2,500 af Duration: 9 days	Trigger: 100 cfs Volume: 350 af Duration: 6 days	Trigger: 100 cfs Volume: 400 af Duration: 6 days
1 Pulse per season	Trigger: 42 cfs Volume: 300 af Duration: 15 days	Trigger: 1,800 cfs Volume: 7,900 af Duration: 11 days	Trigger: 330 cfs Volume: 1,400 af Duration: 9 days	Trigger: 430 cfs Volume: 1,800 af Duration: 9 days
1 Pulse per year	Trigger: 3,000 cfs Volume: 13,600 af Duration: 17 days			
1 Pulse per 2 years	Trigger: 4,500 cfs Volume: 20,400 af Duration: 18 days			
1 Pulse per 5 years (Overbank)	Trigger: 8,100 cfs Volume: 36,700 af Duration: 21 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

af = acre-feet

2.1.2 Colorado River near Ballinger USGS 08126380


Colorado River southwest of Ballinger, about 10 miles upstream from FM 2111 bridge. September 2, 2010 (left).
Colorado River southwest of Ballinger, downstream of FM 2111. September 2, 2010 (right).

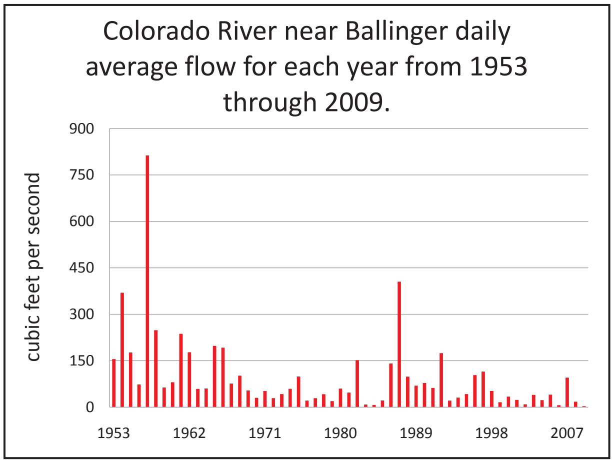
General Area Description (Google Earth 2010; Griffith et al. 2004, USGS 2010)

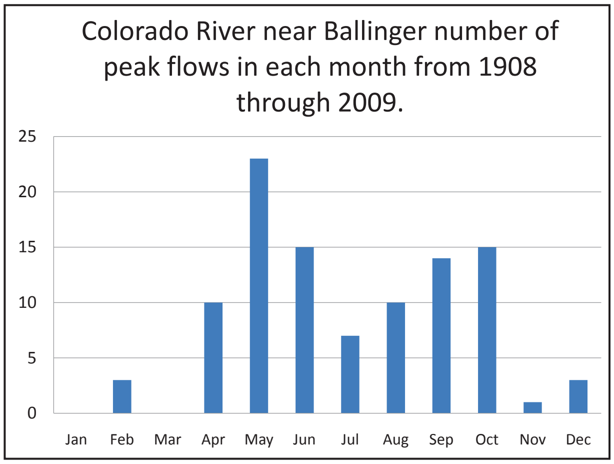
- Approximately 54 miles downstream of E.V. Spence Reservoir and 40 to 50 miles upstream of O.H. Ivie Reservoir depending on reservoir level
- TCEQ Water Quality Segment 1426
- Central Great Plains, EPA Level III ecoregion
- Primary land use: cultivation and grazing
- Grassland with scattered low trees and shrubs
- Rainfall rates do not support forest vegetation
- Subsurface salt deposits and leaching cause high salinity in some streams
- About 666 river miles upstream of river's mouth

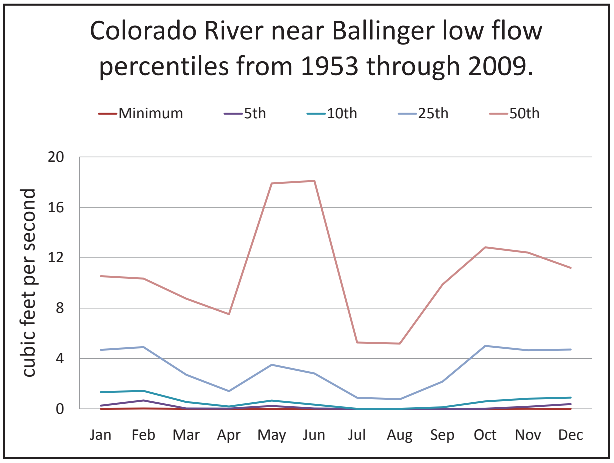
USGS 08126380 Gage Description

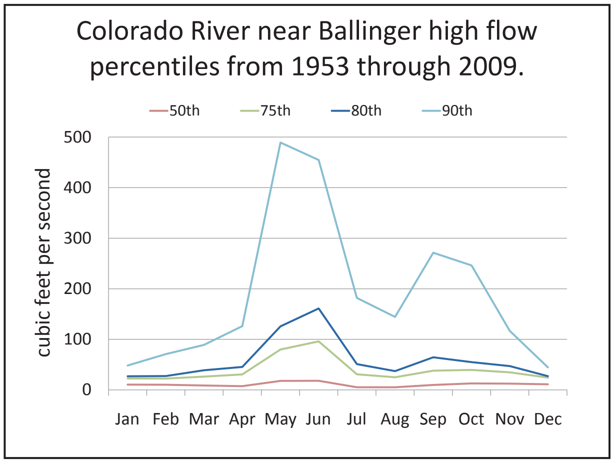
Runnels County, Texas	Hydrologic Unit Code: 12090101	Latitude: 31°42'55", Longitude: 100°01'34" NAD27
Drainage area: 16,358 square miles	Contributing drainage area: 6,098 square miles	
Gage Datum: 1,606.51 feet above sea level NGVD29	Flood stage elevation (NOAA 2010): 18 ft above the USGS gage elevation	

Summary of Historical USGS Flow Records at Colorado River near Ballinger



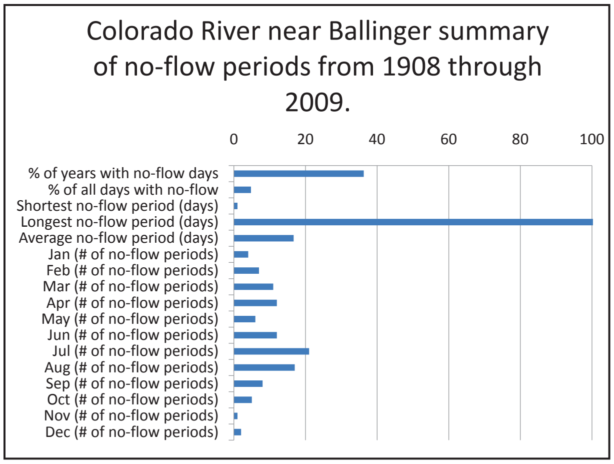


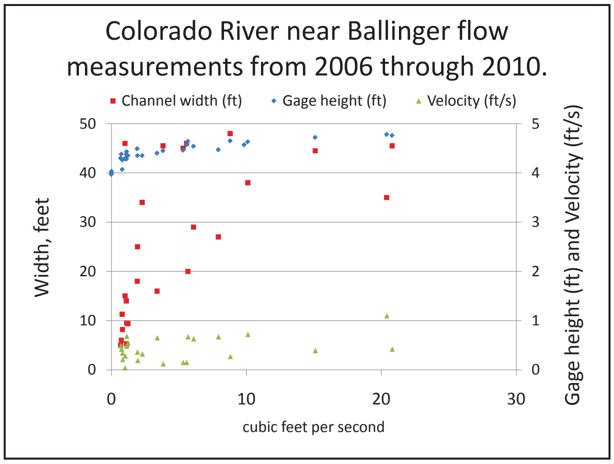




	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	208	794	429	2,286	6,649	3,982	1,067	3,021	3,398	4,073	1,037	310	2,271
Average	21	39	35	82	287	179	63	99	134	147	55	24	97
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0
5th	0.3	1	0	0	0.2	0	0	0	0	0	0.2	0.4	0.1
10th	1	1	1	0.2	1	0.3	0	0	0.1	1	1	1	1
20th	3	4	2	1	2	2	0.5	0.3	1	3	3	3	2
25th	5	5	3	1	4	3	1	1	2	5	5	5	3
50th	11	10	9	8	18	18	5	5	10	13	12	11	11
75th	23	22	26	31	80	96	31	25	38	40	35	24	39
80th	27	28	39	45	126	161	51	37	64	55	47	27	59
90th	48	71	89	126	489	455	182	144	271	246	117	45	190
95th	94	202	228	327	2,143	838	435	535	729	799	308	99	561

Colorado River near Ballinger flow percentiles in cubic feet per second





Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases, two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5^{th}, 25^{th}, 50^{th}, 75^{th}, 80^{th}, and 90^{th} percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured.

Historical Hydrology

Flows in the river near O.H. Ivie Reservoir are believed sustained by springs (TPWD, 1979). Riffles in this reach at a flow of 73.4 cfs ranged from 30 to 150 ft wide and riffle depths ranged from 1 to 22 inches. Riffles consisted of rock, gravel, and rubble. Pools make up about 80% of the habitat, ranging from 50 to 210 ft wide and 1 to 8 ft deep. Most pools had silt bottoms but bedrock, gravel, and boulders were present in some pools.

Site Description

- Review of aerial photography with Google Earth
    - Reviewed 63 river-mile reach from E.V. Spence Reservoir downstream to confluence with Elm Creek (about 9 river miles downstream of USGS gage)
    - Flows for each aerial photography date
        - March 1, 1997: 192 cfs
        - October 21, 2005: 7.7 cfs
        - October 30, 2008: 0.62 cfs
        - February 14, 2010: 4.4 cfs
    - Habitats
        - Long reaches of relatively straight glides and pools separated by riffle-run reaches upstream of the gage and with shallow runs and some rocky riffles downstream of the gage
        - Reach upstream of the USGS gage had 4 low-head dams, a number of tributaries and backwater areas
        - Oxbows not observed
        - Mouths of 3 tributaries and 1 island downstream of the USGS gage to the confluence with Elm Creek
- Field observations on September 2, 2010 at USGS gage site; USGS provisional flow of 0.0 cfs; visually estimated flow of about 1.5 cfs
    - Relatively short riffles, pools and runs observed near gage
    - The riffle and its cobble bottom harbored damselfly nymphs, riffle beetles, snails, Asian clams, filamentous green algae, Tampico pearly mussel, and spike rush
- Field observations by TPWD and TWDB staff on October 13, 2010 near USGS gage site; USGS provisional flow of 0.53 cfs
    - Cattails and water willow in the river, switch grass, *Baccharis*, and saltcedar near the river with ragweed, button bush, poison ivy, soapberry, huisache, black willow, American elm, mesquite, and hackberry higher on the bank
    - Button bush: the only plant in the riparian zone requiring almost continuous wet conditions

Soil Types

Soil data were obtained from the Natural Resource Conservation Service for a 1.5-mile stretch along the river (NRCS 2010).

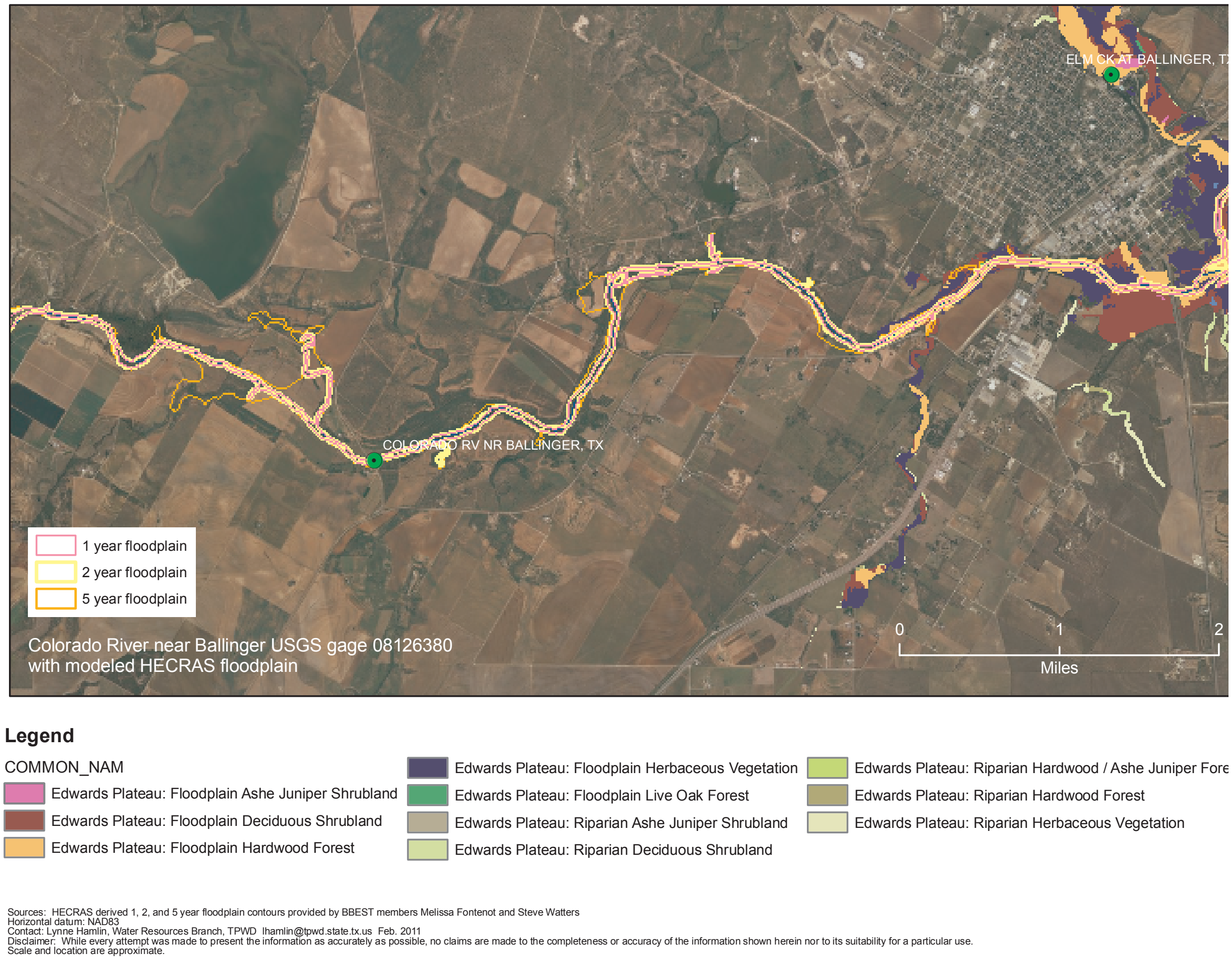
Soil	Setting	Slope %	Wetland Potential	Flood Frequency
Colorado and Yahola	Floodplains on draws	0-1	Well-drained	5-50 times per 100 years

Wetlands

The National Wetland Inventory (USFWS 2010) indicates several areas adjacent to the river that are relatively flat and about 3-7 ft above the water at low flows. Some of these areas support wetland shrubs and grasses typically found in areas that are commonly wet. These areas are expected to flood on an occasional basis. The river is classified as a lower perennial system with a low gradient and velocity, and some flow throughout the year.

Riparian/Flood plain Vegetation

Texas Ecological Systems Classification of vegetation communities has not been completed for the area at the USGS gage, so aerial photography and a site visit were used to review the riparian communities present along this reach. Broadleaf cattail and American water willow were observed in the river channel and the common buttonbush located along the banks are three species of plants, which are only found in wetlands. Their presence indicates the river is perennial along this reach. Black willow, American elm, and *Baccharis* found along the bank are plants frequently found in wetlands that would require a high water table from pulse flow events, precipitation, or flow from surrounding upland areas to support their persistence. HECRAS model results illustrating the area of inundation that occurs during a 1-year flow event, 2-year flow event, and 5-year flow event (shown in the HECRAS model map below) indicate that only the 5-year event appears to inundate areas outside of the river channel. This 5-year flow event likely causes inundation of the riparian areas along tributaries of the Colorado River, and along the riparian areas on the outside of bends in the river.

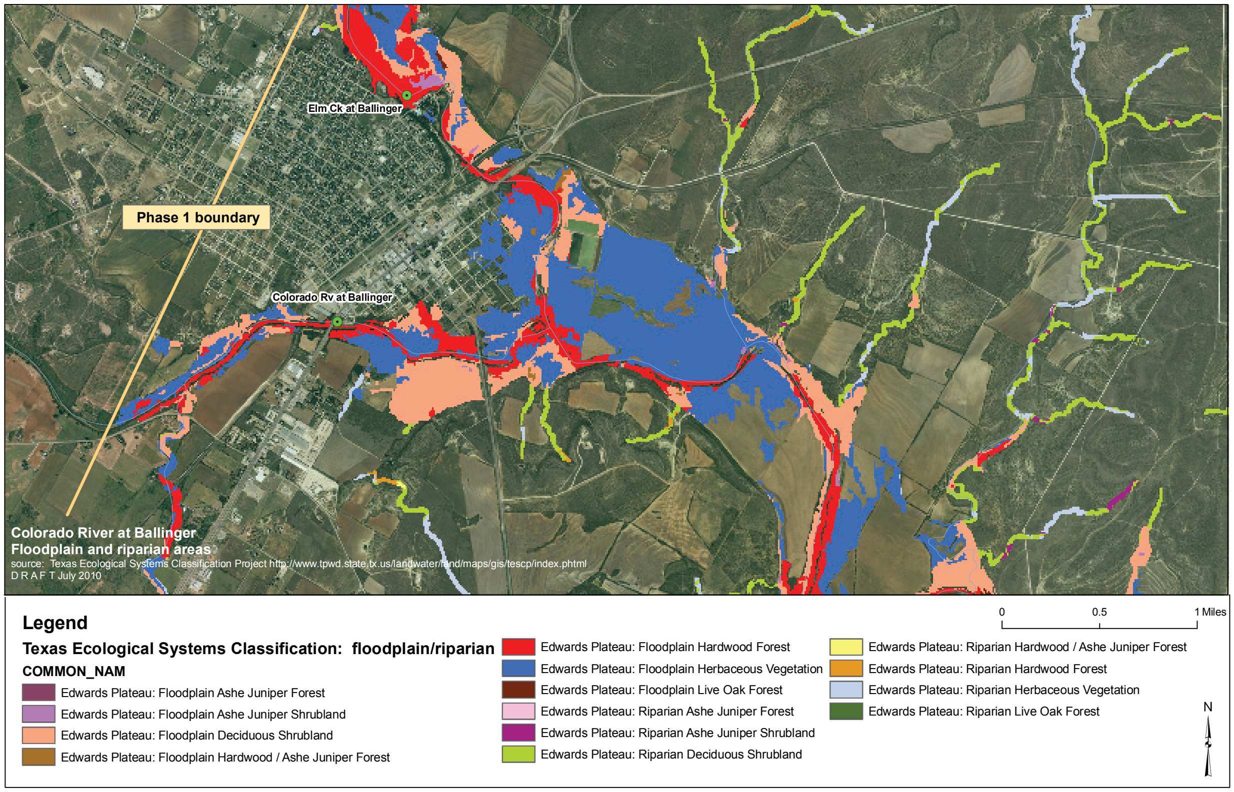


HECRAS Model Results for the Colorado River near Ballinger. The gage location indicated is the site of the current USGS gage.

Texas Ecological Systems Classification of vegetative communities is available for a 5-mile reach of the river extending about 2.5 miles upstream and 2.5 miles downstream of the confluence with Elm Creek (See Riparian Vegetation Map below, German et al. 2009). None of the common plants found in these communities require continuous exposure to wet conditions.

- Edwards Plateau floodplain herbaceous vegetation community with variety of grasses and mesquite; Plateau live oak considered part of this community but have not been observed in this particular reach of the floodplain
- Patches of Edwards Plateau deciduous shrubland common
- Edwards Plateau hardwood vegetative communities common

Black willow and sawgrass were found along some of the pools in the downstream end of this reach near O.H. Ivie Reservoir (TPWD, 1979).



Texas Ecological Systems Classification of Riparian and Floodplain Vegetation. The gage location indicated is no longer an active USGS gage.

Biology

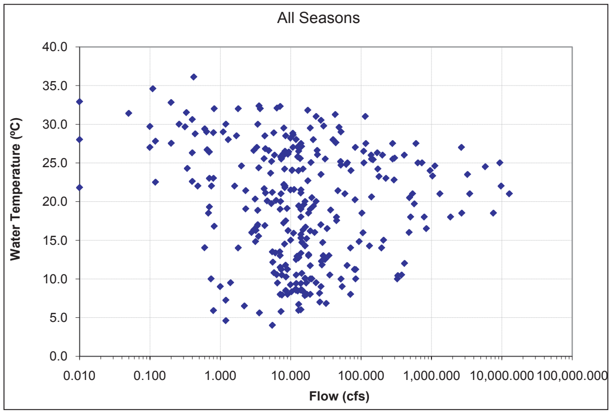
Source	Location	Biology	Observations
Espey, Huston and Associates 1978	Near existing site of O.H. Ivie Reservoir	Sixty-one species of fish and the Asiatic clam	
TPWD 2010b	Downstream of E.V. Spence Reservoir	Fish kill believed caused by toxic golden alga occurred in Colorado River downstream of Spence Reservoir. Carp, catfish and minnows observed	August 1989
TPWD 1979	Colorado and Concho rivers in Runnels, Coleman, and Concho counties	Significant populations of channel catfish, flathead catfish, white crappie, and largemouth bass present. Longnose gar, carp, and river carpsucker were abundant “rough” fish. Aquatic vegetation very limited with small amounts of *Chara*, lotus and sedge. Red shiners most abundant. Other forage fish included gizzard shad, bullhead minnow, and sunfish.	Overhanging trees, undercut banks, and boulders make up about 25% of the river margins in pools.
USFWS 2008	E.V. Spence Reservoir releases	Minimum of 4 cfs, April through September and 1.5 cfs, October through March when reservoir elevation exceeds 1,843.5 ft MSL.	To provide habitat to the Concho water snake, which utilizes riffles and to its fish prey and the vegetation that provides it cover

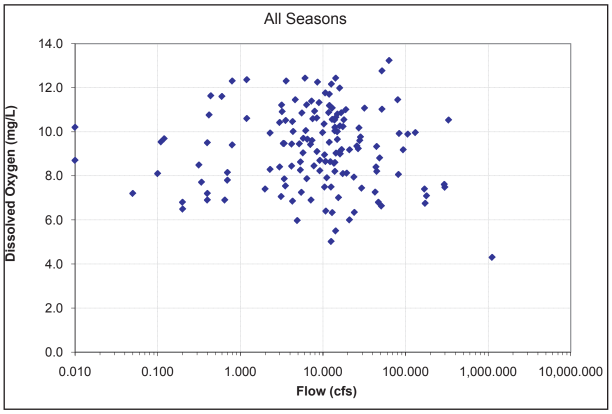
Water Quality

- The water quality period of record for this gage 10/15/1979 to 8/10/2010
- Relationships between flow and water quality parameters
  - Specific conductance decreases with increasing flow.
  - pH shows no correlation.
  - NO2+NO3–Nitrogen shows no correlation.
  - Total phosphorus shows no correlation.
  - Chlorides decrease with increasing flow.
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in the Water Quality Segment 1426, Colorado River below E.V. Spence Reservoir. The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated high aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
  - The segment of river where this gage site is located is not listed on the 303(d) list.

- Relationships between temperature and flow
  - No correlation was observed between water temperature and flow.
  - The highest temperature was 36.1 °C (flow: 0.42 cfs; dissolved oxygen: 10.8 mg/L).
  - The lowest temperature was 4.0 °C (flow: 5.5 cfs; dissolved oxygen: not measured).
  - The lowest flow was 0.01 cfs (temperature: 21.8 °C; dissolved oxygen: 10.2 mg/L).
  - The highest flow was 12,800 cfs (temperature: 21.0 °C; dissolved oxygen: not measured).
- Relationships between dissolved oxygen and flow
  - Dissolved oxygen decreases with increasing flow.
  - The highest dissolved oxygen was 13.2 mg/L (flow: 63.4 cfs; temperature: 11.7 °C).
  - The lowest dissolved oxygen was 4.3 mg/L (flow of 1120 cfs; temperature: 24.6 °C).
  - The lowest flow was 0.01 cfs (temperature: 21.8 °C; dissolved oxygen: 10.2 mg/L).
  - The highest flow was 12,800 cfs (temperature: 21.0 °C; dissolved oxygen: not measured).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria:
  - The maximum observed chloride was 1900 mg/L, which is above the TSWQS of 1000 mg/L.
  - The minimum and maximum pH were 6.4 and 8.5, which is slightly below the low range but within the high range of the TSWQS of 6.5-9.0.
  - The highest observed instantaneous temperature was 36.1 °C, which is above the TSWQS of 35 °C.
  - The minimum observed dissolved oxygen concentration was 4.3 mg/L, which is below the TSWQS of 5.0 mg/L.

The Colorado River in this reach is affected by elevated salt concentrations at least in part from historic oil field production in the basin (Reed 1961). Toxic blooms of the brackish water, golden alga, *Prymnesium parvum*, have caused fish kills in this reach of the river (TPWD 2010b).





Geomorphology

Geomorphological analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77-93% of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows.

Flow Interpretations

No-flow periods: About 5% of days from 1908 through 2010 exhibited no flow. It is not known how change in the frequency and duration of no-flow periods will affect ecosystem health. Increased frequency and duration of no-flow periods is not expected to benefit ecosystem health.

Subsistence flows: When flow at the gage is 0.62 cfs, the river can form isolated pools (Google Earth, 2010) upstream. At this flow, isolated long pools persist. The river exhibits upstream to downstream connectivity at flows of at least 4.4 cfs.

Base flows: Presence of a variety of fish, benthic macroinvertebrates, Tampico pearly mussels, cattails, and water willow indicate the existence of a perennial water body and ecological value is provided by a variety of low flows.

Pulses and overbank flows: Soils next to the river indicate flooding may occur once every 2 to 20 years. The relatively widely scattered riparian and floodplain vegetation combined with the absence of a wide variety of wetland species in the riparian community indicates flooding is probably infrequent.

HEFR/Hydrological Analysis

	Winter (Nov, Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct)
Overbank Flows	Qp: 12,300 cfs with Average Frequency 1 per 5 years Regressed Volume is 25,460 to 94,197 (48,972) Regressed Duration is 2 to 15 (6)			
Overbank Flows	Qp: 7,390 cfs with Average Frequency 1 per 2 years Regressed Volume is 15,496 to 57,286 (29,794) Regressed Duration is 2 to 14 (5)			
High Flow Pulses	Qp: 4,490 cfs with Average Frequency 1 per year Regressed Volume is 9,534 to 35,223 (18,326) Regressed Duration is 2 to 13 (5)			
High Flow Pulses	Qp: 96 cfs with Average Frequency 1 per season Regressed Volume is 255 to 1,730 (664) Regressed Duration is 2 to 17 (6)	Qp: 3,240 cfs with Average Frequency 1 per season Regressed Volume is 8,117 to 23,164 (13,712) Regressed Duration is 2 to 10 (5)	Qp: 625 cfs with Average Frequency 1 per season Regressed Volume is 1,465 to 4,653 (2,610) Regressed Duration is 2 to 9 (4)	Qp: 1,510 cfs with Average Frequency 1 per season Regressed Volume is 3,486 to 9,411 (5,728) Regressed Duration is 2 to 10 (4)
High Flow Pulses	Qp: 27 cfs with Average Frequency 2 per season Regressed Volume is 70 to 481 (184) Regressed Duration is 1 to 11 (4)	Qp: 1,300 cfs with Average Frequency 2 per season Regressed Volume is 3,153 to 8,987 (5,323) Regressed Duration is 2 to 9 (4)	Qp: 128 cfs with Average Frequency 2 per season Regressed Volume is 273 to 867 (486) Regressed Duration is 1 to 6 (3)	Qp: 249 cfs with Average Frequency 2 per season Regressed Volume is 576 to 1,556 (947) Regressed Duration is 1 to 8 (3)
Base Flows (cfs) – High	14(43.8%)	19(42.2%)	14(40.4%)	17(42.5%)
Base Flows (cfs) – Medium	8.8(59.8%)	8.8(58.3%)	5.6(53.2%)	9.8(57.8%)
Base Flows (cfs) – Low	4.6(76.9%)	3.1(74.5%)	1.9(67.4%)	4.3(73.8%)
Subsistence Flows (cfs)	0.4(95.8%)	0.1(95.0%)	0(100.0%)	0(100.0%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:

1. Period of Record used : 1/1/1940 to 12/31/2009.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 0 cfs.

Recommended Environmental Flow Regime

Colorado River near Ballinger, USGS Gage 08126380, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1908-2009	14 periods Max duration: 86 days	41 periods Max duration: 83 days	32 periods Max duration: 107 days	13 periods Max duration: 69 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	4 cfs	3 cfs	2 cfs	4 cfs
Base Medium	9 cfs	9 cfs	6 cfs	9 cfs
Base High	14 cfs	19 cfs	14 cfs	17 cfs
2 Pulses per season	Trigger: 27 cfs Volume: 180 af Duration: 11 days	Trigger: 1,300 cfs Volume: 5,300 af Duration: 9 days	Trigger: 130 cfs Volume: 490 af Duration: 6 days	Trigger: 250 cfs Volume: 950 af Duration: 8 days
1 Pulse per season	Trigger: 96 cfs Volume: 660 af Duration: 17 days	Trigger: 3,200 cfs Volume: 13,700 af Duration: 10 days	Trigger: 630 cfs Volume: 2,600 af Duration: 9 days	Trigger: 1,500 cfs Volume: 5,700 af Duration: 10 days
1 Pulse per year	Trigger: 4,500 cfs Volume: 18,300 af Duration: 13 days			
1 Pulse per 2 years (Overbank)	Trigger: 7,400 cfs Volume: 29,800 af Duration: 14 days			
1 Pulse per 5 years (Overbank)	Trigger: 12,300 cfs Volume: 49,000 af Duration: 15 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			
cfs = cubic feet per second af = acre-feet				

2.1.3 Colorado River near San Saba — USGS 08147000

Colorado River at US 190 near San Saba on September 1, 2010. Upstream view (left). Colorado River at US 190 near San Saba on September 1, 2010. Upstream view (right).

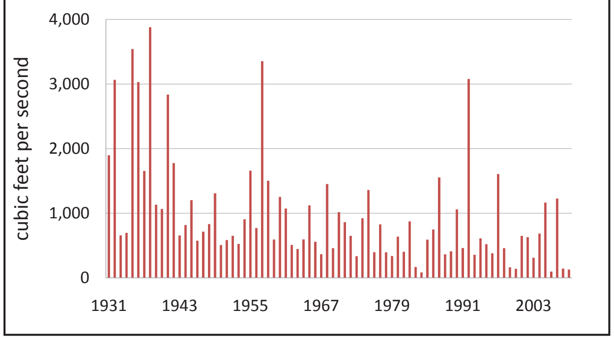
General Area Description (USGS 2010, Griffith et al. 2004, Parsons Engineering, Inc. 1999)

- Approximately 5 river miles downstream of the confluence with the San Saba River
- Approximately 141 river miles downstream of O.H. Ivie Reservoir
- TCEQ Water Quality Segment 1409
- Cross Timbers, EPA Level III ecoregion
- Much of this area overlays sandstone and shale beds with topography consisting of sandstone ridges with a gentle dip slope on one side and a steeper scarp on the other
- Soils: mostly fine sandy loams with clay subsoils that retain water
- Dominant trees: post oak and blackjack oak with an understory of greenbriar, little bluestem, and purpletop grasses
- River base flow supported by groundwater from the Edwards-Trinity and the Ellenburger-San Saba aquifers
- Approximately 474 river miles upstream from the river's mouth.

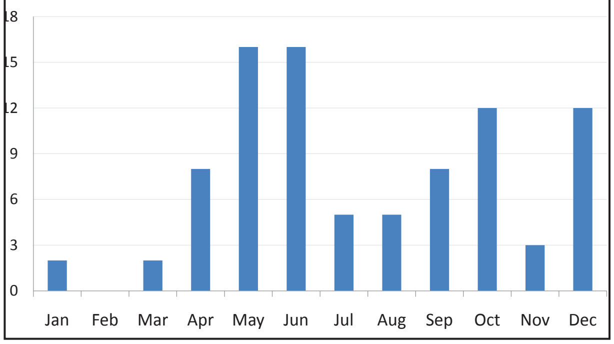
USGS Gage 08147000 Description

Lampasas County, Texas	Hydrologic Unit Code: 12090201	Latitude: 31°13'04", Longitude: 98°33'51" NAD27
Drainage area: 31,217 square miles	Contributing drainage area: 19,819 square miles	
Gage datum: 1,096.22 feet above sea level NGVD29	Flood stage occurs at 30 ft above the USGS gage elevation (NOAA 2010).	

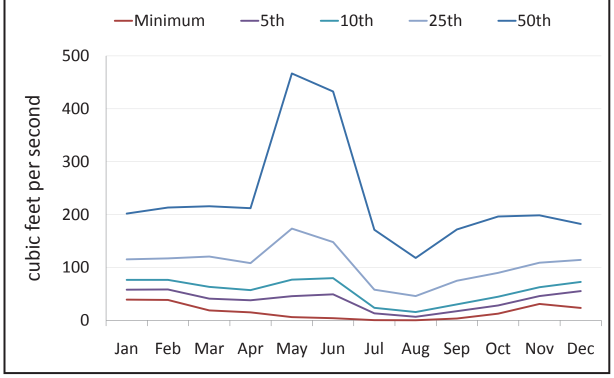
Summary of Historical USGS Flow Records at Colorado River near San Saba, (USGS 2010; NOAA 2010)



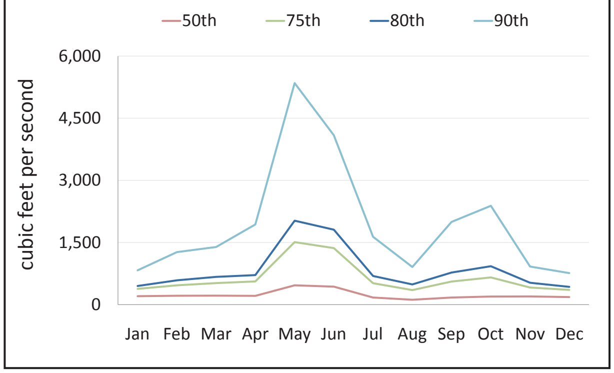
Colorado River near San Saba daily average flow for each year from 1923 through 2009.



Colorado River near San Saba number of peak flows in each month from 1930 through 2009.



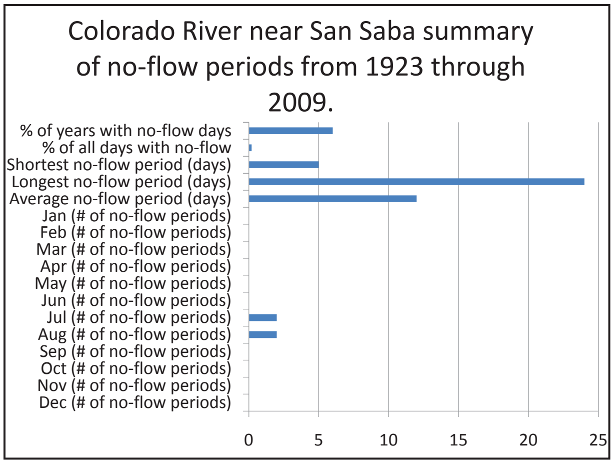
Colorado River near San Saba low flow percentiles from 1931 through 2009.

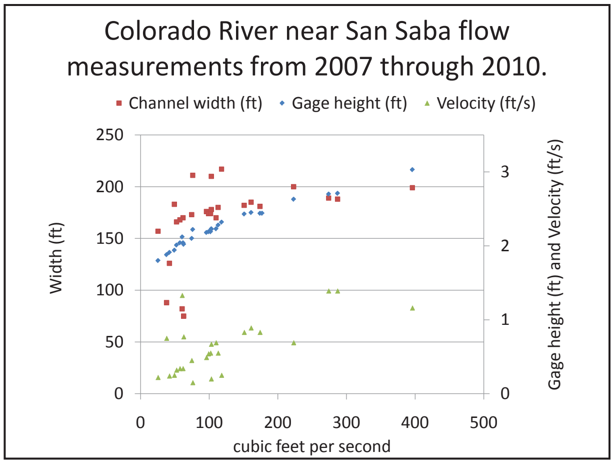


Colorado River near San Saba high flow percentiles from 1931 through 2009.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	9,751	14,354	8,651	17,363	37,587	25,349	44,440	11,454	43,674	27,434	10,429	10,906	21,783
Average	472	641	599	910	2,163	1,653	1,249	485	1,372	1,230	494	439	976
Minimum	39	39	19	15	6	4	0.4	0.1	4	13	31	24	16
5th	58	58	41	38	46	49	13	7	17	28	46	55	38
10th	77	77	63	57	77	80	24	16	30	45	63	73	57
20th	99	103	96	89	137	123	44	38	61	78	91	101	88
25th	115	117	121	108	173	148	58	46	75	90	109	114	106
50th	202	213	216	212	467	433	171	118	172	196	199	182	232
75th	379	466	519	559	1,510	1,365	518	351	558	656	413	356	637
80th	450	586	669	713	2,025	1,808	691	488	775	926	528	429	841
90th	827	1,268	1,391	1,936	5,347	4,087	1,638	908	1,997	2,384	919	762	1,955
95th	1,474	2,609	2,837	4,605	11,490	8,770	5,320	2,114	6,503	6,915	1,560	1,205	4,617

Colorado River near San Saba flow percentiles in cubic feet per second





Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases, two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5^{th}, 25^{th}, 50^{th}, 75^{th}, 80^{th}, and 90^{th} percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured.

Site Description

- Review of aerial photography with Google Earth
  - 17-river-mile reach from US 190 downstream to FM 580
  - Flows for each aerial photography date; no apparent dry reaches between pools
    - January 8, 1995: 281 cfs
    - October 21, 2005: 89 cfs
    - October 30, 2008: 54 cfs
  - Habitats
    - Long shallow runs with some riffles and pools
    - Boulder fields present
    - Riparian zone not extensive
    - Lateral flow connections to water bodies in the floodplain such as split channels or oxbows not observed
    - Island present at flow equal to or greater than 89 cfs that is not surrounded by water at flows of 54 cfs
- Field observations on September 1, 2010; Provisional USGS flow of 42 cfs
  - Long, relatively straight pool/glide of relatively constant width
  - Mosquitofish, leopard frog, and a live fragile sandshell mussel observed
  - Sandy mud bottom with banks of clay with sand
  - Black willow and green ash trees closes to the river; Large pecan trees, elms, sugar hack-berrys, western soapberry, and a few cottonwoods further up the bank
  - Colorado River at SH 16, north of San Saba and about 14 river miles upstream of San Saba River confluence, observed on September 1, 2010
    - Estimated flow: 1 cfs
    - Riffle and pool habitat with large boulders common
    - Minnows in riffle, probably red shiners
- Field observations on October 13, 2010 by TPWD and TWDB staff; Provisional USGS gage flow of 50 cfs
  - Sedges and black willow near the shore
  - Pecan trees, western soapberry, green ash, cedar, and American elm further up the bank
  - Ashe juniper and mesquite furthest from the water's edge

Soil Types

Soil data were obtained from the Natural Resource Conservation Service for a 2 mile stretch along the river (NRCS 2010).

Soil	Setting	Slope %	Wetland Potential	Flood Frequency
Yahola fine sandy loam, frequently flooded	Floodplains	0-1	Well-drained	More than 50 times per 100 years
Weswood silt loam, rarely flooded	Floodplains	0-1	Well-drained	Less than 5 times per 100 years
Nocken fine sandy loam, 5 to 15 percent slopes, very stony	Ridges on hills	5-15	Well-drained	None

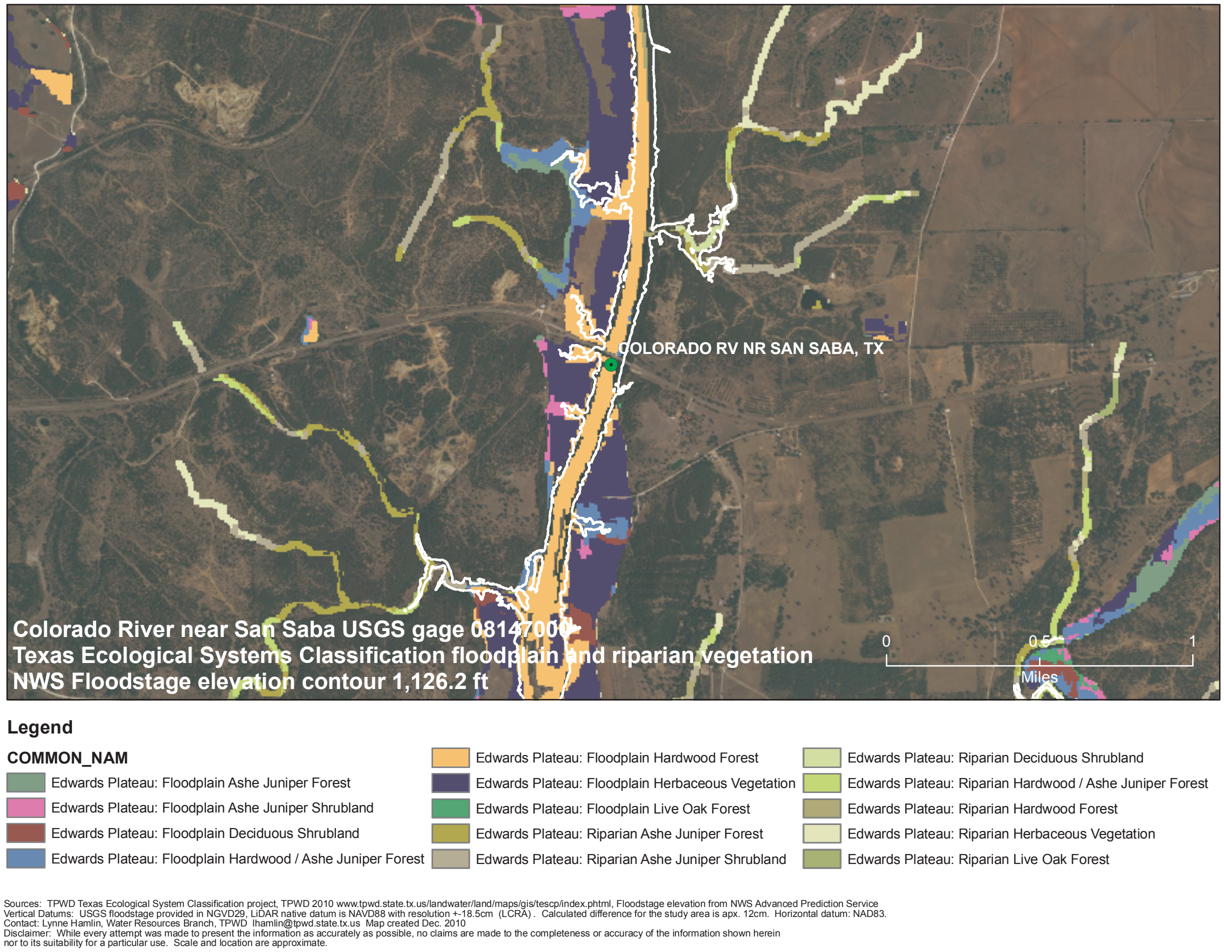
Wetlands

Review of the National Wetland Inventory (USFWS 2010) for about 2.5 miles of river near this site indicates few wetlands adjacent to the river. The river is classified as a lower perennial stream with a low gradient and velocity, and some flow throughout the year.

Riparian/Floodplain Vegetation

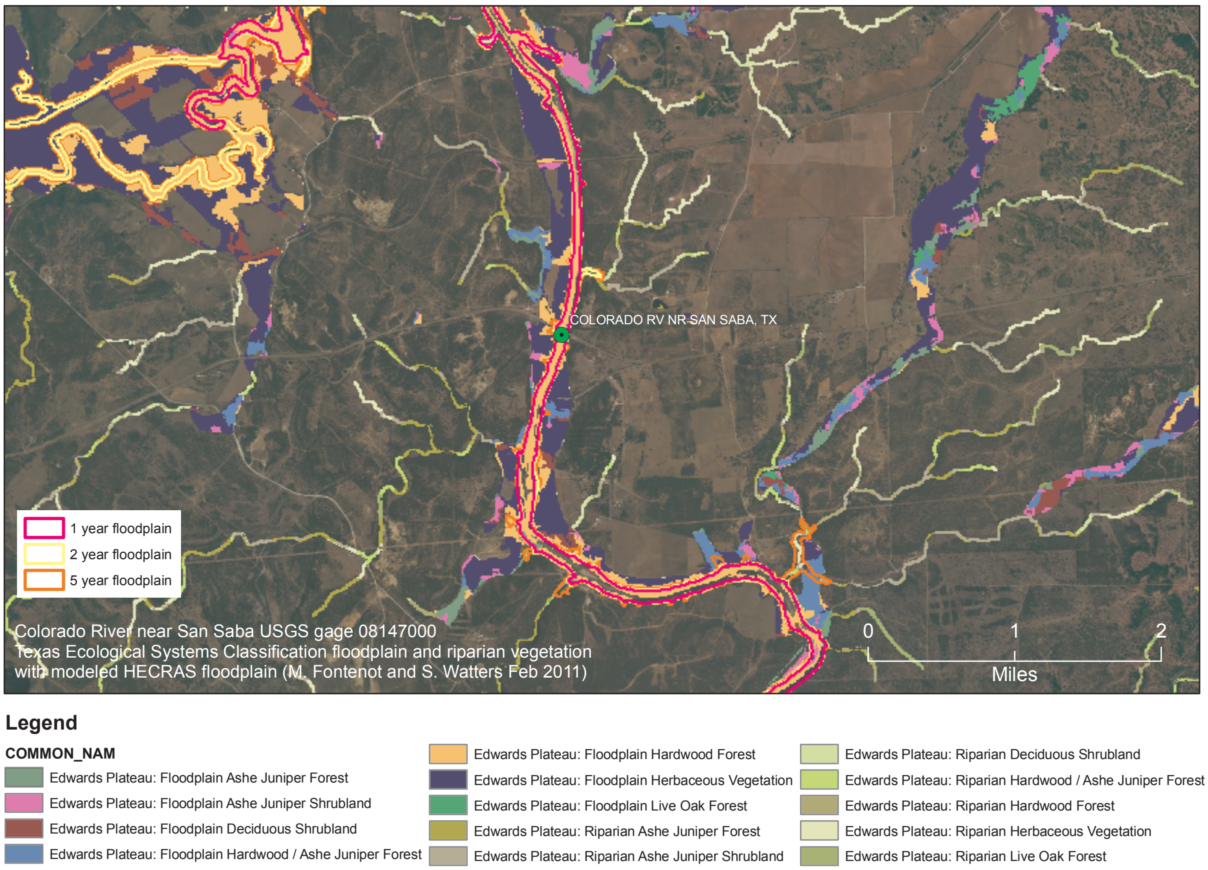
Texas Ecological Systems Classification of vegetative communities has been assessed for about 25 miles of the Colorado River from upstream of its confluence with the San Saba River to downstream of SH 190 (German et al. 2009).

- Edwards Plateau floodplain herbaceous covers most of this reach
- Edwards Plateau floodplain hardwood forest present
- Small patches of Edwards Plateau deciduous shrubland common



Texas Ecological Systems Classification of Riparian and Floodplain Vegetation. The white line represents the calculated NWS flood stage elevation.

HECRAS model results illustrating inundation that occurs during a 1-year flow event, 2-year flow event, and 5-year flow event (shown in the HECRAS model map below) indicate that the 1-year event is confined within the stream channel, and the 2-year and 5-year events inundate portions of tributaries but also remain confined within the channel of the main stem of the river. The floodplain hardwood forest communities grow in a narrow band along the channel. The black willow and green ash trees, which frequently occur in wetlands and that are found along the banks, indicate that the river along this reach is perennial. Other species in this hardwood community that were observed in the field include pecan, American elm, cedar elm, and cottonwood. These species, which are commonly found in wetlands, can withstand periods of inundation and anoxic soil conditions. They also rely on a high water table and periodic pulse flows for seed dispersal, soil moisture, and scouring of germination sites (particularly for cottonwood).



Sources: Texas Ecological System Classification project, TPWD 2010 www.tpwd.state.tx.us/landwater/land/maps/gis/tescp/index.phtml,
HECRAS derived 1, 2, and 5 year floodplain contours provided by BBEST members Melissa Fontenot and Steve Watters
Horizontal datum: NAD83
Contact: Lynne Hamlin, Water Resources Branch, TPWD lhamlin@tpwd.state.tx.us Feb. 2011
Disclaimer: While every attempt was made to present the information as accurately as possible, no claims are made to the completeness or accuracy of the information shown herein nor to its suitability for a particular use.
Scale and location are approximate.

HECRAS Model Results for the Colorado River near San Saba

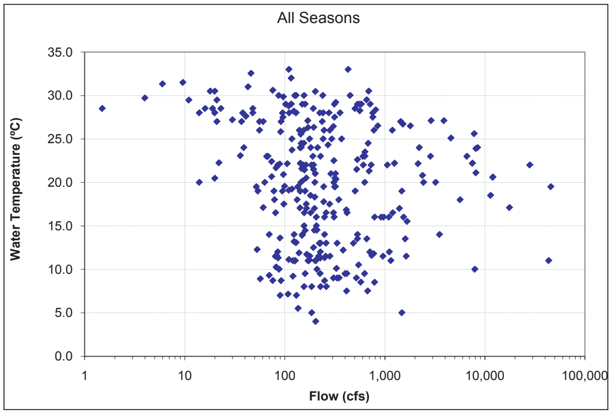
Biology

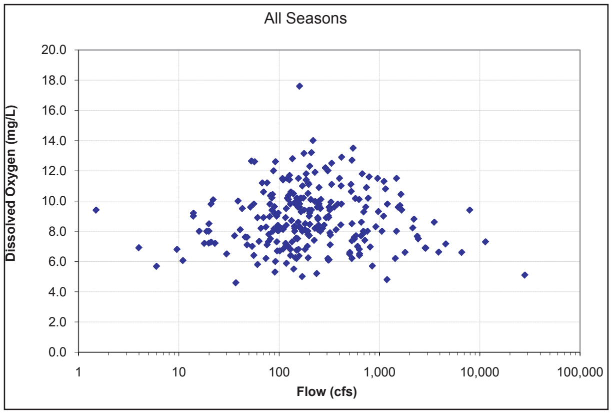
Source	Location	Biology	Observations
BIO-WEST, Inc. 2008	Colorado River near San Saba	Comprehensive review of fish, habitat, and flow	Proposed subsistence flows for the Colorado River at San Saba
LCRA 2009	Colorado River above Lake Buchanan	Fish and benthic macroinvertebrate communities indicated they were supporting aquatic life use designations from intermediate to exceptional.	Assessments based on 2008 information.
TPWD 2010	Colorado River downstream of O.H Ivie Reservoir to the confluence with the San Saba River	Species were yellow bullhead catfish, green sunfish, bluegill, blacktail shiners, pugnose minnow, mosquitofish, common carp, and channel catfish. Also seen were clams and mussel bodies floating in the water	Fish kill caused by toxic golden alga in September 1989

Water Quality

- The water quality period of record for this gage 10/1/1959 to 6/9/2010
- Relationships between flow and water quality parameters
  - Specific conductance decreases with increasing flows.
  - pH increases with increasing flow.
  - NO2+NO3–Nitrogen shows no correlation.
  - Total phosphorus increases with increasing flow.
  - Chlorides decrease with increasing flow.
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in the Water Quality Segment 1409, Colorado River above Lake Buchanan. The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated high aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
  - The segment of river where this gage site is located not listed on the 303(d) list.
- Relationships between temperature and flow
  - No correlation was observed between water temperature and flow.
  - The highest temperature was 33.0 °C (flow: 46 cfs; dissolved oxygen:7.6 mg/L).
  - The lowest temperature was 4.0 °C (flow: 204 cfs; dissolved oxygen: not measured).
  - The lowest flow was 0.1 cfs (temperature: not measured; dissolved oxygen: not measured).
  - The highest flow was 45,600 cfs (temperature: 19.5 °C; dissolved oxygen: not measured).

- Relationships between dissolved oxygen and flow
  - Dissolved oxygen decreases with increasing flow.
  - The highest dissolved oxygen was 17.6 mg/L (flow: 160 cfs; temperature: 9.5 °C).
  - The lowest dissolved oxygen was 4.6 mg/L (flow of 37.1 cfs; temperature: 27 °C).
  - The lowest flow was 0.1 cfs (temperature: not measured; dissolved oxygen: not measured).
  - The highest flow was 45,600 cfs (temperature: 19.5 °C; dissolved oxygen: not measured).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - The maximum for chloride was 1000 mg/L, which is above the TSWQS of 200 mg/L.
  - The minimum and maximum pH were 6.6 and 8.8, which were within the TSWQS range of 6.5-9.0.
  - The highest temperature was 33.0 °C, which is at the TSWQS of 33 °C.
  - The minimum dissolved oxygen 4.6 mg/L, which is below the TSWQS of 5.0 mg/L.





Geomorphology

Geomorphological analysis was conducted for this reach and is described in Section 3.10 of this report and summarized below.

1. The existing channel at the Colorado River near San Saba appears stable.

2. The HEFR regime flows including subsistence, base flows and the two per season and one per season pulses shown in the HEFR table in this section, provide 27% of the historic annual flow (1940-1998) of the Colorado River near San Saba.

3. Based on the calculations and parameters used in Section 3.10, the Colorado River near San Saba could maintain a stable channel if the annual average flow as determined from 1940-1998 was not reduced by more than 23%. More extensive analysis than described in Section 3.10 may show that a stable channel may be maintained at a lower annual average flow than examined in this study.

Flow Interpretations

No-flow periods: About 0.2% of the days over the period from 1924 through 2009 exhibited no flow. Increased frequency and duration of no-flow periods is not expected to beneficially affect the river ecosystem. Four periods of no flow occurred during July and August with an average duration of 12 days.

Subsistence flows: Subsistence flow conditions at this location and in the river downstream are only representative of the Colorado River downstream of its confluence with the San Saba River. Propose adopting subsidence flows for this site from BIO-WEST, Inc. (2008): November through June, 50 cfs as an instantaneous minimum each month, July through October, 30 cfs as an instantaneous minimum each month. The National Weather Service lowest flow for 7 days that has the likelihood of occurring at least once every 2 years is 38 cfs. Subsistence flow that maintains water quality for a relatively short period of time during drought is likely to be somewhat less than 38 cfs.

Base flows: Base flow conditions at this location and in the river downstream are only representative of the Colorado River downstream of its confluence with the San Saba River. On September 1, 2010, the estimated flow in the Colorado River upstream of the San Saba River was 1 cfs, the San Saba River flow was 38 cfs, and the Colorado River downstream of the San Saba River was 42 cfs. Biological monitoring indicates diverse communities of fish and benthic macroinvertebrates, which benefit from variable levels of flow.

Pulses and overbank flows: Soil types adjacent to the river indicate flooding may occur nearly every year to between once every 2 to 20 years.

HEFR/Hydrologic Regime

	Winter (Nov, Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct)
High Flow Pulses	Qp: 39,600 cfs with Average Frequency 1 per 5 years Regressed Volume is 163,228 to 553,287 (300,520) Regressed Duration is 6 to 31 (14)	Qp: 39,600 cfs with Average Frequency 1 per 5 years Regressed Volume is 163,228 to 553,287 (300,520) Regressed Duration is 6 to 31 (14)	Qp: 39,600 cfs with Average Frequency 1 per 5 years Regressed Volume is 163,228 to 553,287 (300,520) Regressed Duration is 6 to 31 (14)	Qp: 39,600 cfs with Average Frequency 1 per 5 years Regressed Volume is 163,228 to 553,287 (300,520) Regressed Duration is 6 to 31 (14)
High Flow Pulses	Qp: 30,400 cfs with Average Frequency 1 per 2 years Regressed Volume is 120,703 to 408,898 (222,160) Regressed Duration is 6 to 28 (13)	Qp: 30,400 cfs with Average Frequency 1 per 2 years Regressed Volume is 120,703 to 408,898 (222,160) Regressed Duration is 6 to 28 (13)	Qp: 30,400 cfs with Average Frequency 1 per 2 years Regressed Volume is 120,703 to 408,898 (222,160) Regressed Duration is 6 to 28 (13)	Qp: 30,400 cfs with Average Frequency 1 per 2 years Regressed Volume is 120,703 to 408,898 (222,160) Regressed Duration is 6 to 28 (13)
High Flow Pulses	Qp: 18,900 cfs with Average Frequency 1 per year Regressed Volume is 70,153 to 237,437 (129,062) Regressed Duration is 5 to 23 (10)	Qp: 18,900 cfs with Average Frequency 1 per year Regressed Volume is 70,153 to 237,437 (129,062) Regressed Duration is 5 to 23 (10)	Qp: 18,900 cfs with Average Frequency 1 per year Regressed Volume is 70,153 to 237,437 (129,062) Regressed Duration is 5 to 23 (10)	Qp: 18,900 cfs with Average Frequency 1 per year Regressed Volume is 70,153 to 237,437 (129,062) Regressed Duration is 5 to 23 (10)
High Flow Pulses	Qp: 1,640 cfs with Average Frequency 1 per season Regressed Volume is 5,223 to 23,446 (11,066) Regressed Duration is 2 to 15 (6)	Qp: 11,200 cfs with Average Frequency 1 per season Regressed Volume is 43,413 to 113,422 (70,171) Regressed Duration is 4 to 13 (7)	Qp: 1,430 cfs with Average Frequency 1 per season Regressed Volume is 3,587 to 11,788 (6,502) Regressed Duration is 2 to 7 (4)	Qp: 3,760 cfs with Average Frequency 1 per season Regressed Volume is 10,803 to 34,218 (19,226) Regressed Duration is 2 to 12 (5)
High Flow Pulses	Qp: 522 cfs with Average Frequency 2 per season Regressed Volume is 1,470 to 6,617 (3,119) Regressed Duration is 1 to 9 (4)	Qp: 5,830 cfs with Average Frequency 2 per season Regressed Volume is 19,345 to 50,489 (31,252) Regressed Duration is 3 to 9 (5)	Qp: 511 cfs with Average Frequency 2 per season Regressed Volume is 1,060 to 3,493 (1,925) Regressed Duration is 1 to 4 (2)	Qp: 887 cfs with Average Frequency 2 per season Regressed Volume is 1,982 to 6,296 (3,533) Regressed Duration is 1 to 6 (3)
Base Flows (cfs) – High	210(43.0%)	356(42.2%)	198(37.6%)	226(40.4%)
Base Flows (cfs) – Medium	148(61.2%)	190(59.6%)	117(50.2%)	143(55.8%)
Base Flows (cfs) – Low	99(78.8%)	115(77.1%)	72(62.8%)	91(71.4%)
Subsistence Flows (cfs)	54(95.0%)	42(95.0%)	7.7(95.0%)	22(95.3%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:

1. Period of Record used : 1/1/1940 to 12/31/2009.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 28 cfs.

Recommended Environmental Flow Regime

Subsistence and base flow conditions at this location and in the river downstream are only representative of the Colorado River downstream of its confluence with the San Saba River.

Colorado River near San Saba,USGS Gage 08147000, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1923-2009	0 periods Max duration: 0 days	0 periods Max duration: 0 days	4 periods Max duration: 24 days	0 periods Max duration: 0 days
Subsistence	50 cfs	50 cfs	30 cfs	30 cfs
Base Low	95 cfs	120 cfs	72 cfs	95 cfs
Base Medium	150 cfs	190 cfs	120 cfs	150 cfs
Base High	210 cfs	360 cfs	210 cfs	210 cfs
2 Pulses per season	Trigger: 520 cfs Volume: 3,100 af Duration: 9 days	Trigger: 5,800 cfs Volume: 31,300 af Duration: 9 days	Trigger: 510 cfs Volume: 1,900 af Duration: 4 days	Trigger: 890 cfs Volume: 3,500 af Duration: 6 days
1 Pulse per season	Trigger: 1,600 cfs Volume: 11,100 af Duration: 15 days	Trigger: 11,000 cfs Volume: 70,200 af Duration: 13 days	Trigger: 1,400 cfs Volume: 6,500 af Duration: 7 days	Trigger: 3,800 cfs Volume: 19,200 af Duration: 12 days
1 Pulse per year	Trigger: 18,900 cfs Volume: 129,100 af Duration: 23 days			
1 Pulse per 2 years	Trigger: 30,400 cfs Volume: 222,200 af Duration: 28 days			
1 Pulse per 5 years	Trigger: 39,600 cfs Volume: 300,500 af Duration: 31 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second

af = acre-feet

2.2 Colorado Tributaries

2.2.1 Elm Creek at Ballinger

USGS 08127000

Elm Creek downstream of dam in city park in Ballinger. View towards downstream on September 2, 2010 (left). Elm Creek in city park in Ballinger. View from right bank towards left bank on September 2, 2010 (right).

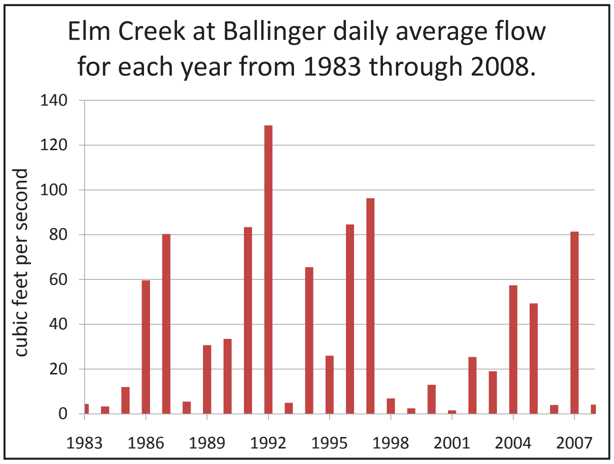
General Area Description (Google Earth 2010; Griffith et al. 2004, UCRA 2000, USGS 2010)

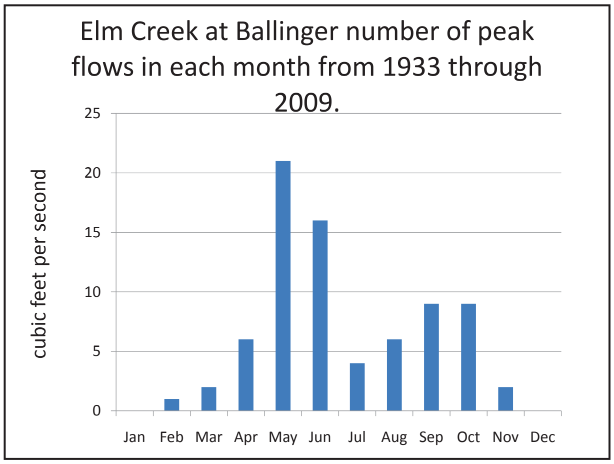
- Approximately 2 miles upstream of confluence with Colorado River
- TCEQ Water Quality Segment 1426
- Central Great Plains, EPA Level III ecoregion
- Primary land use: cultivation and grazing
- Grassland with scattered low trees and shrubs
- Rainfall rates do not support forest vegetation
- About 6% of the Colorado River watershed between E.V. Spence Reservoir and O.H. Ivie Reservoir

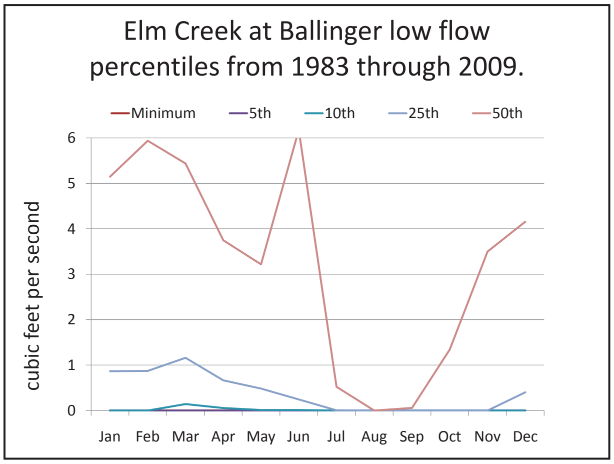
USGS Gage 08127000 Description

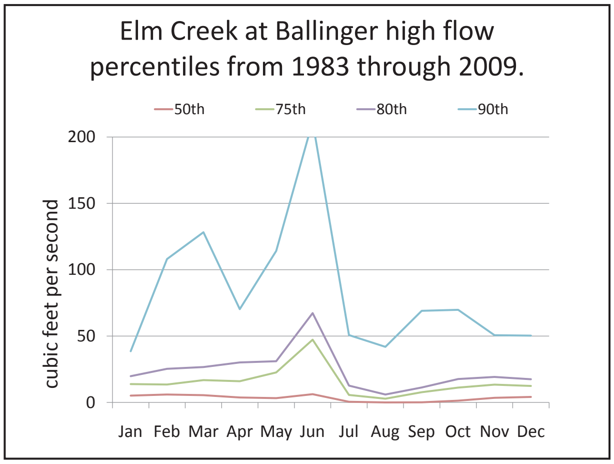
Runnels County, Texas	Hydrologic Unit Code: 12090101	Latitude: 31°44’57”, Longitude: 99°56’51” NAD27
Drainage area: 450 square miles	Contributing drainage area: 450 square miles	
Gage Datum: 1,617.72 feet above sea level NGVD29	Flood stage elevation: 7 ft above the USGS gage elevation (NOAA, 2010)	

Summary of Historical USGS Flow Records at Elm Creek at Ballinger



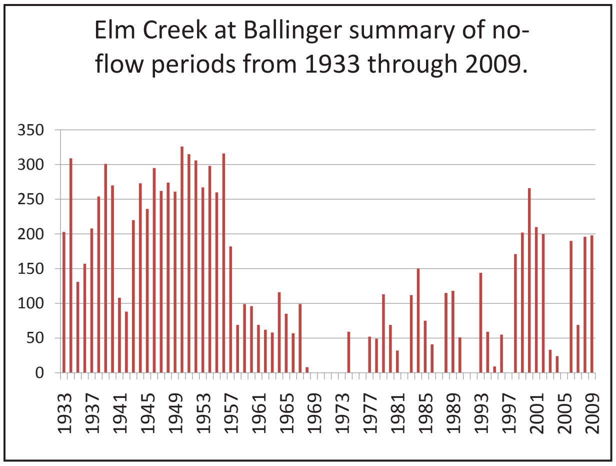


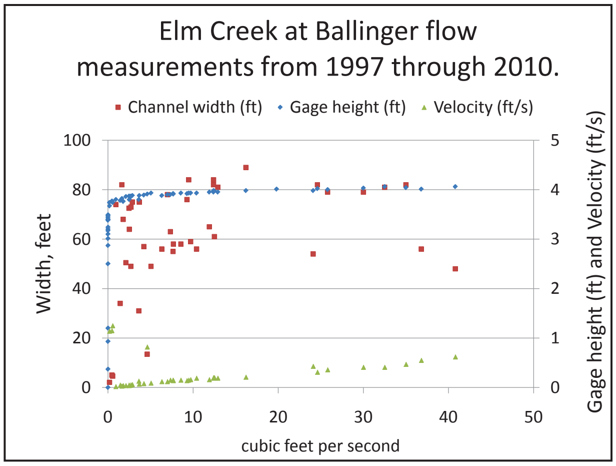




	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	164	947	388	142	1,011	1,821	225	300	857	433	483	608	615
Average	15	53	34	18	57	104	16	16	41	27	28	32	37
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0
5th	0	0	0	0	0	0	0	0	0	0	0	0	0
10th	0	0	0.1	0.1	0	0	0	0	0	0	0	0	0
20th	0.4	1	1	0.3	0.3	0.1	0	0	0	0	0	0.1	0
25th	1	1	1	1	0.5	0.2	0	0	0	0	0	0.4	0
50th	5	6	5	4	3	6	1	0	0.1	1	3	4	3
75th	14	13	17	16	23	47	6	3	8	11	13	12	15
80th	20	25	27	30	31	67	13	6	11	18	19	17	24
90th	39	108	128	70	114	212	51	42	69	70	51	50	84
95th	117	649	306	119	699	1,246	172	212	572	309	326	395	427

Elm Creek at Ballinger flow percentiles in cubic feet per second





Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases, two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5th, 25th, 50th, 75th, 80th, and 90th percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured.

Historical Hydrology

Elm Creek has experienced reduced flow as a result of brush infestation in the watershed since the drought of the 1950s (UCRA 2000). Mesquite, saltcedar, ashe juniper, which uptake more water than the grasslands they replaced, reduce groundwater flow into the streams like Elm Creek. TCEQ sampled Elm Creek in 1995 at a flow of 6.7 cfs and determined there appeared to be a number of small springs and seeps to the creek in the reach sampled upstream of the wastewater treatment plant (TCEQ 1996).

Site Description

- Review of aerial photography with Google Earth
  - 12 river-mile reach from confluence with Colorado River upstream to County Road 202
  - Flows for each aerial photography date
    - January 9, 1995: 14 cfs
    - October 21, 2005: 5.5 cfs
    - October 30, 2008: 0 cfs
  - Habitats
    - Lower portion of creek consists of pools impounded behind a series of 5 dams
    - Upstream of the furthest upstream dam are relatively small pools and glides separated by riffle-run sequences
    - Long pools present at 0 cfs flow
    - Mouths of 4 tributaries
    - Abandoned creek channel parallels left bank for 3 miles
    - Oxbows absent
    - Riparian vegetation zone relatively narrow
- Field observations on September 2, 2010 at dam forming the pool where the USGS gage is located; USGS provisional flow of 0.0 cfs
  - USGS gage located on a run-of-the-creek reservoir formed by a relatively high dam in the city of Ballinger
  - Much of the creek is reservoir-like with short riffles over bedrock downstream of the dams at low flows

Soil Types

Soil data were obtained from the Natural Resource Conservation Service for a 1.5 mile stretch along the creek upstream of Ballinger (NRCS 2010).

Soil	Setting	Slope %	Wetland Potential	Flood Frequency
Colorado and Yahola	Floodplains on draws	0-1	Well-drained	5-50 times per 100 years
Spur loam	Floodplain steps on river valleys	0-1	Well-drained	5-50 times per 100 years

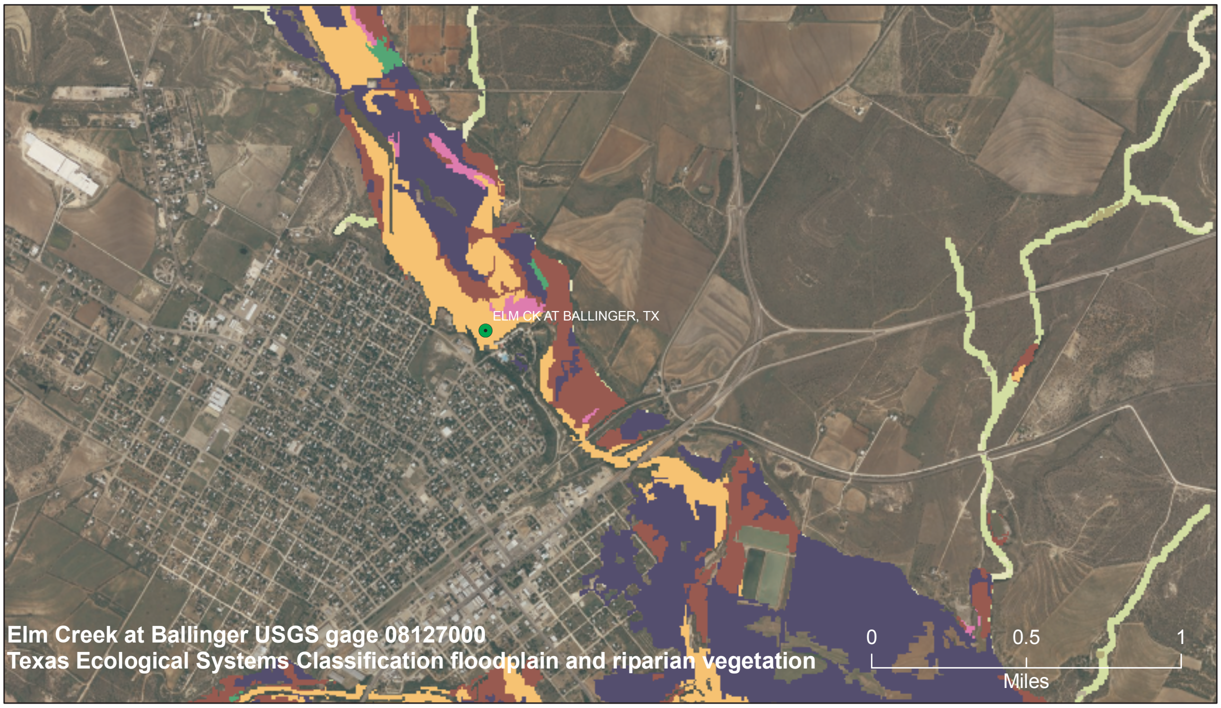
Wetlands

The National Wetland Inventory (USFWS 2010) indicates several areas adjacent to the river that are relatively flat. Some of these areas support shrubs and grasses that grow in areas that are commonly wet. These areas are expected to flood on an occasional basis. The creek in this reach is classified as lake-like behind a dam. There is a possible abandoned creek channel about 170 meters from the creek that is classified as a persistent wetland with emergent wetland vegetation that is seasonally flooded. There are also several wetlands with scrub-shrub vegetation that appear to experience temporary flooding adjacent to the creek.

Riparian/Flood Plain Vegetation

Texas Ecological Systems Classification of vegetative communities is available for about a 3-mile reach of the creek starting about 1 mile upstream of the confluence with the Colorado River (See Riparian Vegetation Map below, German et al. 2009).

- Edwards Plateau floodplain herbaceous vegetation community with a variety of grasses and mesquite trees covers the greatest area of the floodplain; Some plateau live oak trees may be present but are not known to occur around this site
- Patches of Edwards Plateau deciduous shrubland
- Edwards Plateau flood plain hardwood forests common



Legend

COMMON_NAM

- Edwards Plateau: Floodplain Ashe Juniper Shrubland
- Edwards Plateau: Floodplain Deciduous Shrubland
- Edwards Plateau: Floodplain Hardwood Forest
- Edwards Plateau: Floodplain Herbaceous Vegetation
- Edwards Plateau: Floodplain Live Oak Forest
- Edwards Plateau: Riparian Ashe Juniper Shrubland
- Edwards Plateau: Riparian Deciduous Shrubland
- Edwards Plateau: Riparian Hardwood / Ashe Juniper Forest
- Edwards Plateau: Riparian Hardwood Forest
- Edwards Plateau: Riparian Herbaceous Vegetation

Sources: Texas Ecological System Classification project, TPWD 2010 www.tpwd.state.tx.us/landwater/land/maps/gis/tescp/index.phtml,
Horizontal datum: NAD83.
Contact: Lynne Hamlin, Water Resources Branch, TPWD lhamlin@tpwd.state.tx.us Map created Dec. 2010
Disclaimer: While every attempt was made to present the information as accurately as possible, no claims are made to the completeness or accuracy of the information shown herein nor to its suitability for a particular use.
Scale and location are approximate.

Texas Ecological Systems Classification for Riparian and Floodplain Vegetation for Elm Creek at Ballinger

Biology

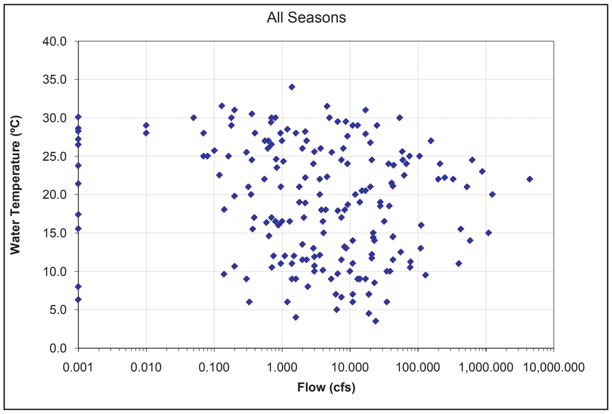
Source	Location	Biology	Observations
Linam et al. 2002	Elm Creek at unnamed road north of Ballinger	Collected 13 species of fish (gizzard shad, mosquitofish, red shiner, longnose gar, river carpsucker, bullhead minnow, orangethroat darter, longear sunfish, bluegill sunfish, largemouth bass, green sunfish, channel catfish, and common carp) on August 23, 1988.	At a flow of 0.1 cfs, stream bends were not well defined. Substrate varied from mud/ silt in some of the deep pools, broken bedrock covered with a layer of silt in shallower pools and glides, to gravel and rubble in the riffles.
TCEQ 1996	Elm Creek near Ballinger wastewater treatment plant	20 species of fish and 27 benthic macroinvertebrate taxa collected at 2 sites Turtles present TCEQ concluded that Elm Creek supported a high aquatic life use	Sampled Dec. 13-15, 1995 at a flow of 6.7 cfs About 80% pools, 5% riffles, and 15% runs Instream cover was undercut banks, logs/stumps, large boulders, and overhanging vegetation Riparian zone 10 ft wide
TPWD 2010	Elm Creek 9 miles north of Ballinger	Fish kill	Undetermined cause killed an undetermined number of fish
TPWD 2010a	Elm Creek in Ballinger	Fish kill	Caused by toxic golden alga
Burlakova and Karatayev 2010	Elm Creek above Ballinger	State-threatened mussel, Texas pimpleback, collected prior to 2005 but absent in 2008. State-threatened Texas fat mucket was found (1 live mussel) in 2008. Tampico pearlymussel and southern mapleleaf mussels collected in 2008	2008 samples collected during low flow conditions
TPWD 2010b	Elm Creek above Ballinger	Habitat utilized by the Concho water snake	Concho water snake utilizes riffle habitat. Feeds on fish and utilizes adjacent vegetation for cover

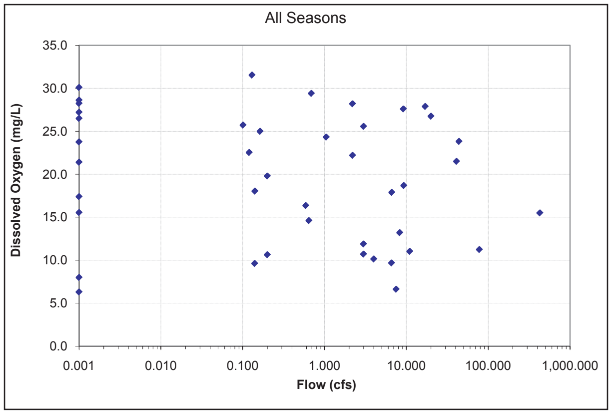
Water Quality

- The water quality period of record for this gage is
- 3/11/1964 to 7/7/2009
- Relationships between flow and water quality parameters
  - Specific conductance decreases with increasing flow.
  - pH shows no correlation.
  - NO2+NO3–Nitrogen shows no correlation.
  - Total phosphorus shows no correlation.
  - Chloride decreases with increasing flow.
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in the Water Quality Segment 1426, Colorado River below E.V. Spence Reservoir. The 2008 Texas

Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated high aquatic life use.

- Water quality impairments, if any, listed on the 303(d) list
  - The segment of river where this gage site is located is not listed on the 303(d) list.
- Relationship between temperature and flow No correlation was observed between water temperature and flow.
  - The highest temperature was 34.0 °C (flow: 1.4 cfs; dissolved oxygen: not measured).
  - The lowest temperature was 3.5 °C (flow: 24 cfs; dissolved oxygen: not measured).
  - The lowest flow was 0 cfs.
  - The highest flow was 6400 cfs (temperature: not measured; dissolved oxygen: not measured).
- Relationship between dissolved oxygen and flow
  - No correlation was observed between dissolved oxygen and flow.
  - The highest dissolved oxygen was 12.3 mg/L (flow: 0.14 cfs; temperature: 9.6 °C).
  - The lowest dissolved oxygen was 3.9 mg/L (flow of 1.05 cfs; temperature: 24.3 °C).
  - The lowest flow was 0 cfs.
  - The highest flow was 6400 cfs (temperature: not measured; dissolved oxygen: not measured).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria:
  - The maximum observed chloride was 1150 mg/L, which is above the TSWQS of 1000 mg/L.
  - The minimum and maximum pH were 6.5 and 9.0, which are within the TSWQS range of 6.5-9.0.
  - The highest observed instantaneous temperature was 34.0 °C, which is below the TSWQS of 35 °C.
  - The minimum observed dissolved oxygen concentration 3.9 mg/L, which is below the TSWQS of 5.0 mg/L.





Geomorphology

Geomorphological analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77-93% of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows..

Flow Interpretations

No-flow periods: About 36% of the days over the period from 1932 through 2009 exhibited no flow. Periods of no flow occurred throughout the year over the period of record and dominated some years. For example, in 1950, 89% of the days had daily average flow values of 0 cfs. Long pools and glides appear to persist during periods of no flow. The effects of change in the frequency and duration of no-flow periods are not known. Increased frequency and duration of no-flow periods is not expected to beneficially affect ecosystem health.

Subsistence flows: River flows at or above 5.5 cfs at this gage appear to maintain perennial flow and upstream-downstream connectivity in the creek.

Base flows: Presence of turtles, 20 species of fish, and 27 benthic macroinvertebrate taxa, combined with a wetted channel observed at different flows on Google Earth indicate the existence of a perennial water body. The variety of aquatic taxa with their habits and physical habitat requirements indicates ecological value is provided by variable low flows. Additionally, TCEQ's 1995 survey indicates groundwater contributions to base flow during the winter.

Pulses and overbank flows: Soils adjacent to the river indicate flooding may occur once every 2 to 20 years. The relatively widely scattered riparian and floodplain vegetation indicate flooding is probably infrequent. Historical hydrology indicates pulses occurred most frequently during the late spring and fall.

HEFR/Hydrologic Analysis

	Winter (Nov, Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct)
Overbank Flows	Qp: 6,340 cfs with Average Frequency 1 per 5 years Regressed Volume is 11,768 to 43,876 (22,723) Regressed Duration is 3 to 22 (8)			
High Flow Pulses	Qp: 3,540 cfs with Average Frequency 1 per 2 years Regressed Volume is 6,786 to 25,277 (13,097) Regressed Duration is 3 to 20 (8)			
High Flow Pulses	Qp: 1,890 cfs with Average Frequency 1 per year Regressed Volume is 3,751 to 13,959 (7,236) Regressed Duration is 3 to 18 (7)			
High Flow Pulses	Qp: 40 cfs with Average Frequency 1 per season Regressed Volume is 110 to 673 (272) Regressed Duration is 2 to 16 (5)	Qp: 1,040 cfs with Average Frequency 1 per season Regressed Volume is 2,305 to 6,371 (3,832) Regressed Duration is 2 to 12 (5)	Qp: 74 cfs with Average Frequency 1 per season Regressed Volume is 176 to 523 (303) Regressed Duration is 2 to 10 (5)	Qp: 192 cfs with Average Frequency 1 per season Regressed Volume is 462 to 1,557 (848) Regressed Duration is 2 to 15 (6)
High Flow Pulses	Qp: 11 cfs with Average Frequency 2 per season Regressed Volume is 29 to 176 (71) Regressed Duration is 1 to 10 (3)	Qp: 375 cfs with Average Frequency 2 per season Regressed Volume is 848 to 2,343 (1,410) Regressed Duration is 2 to 10 (4)	Qp: 6 cfs with Average Frequency 2 per season Regressed Volume is 15 to 44 (25) Regressed Duration is 1 to 6 (3)	Qp: 9 cfs with Average Frequency 2 per season Regressed Volume is 25 to 85 (46) Regressed Duration is 1 to 9 (3)
Base Flows (cfs) – High	3.6(45.8%)	5(44.4%)	0.05(44.1%)	0.74(44.6%)
Base Flows (cfs) – Medium	0.7(63.7%)	1(63.7%)	0(100.0%)	0(100.0%)
Base Flows (cfs) – Low	0(100.0%)	0(100.0%)	0(100.0%)	0(100.0%)
Subsistence Flows (cfs)	0(100.0%)	0(100.0%)	0(100.0%)	0(100.0%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:
1. Period of Record used : 1/1/1940 to 12/31/2009.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 0 cfs.

Recommended Environmental Flow Regime

Elm Creek at Ballinger, USGS Gage 08127000, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1933-2009	Average number of days each year with no flow = 130			
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	1 cfs	1 cfs	1 cfs	1 cfs
Base Medium	1 cfs	1 cfs	1 cfs	1 cfs
Base High	4 cfs	5 cfs	1 cfs	1 cfs
2 Pulses per season	Trigger: 10 cfs Volume: 71 af Duration: 10 days	Trigger: 380 cfs Volume: 1,400 af Duration: 10 days	Trigger: 6 cfs Volume: 25 af Duration: 6 days	Trigger: 10 cfs Volume: 46 af Duration: 9 days
1 Pulse per season	Trigger: 40 cfs Volume: 270 af Duration: 16 days	Trigger: 1,000 cfs Volume: 3,800 af Duration: 12 days	Trigger: 74 cfs Volume: 300 af Duration: 10 days	Trigger: 190 cfs Volume: 850 af Duration: 15 days
1 Pulse per year	Trigger: 1,900 cfs Volume: 7,200 af Duration: 18 days			
1 Pulse per 2 years	Trigger: 3,500 cfs Volume: 13,100 af Duration: 20 days			
1 Pulse per 5 years (Overbank)	Trigger: 6,300 cfs Volume: 22,700 af Duration: 22 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second ,

af = acre-feet

2.2.2 Concho River at Paint Rock

USGS 08136500

Concho River at Paint Rock, about 10 meters upstream of low water crossing. View from right bank towards left bank. September 2, 2010 (left). Concho River, about 50 meters downstream of the low water crossing in Paint Rock. September 2, 2010 (right).

Concho River at low water crossing in Paint Rock. Habitat in which the Concho water snake may be encountered. September 2, 2010.

General Area Description (Griffith et al. 2004, UCRA 2000a, USGS 2010)

- Approximately 20 river miles upstream of its former confluence with the Colorado River; Confluence now inundated by O.H. Ivie Reservoir: Distance to the reservoir from the USGS gage site varies with reservoir level
- TCEQ Water Quality Segment 1421
- Central Great Plains, EPA Level III ecoregion
- Primary land use: cultivation and grazing
- Grassland with scattered low trees and shrubs
- Rainfall rates do not support forest vegetation
- Average annual rainfall in the watershed: 23.6 inches

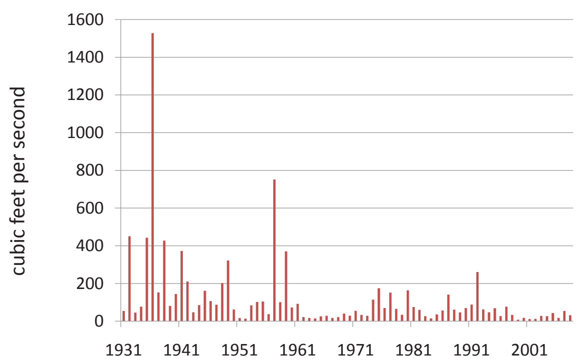
- Land use in the watershed: 59% brush, 5% oak, 10% open range and pasture, 26% crops, and <1% other

USGS Gage 08136500 Description

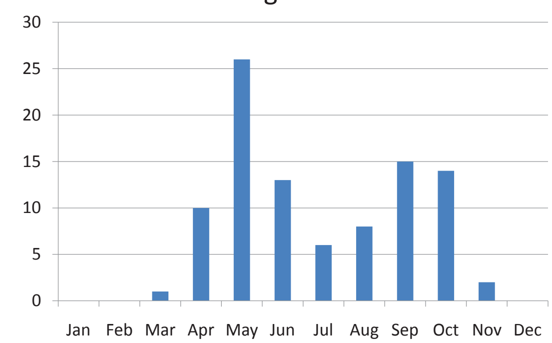
Concho County, Texas	Hydrologic Unit Code: 12090105	Latitude: 31°30'57", Longitude: 99°55'09" NAD27
Drainage area: 5,433 square miles	Contributing drainage area: 450 square miles	
Gage Datum: 1,574.35 feet above sea level NGVD29	Flood stage elevation: 26 ft above the USGS gage elevation (NOAA 2010)	

Summary of Historical USGS Flow Records at Concho River at Paint Rock

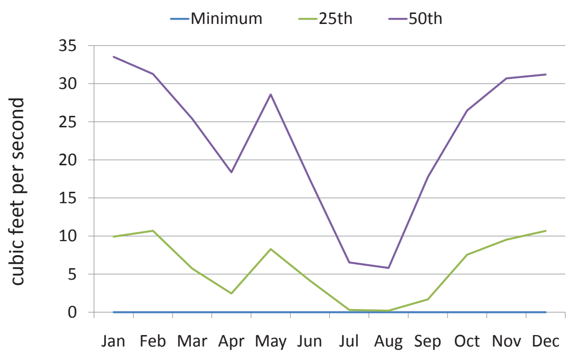
Concho River at Paint Rock daily average flow for each year from 1931 through 2007.



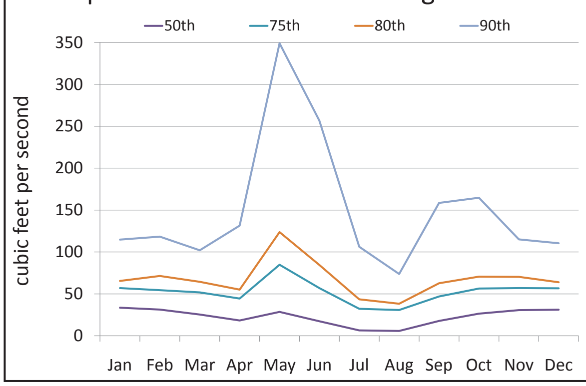
Concho River at Paint Rock number of peak flows in each month from 1916 through 2009.



Concho River at Paint Rock low flow percentiles from 1931 through 2009.

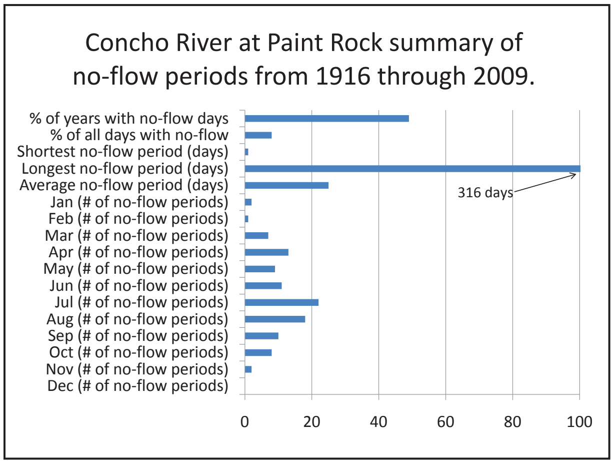


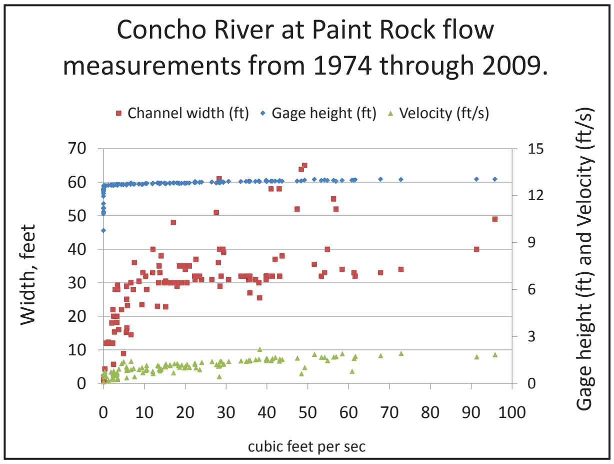
Concho River at Paint Rock high flow percentiles from 1931 through 2009.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	487	1,059	904	4,536	8,773	3,494	6,924	2,087	20,678	7,325	886	747	4,825
Average	48	61	51	122	263	125	134	55	329	176	55	52	123
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0
20th	6	7	4	1	5	3	0.1	0.1	1	4	7	8	4
25th	10	11	6	2	8	4	0.3	0.2	2	8	10	11	6
50th	34	31	25	18	29	17	7	6	18	26	31	31	23
75th	57	54	52	44	85	57	32	31	47	56	57	57	52
80th	65	71	64	55	124	85	43	38	63	71	70	64	68
90th	115	118	102	132	349	257	106	74	159	165	115	110	150
95th	166	220	182	419	1,273	601	253	156	430	466	187	176	378

Concho River at Paint Rock flow percentiles in cubic feet per second





Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases, two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5th, 25th, 50th, 75th, 80th, and 90th percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured.

Historical Hydrology

The Concho River downstream of San Angelo (UCRA 2000a)

- Perennial stream
- Gains flow in the downstream part of the river as water flows into the stream from the shallow alluvial aquifers in contact with the stream
- Hydrologic studies and groundwater modeling indicate the Concho historically received an average of approximately 7,000 ac-ft of water per year (1915-1998) from dewatering of the Leona Aquifer in Tom Green and Concho Counties. This amount averages 9.7 cfs for a year.
- Several tributaries perennial until the drought of the 1950s after which brush infestations prevented the return of perennial flow

Accounts from a Mendoza expedition in 1683 describe the Concho Valley, at the mouth of Kiowa Creek in southern Sterling County, on the North Concho River upstream of present day San Angelo (UCRA 2000a). One entry in the record of the expedition states:

> "In this place were the first pecan trees we saw, for its bottoms have many groves of them; many nuts were gathered,... It also has shells, a variety of fish, and very lofty live oaks, so large that carts and other bulky things can be made of them. There is a great variety of plants and of wild hens, which make noise at dawn. The river bottoms are very extensive and fertile, in its groves are many grape vines and springs, and many prickly pear patches; and all of the foregoing are on both sides of the river."

Concho River width was measured during a 1981 survey (Ezell 1983). Average stream width at 6 sites ranged from 28.6 to 64.5 ft. Stream velocity based on time-of-travel measurements was estimated to be 0.1 ft/second.

Espey, Huston & Associates, Inc. (1978) concluded:

- Variable nature of flow: primary factor affecting habitat availability
- Concho River perennial, although periods of low flow and subsurface flow occurred
- Tributary mouths support fish spawning when tributaries flowed
- Rock, ranging from coarse gravel to limestone bedrock, covered much of the stream bottom
- Pools separated by extensive riffles most common habitat available

The Concho River Basin experienced drought from 1962-1968 (Sauer 1972). Analysis of rainfall and runoff patterns in the basin indicated:

- Runoff generated by high intensity and long-duration rainfall preceded by moderate amounts of antecedent rain
- 2% chance in any year that a 1.9 inch rainfall will occur at any point
- 2% chance in any year that a 1.2 inch rainfall will occur over at least 300 square miles
- Changes in land use and soil conservation efforts since 1916 reduced runoff during 1962-1968 by about 7%

Substantial changes in the Concho River Basin watershed condition have occurred (UCRA 2008).

- Historic overgrazing and fire suppression shifted landscape from predominately grassland prairie to brush infested. Brush is comprised mostly of mesquite and juniper, which have decreased watershed yields and base flows.
- Reservoir construction above San Angelo eliminated downstream scouring floods and affected base flows.
- Urban stormwater runoff dominates water quality conditions in San Angelo and downstream reaches of the river.
- Proliferation of deeper groundwater development causing induced blending of deeper Permian aquifers and the shallow alluvial aquifer, which reduces groundwater quality in the Lipan Aquifer and surface water quality in the river.
- Increased pumping of the Lipan Aquifer diminished river base flows.

Concho River base flow according to Texas Clean Rivers Program records declined during the period from 1998–2002. The river intermittently ceased to flow while many pools completely dried-up, forcing the City of Paint Rock, which uses the Concho River for its public water supply, to seek alternative supplies (UCRA 2008). Possible causes of reduced base flow include:

- Increased irrigation with groundwater; Number of irrigation wells in the Lipan Aquifer increased from about 200 in 1990 to more than 1,000 in 2000. Irrigation pumping increased from 15,000 ac-ft per year in the late 1980s to over 65,000 ac-ft per year by the late 1990s
- Impoundment of flows in upstream reservoirs
- Infestation of 285,000 acres with moderate to heavy density of brush

Site Description

- Review of aerial photography with Google Earth
  - 9-river-mile reach from USGS gage downstream to the last riffle-run upstream of O.H. Ivie Reservoir at flows of 30 cfs; Distance to Lake O.H. Ivie with reservoir full is approximately 7 river miles
  - Flows for each aerial photography date
    - January 9, 1995: 41 cfs
    - February 14, 1997: flow data not available

        - October 21, 2005: 36 cfs
        - October 30, 2008: 10 cfs
        - February 14, 2010: 30 cfs
    - Habitats
        - Long pools with rocky run-riffles common and a relatively narrow riparian zone
        - Six islands and several backwater areas present
        - Lateral features such as split channels or oxbows not observed
        - Low-water dam 450 meters downstream of the USGS gage and about 15 others upstream of the gage towards San Angelo; Between these dams are reaches where the river is free-flowing with pools separated by riffle-run sequences; A few backwater areas and mouths of tributaries that provide habitat; Also reaches where the land is plowed practically to the river's edge
- Field observations on September 2, 2010 at USGS gage site; USGS provisional flow of 5.3 cfs
    - Long, relatively straight pool of relatively constant width upstream of the USGS gage
- Field observations by TPWD and TWDB staff on October 11, 2010 just downstream of the USGS gage site; USGS provisional flow of 2.1 cfs
    - Riparian zone dominated by herbaceous vegetation like nightshade, cockle burs, ragweed, sunflower species, Bermuda grass, prickly pear, and pencil cactus
    - Emergent aquatic plant, water willow, observed in the river
    - Pecan, mesquite, and hackberry observed higher on the bank

Soil Types

Soil data were obtained from the Natural Resource Conservation Service for a 5-mile stretch along the river from about 1 mile downstream of the USGS gage and 4 miles upstream of the gage (NRCS 2010).

Soil	Setting	Slope %	Wetland Potential	Flood Frequency
Frio silty clay loam, frequently flooded	Flood plains and flood plains on draws	0-2	Well drained	More than 50 times per 100 years
Frio silty clay loam, occasionally flooded	Flood plains and flood plains on draws	0-1	Well drained	5 to 50 times per 100 years
Dev gravelly loam	Flood plains and flood plains on draws	0-3	Well drained	More than 50 times per 100 years
Lueders-Throck association, hilly	Hillslopes on ridges	5-30	Well drained	None
Gageby loam, rarely flooded	Flood plain steps on draws	0-1	Well drained	1 to 5 times per 100 years

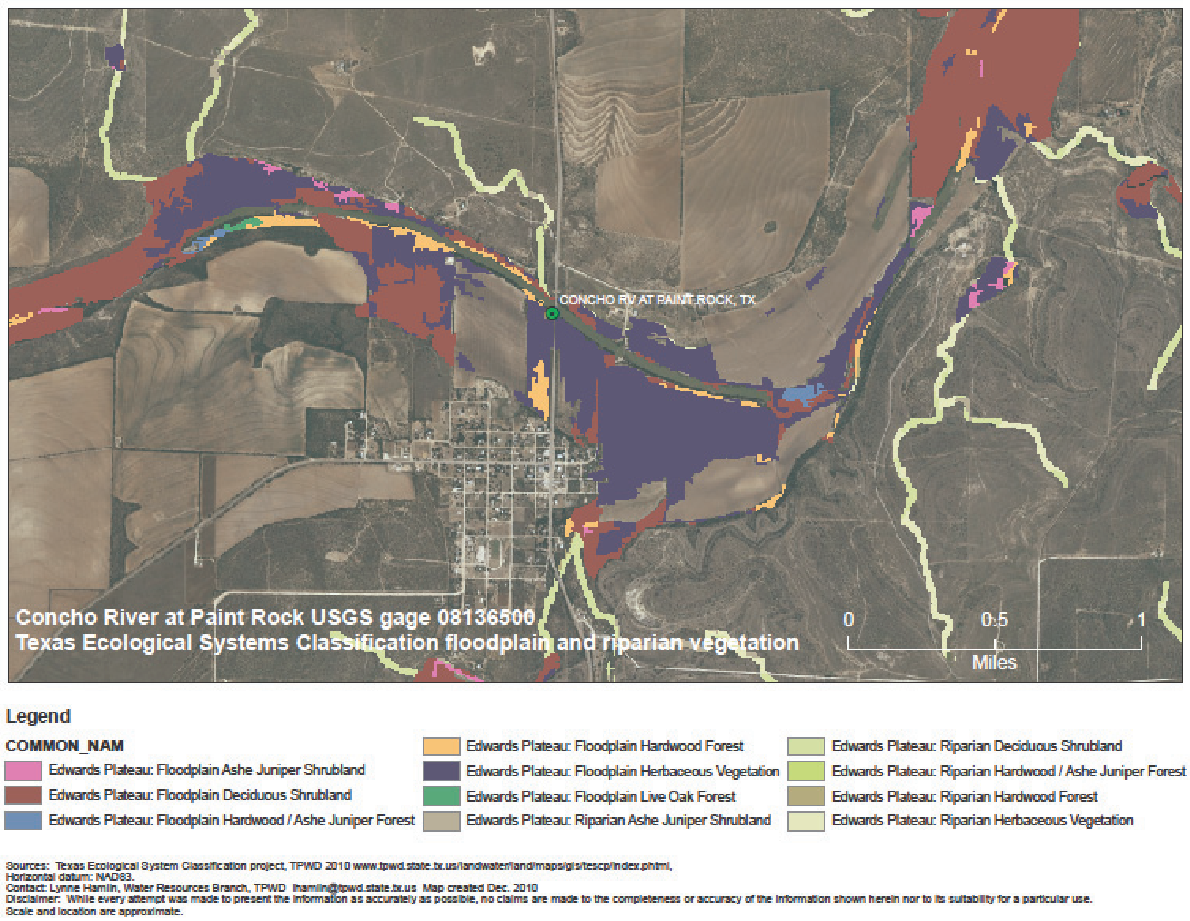
Wetlands

Review of the National Wetland Inventory (USFWS 2010) for about 3.5 miles of river near this site indicates scattered, relatively small areas adjacent to the river that appear to be forested wetlands. These areas are expected to flood on an occasional basis. The river for much of the upstream reach is classified as lake-like behind a dam. The river is classified as a lower perennial stream with a low gradient and velocity, and some flow throughout the year.

Riparian/Flood Plain Vegetation

Texas Ecological Systems Classification of vegetative communities was analyzed for about 13 miles upstream and downstream of the USGS gage (See Riparian Vegetation Map below, German et al. 2009).

- Edwards Plateau floodplain herbaceous vegetation community with a variety of grasses and mesquite trees
- Edwards Plateau deciduous shrubland common
- Small patches of Edwards Plateau hardwood vegetative communities



Texas Ecological Systems Classification of Riparian and Floodplain Vegetation for the Concho River at Paint Rock

Biology

Source	Location	Biology	Observations
Ezell 1983	Concho River downstream of San Angelo	79 taxa of benthic macroinvertebrates were collected at 5 sites	Measures of diversity, equitability, redundancy, and trophic classification indicated clean water conditions
TWQB 1974	Concho River downstream of San Angelo	26 taxa of benthic macroinvertebrates were collected at 7 sites	Benthic community composition indicated adequate water quality
Espey, Huston & Associates, Inc. 1978	Concho and Colorado rivers near their confluence	61 species of fish were expected to occur in the Colorado and Concho rivers where they met	
TPWD 1979	Colorado and Concho rivers in Runnels, Coleman, and Concho counties	Significant populations of channel catfish, flathead catfish, white crappie, and largemouth bass present. Longnose gar, carp, and river carpsucker were abundant "rough" fish. Aquatic vegetation was very limited with small amounts of *Chara*, lotus and sedge. Red shiners were most abundant. Other forage fish included gizzard shad, bullhead minnow, and sunfish.	Overhanging trees, undercut banks, and boulders make up about 25% of the river margins in pools.
TPWD 2010	Concho River from San Angelo to Paint Rock	Fish included gizzard and threadfin shad, largemouth bass, channel and blue catfish, river carpsucker, carp, white crappie, and sunfish	Fish kills documented in the Concho River from 1973 to 2009. Causes included urban nonpoint sources, agriculture runoff, and possible toxic golden alga blooms
Burlakova and Karatayev 2010	Concho River near Paint Rock	A population of the central Texas endemic and state threatened mussel, the Texas pimpleback, *Quadrula petrina,* found during summer 2008.	Mussels were all large, indicating it may not be a successfully reproducing population. Authors speculate reduced flow due to drought, upstream reservoirs, and water withdrawals downstream of San Angelo may affect the population.

Water Quality

- The water quality period of record for this gage 3/11/1964 to 8/4/2010

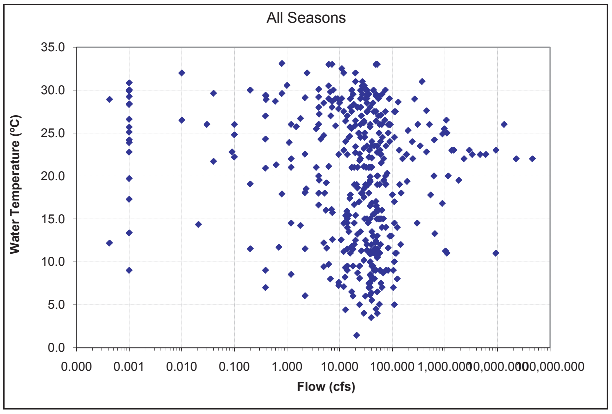
- Relationships between flow and water quality parameters
    - Specific conductance decreases with increasing flow.
    - pH shows no correlation.
    - NO2+NO3–Nitrogen shows no correlation.
    - Total phosphorus shows no correlation.
    - Chloride decreases with increasing flow.
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in the Water Quality Segment 1421, Concho River. The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated high aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
    - The segment of river where this gage site is located is not listed on the 303(d) list.
- Relationships between temperature and flow
    - No correlation was observed between water temperature and flow.
    - The highest temperature was 33.1 °C (flow: 0.8 cfs; dissolved oxygen: 9.3 mg/L).
    - The lowest temperature was 1.4 °C (flow: 21 cfs; dissolved oxygen: 12.2 mg/L).
    - The lowest flow was 0 cfs.
    - The highest flow was 46,400 cfs (temperature: 22 °C; dissolved oxygen: not measured).
- Relationships between dissolved oxygen and flow
    - No correlation was observed between dissolved oxygen and flow.
    - The highest dissolved oxygen was 18.5 mg/L (flow: 52 cfs; temperature: 10.5 °C).
    - The lowest dissolved oxygen was 2.4 mg/L (flow of 0.2 cfs; temperature: 30 °C).
    - The lowest flow was 0 cfs.
    - The highest flow was 46,400 cfs (temperature: 22 °C; dissolved oxygen: not measured).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
    - The maximum observed chloride was 1385 mg/L, which is above the TSWQS of 610 mg/L.
    - The minimum and maximum pH were 6.4 and 10.4, which are outside the TSWQS range of 6.5-9.0.
    - The highest observed instantaneous temperature was 33.1 °C, which is above the TSWQS of 32°C.
    - The minimum observed dissolved oxygen concentration was 2.4 mg/L, which is below the TSWQS of 5.0 mg/L.

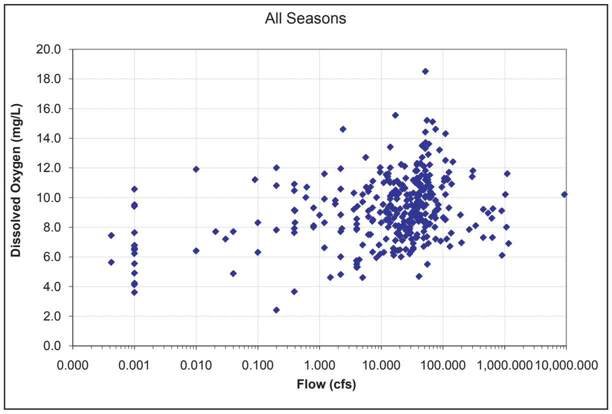
The Concho River upstream of Paint Rock has had periods when nitrate levels have exceeded the drinking water standard of 10 mg/L (UCRA 2000b). It is believed higher than normal nitrate levels in that reach result from aquifer discharge to the river.

Identified threats to and known water quality problems in the Concho River include the following (UCRA 2008):

- Impacts from noncompliant concentrated animal-feeding operations
- Potential impacts from farming
- Impacts from urban runoff

- Potential impacts from oil and gas exploration and production
- Potential impacts from abandoned/unused water wells
- Potential impacts from intensive development of rural areas





Geomorphology

Geomorphological analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77-93% of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows.

Flow Interpretations

No-flow periods: About 8% of days from 1916 to 2010 exhibited no flow. Change in the frequency and duration of no-flow periods from historical patterns is expected to affect the aquatic ecosystem. Increased frequency and duration of no-flow periods is not expected to beneficially affect ecosystem health.

Subsistence flows: Review of Google Earth aerial photography from the gage upstream to San Angelo indicates there is upstream to downstream connectivity in the river when flows at the gage are 10 cfs or higher. Subsistence flow is probably substantially lower than 10 cfs since this reach experiences periods of no flow.

Base flows: A number of references document the existence of base flow in the river except during some droughts. Presence of a wide variety of fish, benthic macroinvertebrates, and instream habitats indicate a need for variability in stable flows.

Pulses and overbank flows: Soils adjacent to the river indicate occasional flooding although the relatively widely scattered presence of typical riparian and floodplain vegetation indicates flooding is probably infrequent. Only 16 peak flows since 1931 have exceeded the flood stage gage height, a rate of about one flood every 5 years.

HEFR/Hydrologic Analysis

	Winter (Nov, Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct)
High Flow Pulses	Qp: 12,300 cfs with Average Frequency 1 per 5 years Regressed Volume is 26,796 to 113,996 (55,269) Regressed Duration is 5 to 29 (12)			
High Flow Pulses	Qp: 5,150 cfs with Average Frequency 1 per 2 years Regressed Volume is 11,381 to 48,307 (23,447) Regressed Duration is 4 to 23 (9)			
High Flow Pulses	Qp: 2,950 cfs with Average Frequency 1 per year Regressed Volume is 6,578 to 27,889 (13,544) Regressed Duration is 3 to 19 (8)			
High Flow Pulses	Qp: 163 cfs with Average Frequency 1 per season Regressed Volume is 460 to 3,045 (1,184) Regressed Duration is 2 to 16 (6)	Qp: 1,410 cfs with Average Frequency 1 per season Regressed Volume is 3,244 to 9,884 (5,663) Regressed Duration is 3 to 11 (5)	Qp: 112 cfs with Average Frequency 1 per season Regressed Volume is 269 to 1,011 (522) Regressed Duration is 2 to 8 (4)	Qp: 301 cfs with Average Frequency 1 per season Regressed Volume is 678 to 2,631 (1,336) Regressed Duration is 2 to 10 (4)
High Flow Pulses	Qp: 61 cfs with Average Frequency 2 per season Regressed Volume is 154 to 1,023 (397) Regressed Duration is 1 to 10 (3)	Qp: 503 cfs with Average Frequency 2 per season Regressed Volume is 1,172 to 3,566 (2,044) Regressed Duration is 2 to 8 (4)	Qp: 32 cfs with Average Frequency 2 per season Regressed Volume is 73 to 276 (142) Regressed Duration is 1 to 6 (2)	Qp: 74 cfs with Average Frequency 2 per season Regressed Volume is 165 to 643 (326) Regressed Duration is 1 to 7 (3)
Base Flows (cfs) – High	36(43.4%)	27(42.8%)	12(40.1%)	29(42.7%)
Base Flows (cfs) – Medium	20(61.2%)	14(58.2%)	3.9(53.5%)	16(57.9%)
Base Flows (cfs) – Low	7.9(77.5%)	3.6(75.1%)	0.7(67.6%)	4.6(73.7%)
Subsistence Flows (cfs)	0.03(95.0%)	0(100.0%)	0(100.0%)	0(100.0%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:
1. Period of Record used : 1/1/1940 to 12/31/2009.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 0 cfs.

Recommended Environmental Flow Recommendation

Concho River at Paint Rock, USGS Gage 08136500, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1916-2009	5 periods Max duration: 42 days	40 periods Max duration: 78 days	40 periods Max duration: 316 days	18 periods Max duration: 154 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	8 cfs	4 cfs	1 cfs	5 cfs
Base Medium	20 cfs	14 cfs	4 cfs	16 cfs
Base High	36 cfs	27 cfs	12 cfs	29 cfs
2 Pulses per season	Trigger: 61 cfs Volume: 400 af Duration: 10 days	Trigger: 500 cfs Volume: 2,000 af Duration: 8 days	Trigger: 32 cfs Volume: 140 af Duration: 6 days	Trigger: 74 cfs Volume: 330 af Duration: 7 days
1 Pulse per season	Trigger: 160 cfs Volume: 1,200 af Duration: 16 days	Trigger: 1,400 cfs Volume: 5,700 af Duration: 11 days	Trigger: 110 cfs Volume: 520 af Duration: 8 days	Trigger: 300 cfs Volume: 1,300 af Duration: 10 days
1 Pulse per year	Trigger: 3,000 cfs Volume: 13,500 af Duration: 19 days			
1 Pulse per 2 years	Trigger: 5,200 cfs Volume: 23,400 af Duration: 23 days			
1 Pulse per 5 years	Trigger: 12,300 cfs Volume: 55,300 af Duration: 29 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second
af = acre-feet

2.2.3 South Concho River at Christoval

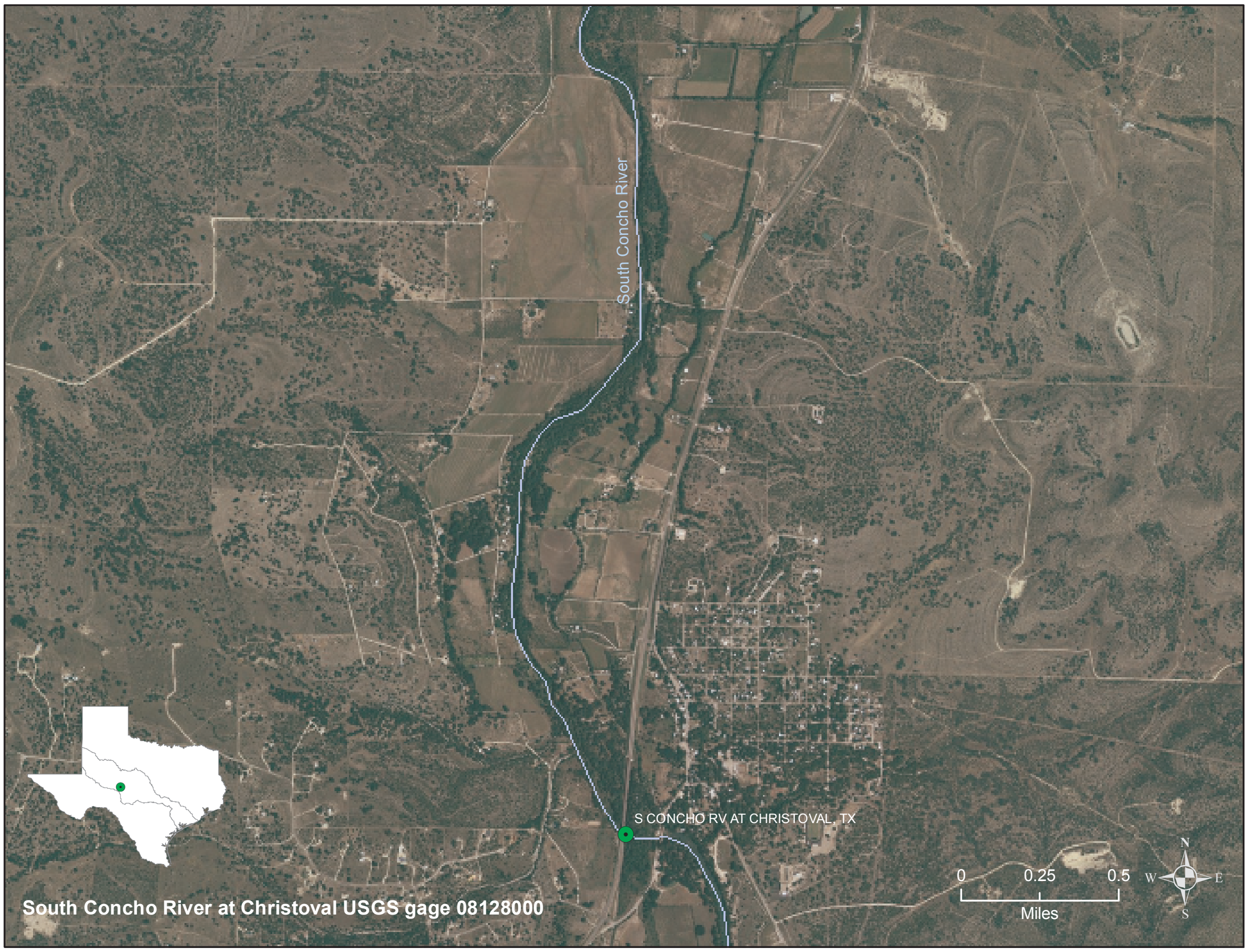
USGS Gage 08128000

South Concho River at Christoval on September 2, 2010.

General Area Description (UCRA 2008, Griffith et al. 2004, Huang 2006, Wilcox et al. 2008)

- Originates from Anson and Cold Creek springs; Approximately 4 miles upriver from the USGS gage
- Western, relatively dry portion of the Edwards Plateau, Level III ecoregion of Texas
- TCEQ Water Quality Segment 1424
- Rainfall inadequate to support closed canopy forests
- Cretaceous limestone
- River perennial and similar to Edwards Plateau streams to the east
- Ashe juniper most common tree in the watershed with honey mesquite and plateau live oak still present; Live oak primarily restricted to floodplains
- Common arid-land shrubs: lotebush, lechuguilla, sotol, and redberry juniper
- Short grasses, such as buffalograss, tobosa, and black grama common

- Primary land use: Ranching with no more than 3% land used as cropland
- Native vegetation changed from pristine prairie savanna prior to 1880, to a degraded grassland/shrubland up to 1960, and since 1960 to a woodland/savanna
- Reductions in grazing since 1960 have improved range conditions, particularly since 1990

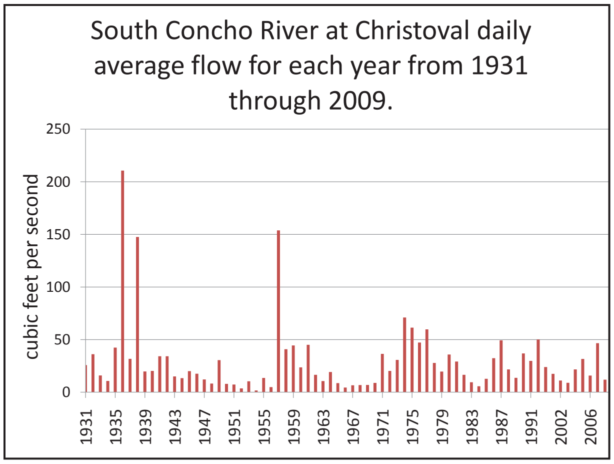


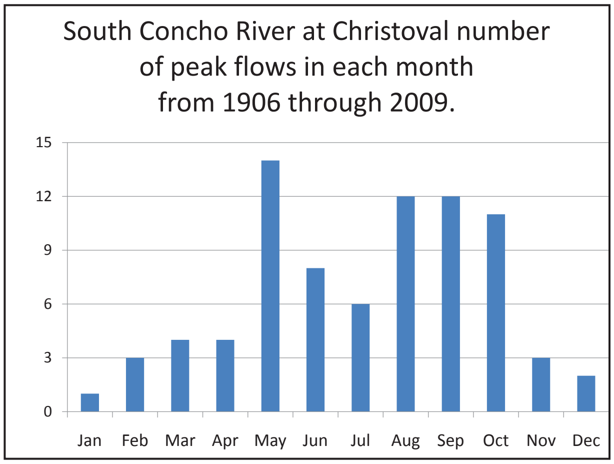
Aerial Photograph of the South Concho River at Christoval

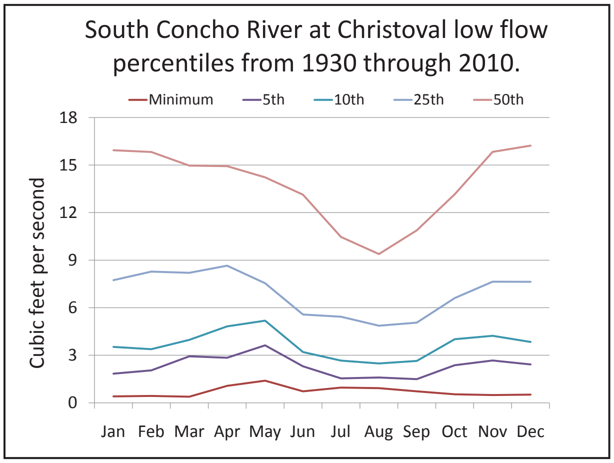
USGS Gage 08128000 Description

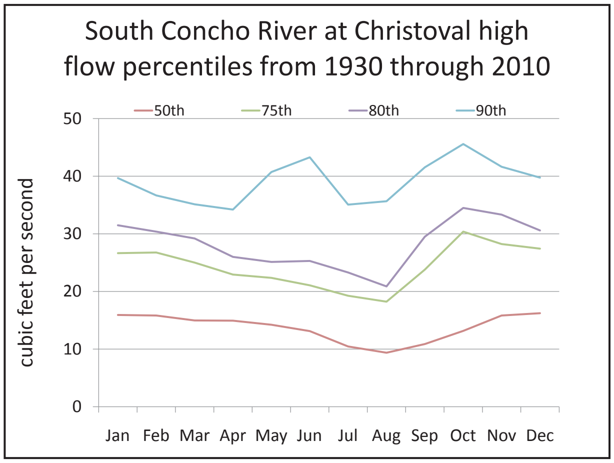
Tom Green County, Texas	Hydrologic Unit Code: 12090102	Latitude: 31°11’13”, Longitude: 100°30’06” NAD27
Drainage area: 413 square miles	Contributing drainage area: 354 square miles	
Gage datum: 2,010.22 feet above sea level NGVD29	Flood stage occurs at 10 ft above the USGS gage elevation (NOAA 2010).	

Summary of Historical USGS Flow Records at South Concho River at Christoval (USGS 2010; NOAA 2010)



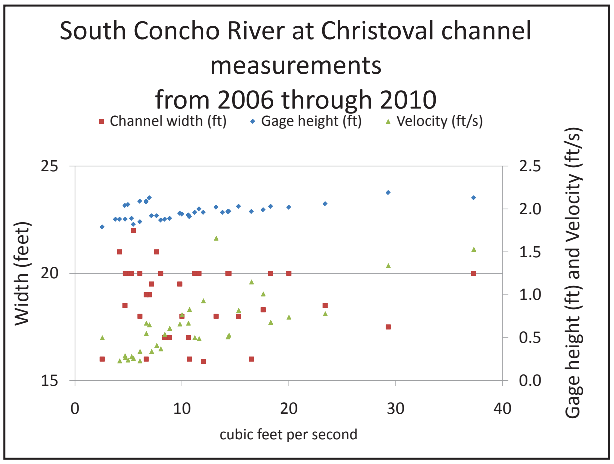






	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	100	124	128	692	1399	630	1,714	731	2,958	1,589	229	185
Minimum	0.4	0.4	0.4	1	1	1	1	1	1	1	0.5	1
Average	19	20	20	27	39	25	37	24	59	44	22	21
5th	2	2	3	3	4	2	2	2	1	2	3	2
10th	4	3	4	5	5	3	3	2	3	4	4	4
20th	7	7	7	7	7	5	4	4	4	6	6	6
25th	8	8	8	9	8	6	5	5	5	7	8	8
50th	16	16	15	15	14	13	10	9	11	13	16	16
75th	27	27	25	23	22	21	19	18	24	30	28	27
80th	31	30	29	26	25	25	23	21	30	34	33	31
90th	40	37	35	34	41	43	35	36	42	46	42	40
95th	44	54	52	55	76	62	49	48	76	65	54	50

South Concho River at Christoval flow percentiles in cubic feet per second



Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases, two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5th, 25th, 50th, 75th, 80th, and 90th percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured.

Historical Hydrology

Baseflow accounts for 70% of the stream flow in the South Concho River Basin (Huang 2006).

- The relatively high contribution of base flow to stream flow results from the river's contact with the highly permeable Edwards group – permeable limestone and dolomite.
- This geologic feature allows the river to mix directly with regional groundwater of Edwards-Trinity Aquifer (UGRA 2008).

The current hydrologic regime is similar to the pre-disturbance condition although:

- Woody plant cover has increased following overgrazing and drought disturbances of previous decades (Huang 2006).
- Current hydrologic regime reflects a decrease in stream flow, which is not statistically significant, a decrease in storm flow, and an increase in base flow from 1977 to 1994 when compared to the period from 1931 to 1949 (excluding 1936, a year of extreme flooding).

Precipitation peaked in May and September and averaged 19.6 inches per year from 1942 to 1994 (Wilcox et al. 2008).

- The annual total stream flow ranges from 8% to 10% of the total volume of precipitation on the watershed during the year.
- Precipitation runoff has decreased since 1960, probably as a result of increased brush invasion in the watershed.

Site Description

- Review of aerial photography with Google Earth
  - 6 river miles downstream of US 277 in Christoval
  - Flows for each aerial photography date
    - February 4, 1996: not available
    - March 15, 2003: 13 cfs
    - October 21, 2005: 25 cfs
    - October 30, 2008: 8 cfs
    - February 14, 2010: 14 cfs
  - Habitats
    - Relatively short glides and pools separated by frequent, relatively long, riffle-run sequences
    - Three low-head dams cross the river in this reach and approximately 6 backwater areas
    - One oxbow-like feature was present that would be inundated with a 1 ft rise in the river
    - Riparian zone ranged from 30 to 500 ft wide and in areas the canopy was dense enough to obscure the river from aerial view

- Field observations on September 2, 2010; USGS provisional flow of 1.8 cfs.
  - Water clear with a variety of aquatic macrophytes present
  - Riparian forest shades most of the river
  - Fish and aquatic invertebrates observed

Soil Types

Soil data were obtained from the Natural Resource Conservation Service for a 4-mile stretch from about 1 mile upstream of US 277 to 3 miles downstream of US 277 (NRCS 2010).

Soil	Setting	Slope %	Wetland Potential	Flood Frequency
Rioconcho and Spur	Floodplains on draws	0-1	Moderately well-drained	5-50 times per 100 years

Wetlands

Wetland data are not available from the National Wetland Inventory for this portion of the river (USFWS 2010).

Riparian/Flood Plain Vegetation

Texas Ecological Systems Classification of vegetative communities has not been done for this area (German 2009).

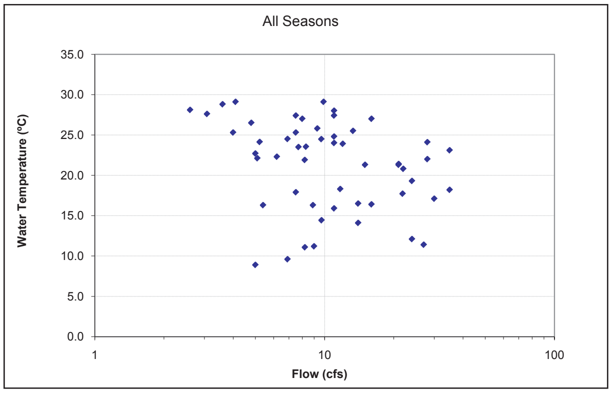
Lt. F.T. Bryan of the U.S. Army Topographical Engineers, in an 1849 report, described riparian vegetation near the South Concho River. He reported "heavy timber" on the banks but not extending far from the banks. He also said there were large pecan trees in the area (UCRA 2000).

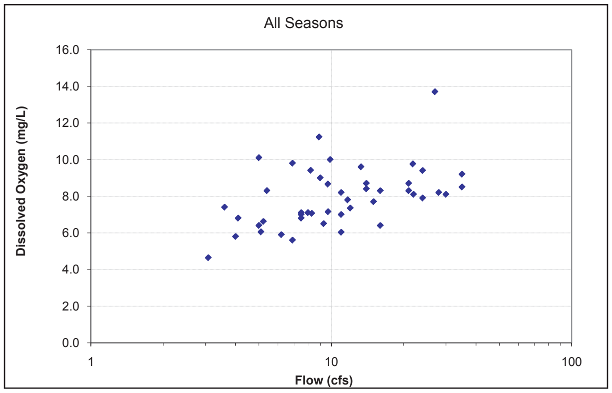
Biology

Source	Location	Biology	Observations
Moring (1986)	South Concho River at Christoval	Orangethroat darters and greenthroat darters use different habitats. 65% of orangethroat darters were collected in riffles with velocities from 0.4 to 1.1 ft/s. 75% of greenthroat darters were collected along the stream margin and in vegetation along the stream margin where velocities were 0 to 0.2 ft/s.	Orangethroat darters ate primarily chironomid larvae found in riffles and greenthroat darters ate mainly amphipods found in vegetation.

Water Quality

- The water quality period of record for this gage is 9/23/1964 to 6/7/2010
- Relationships between flow and water quality parameters
  - Specific conductance decreases with increasing flow.
  - pH shows no correlation.
  - NO2+NO3-Nitrogen shows no correlation.
  - Total phosphorus shows no correlation.
  - Chloride shows no correlation.
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in the Water Quality Segment 1424, Middle Concho/South Concho River. The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated high aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
  - The segment of river where this gage site is located is not listed on the 303(d) list.
- Relationships between temperature and flow
  - No correlation was observed between water temperature and flow.
  - The highest temperature was 29.1 °C (flow: 4.1 cfs; dissolved oxygen: 6.8 mg/L).
  - The lowest temperature was 8.9 °C (flow: 5 cfs; dissolved oxygen: 10.1 mg/L).
  - The lowest flow was 2.6 cfs (temperature: 28.1 °C; dissolved oxygen: not measured).
  - The highest flow was 670 cfs (temperature: not measured; dissolved oxygen: not measured).
- Relationships between dissolved oxygen and flow
  - Dissolved oxygen levels increase with increasing flows.
  - The highest dissolved oxygen was 13.7 mg/L (flow: 27 cfs; temperature: 11.4 °C).
  - The lowest dissolved oxygen was 4.6 mg/L (flow of 3.1 cfs; temperature: 27.6 °C).
  - The lowest flow was 2.6 cfs (temperature: 28.1 °C; dissolved oxygen: not measured).
  - The highest flow was 670 cfs (temperature: not measured; dissolved oxygen: not measured).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - The maximum observed chloride was 106 mg/L, which is below the TSWQS of 150 mg/L.
  - The minimum and maximum pH were 7.1 and 8.9, which are within the TSWQS range of 6.5-9.0.
  - The highest temperature was 29.1 °C, which is below the TSWQS of 32 °C.
  - The minimum observed dissolved oxygen concentration was 4.6 mg/L, which is below the TSWQS of 5.0 mg/L.





Geomorphology

Geomorphological analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77-93% of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows..

Flow Interpretations

No-flow periods: The river has flowed continuously during the period of record.

Subsistence flows: Review of Google Earth aerial photography indicates upstream to downstream connection is maintained at flows of at least 8 cfs. Subsistence flows may be lower than 8 cfs.

Base flows: Presence of a variety of fish, benthic macroinvertebrates, aquatic macrophytes, and large trees supports a need for base flows. Scientific literature indicates base flows have been characteristic of the river throughout its period of record.

Pulses and overbank flows: Review of historical hydrology and soil types indicate pulse flows occur relatively infrequently, perhaps one every 2 to 20 years.

HEFR/Hydrologic Analysis

	Winter (Nov, Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct)
High Flow Pulses	Qp: 2,590 cfs with Average Frequency 1 per 5 years Regressed Volume is 2,616 to 17,651 (6,795) Regressed Duration is 1 to 11 (3)			
High Flow Pulses	Qp: 932 cfs with Average Frequency 1 per 2 years Regressed Volume is 1,082 to 7,231 (2,797) Regressed Duration is 1 to 10 (3)			
High Flow Pulses	Qp: 415 cfs with Average Frequency 1 per year Regressed Volume is 537 to 3,574 (1,385) Regressed Duration is 1 to 9 (3)			
High Flow Pulses				Qp: 45 cfs with Average Frequency 1 per season Regressed Volume is 75 to 472 (188) Regressed Duration is 1 to 7 (2)
Base Flows (cfs) – High	24 (27.8%)	21 (30.3%)	20 (25.6%)	23 (27.8%)
Base Flows (cfs) – Medium	16 (50.7%)	14 (52.0%)	11 (49.1%)	13 (49.1%)
Base Flows (cfs) – Low	8.9 (69.6%)	8.3 (71.6%)	7 (66.0%)	6.9 (70.6%)
Subsistence Flows (cfs)	2 (95.8%)	2.7 (95.6%)	1.4 (96.1%)	1.7 (95.1%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:

1. Period of Record used : 1/1/1940 to 12/31/2003.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 2 cfs.

Recommended Environmental Flow Regime

South Concho River at Christoval, USGS Gage 08128000, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1931-1994	0 days with no flow during period of record			
Subsistence	2 cfs	3 cfs	2 cfs	2 cfs
Base Low	9 cfs	9 cfs	7 cfs	7 cfs
Base Medium	15 cfs	15 cfs	12 cfs	12 cfs
Base High	22 cfs	22 cfs	22 cfs	22 cfs
2 Pulses per season	Not applicable	Not applicable	Not applicable	Not applicable
1 Pulse per season	Not applicable	Not applicable	Not applicable	Trigger: 45 cfs Volume: 190 af Duration: 7 days
1 Pulse per year	Trigger: 420 cfs Volume: 1,400 af Duration: 9 days			
1 Pulse per 2 years	Trigger: 930 cfs Volume: 2,800 af Duration: 10 days			
1 Pulse per 5 years	Trigger: 2,600 cfs Volume: 6,800 af Duration: 11 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second
af = acre-feet

2.2.4 Pecan Bayou near Mullin

USGS 08143600

Pecan Bayou near Mullin at FM 573 on September 1, 2010. View towards the downstream from underneath the bridge (left). Pecan Bayou near Mullin at FM 573 on September 1, 2010. View towards upstream from bridge (right)

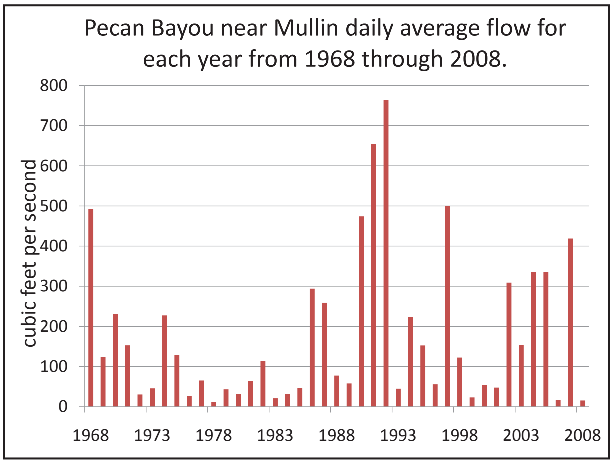
General Area Description (Griffith et al., 2004)

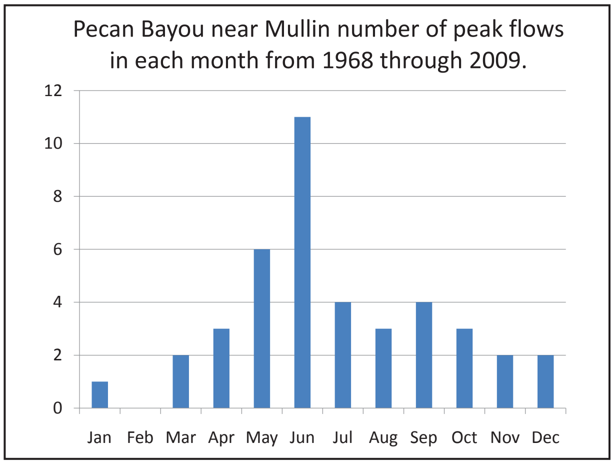
- Pecan Bayou downstream of Lake Brownwood for 57 miles to its confluence with the Colorado River in Mills County
- TCEQ Water Quality Segment 1417
- Cross Timbers, EPA Level III ecoregion
- Primary land use: pasture and livestock grazing
- Much of this area overlays sandstone and shale beds with topography consisting of sandstone ridges with a gentle dip slope on one side and a steeper scarp on the other
- Mostly fine sandy loams with clay subsoils that retain water
- Potential natural vegetation: post oak and blackjack oak with an understory of greenbriar, little bluestem, and purpletop grasses
- Flow regimes are influenced by Lake Brownwood releases, stormwater, and treated wastewater discharges from the city of Brownwood

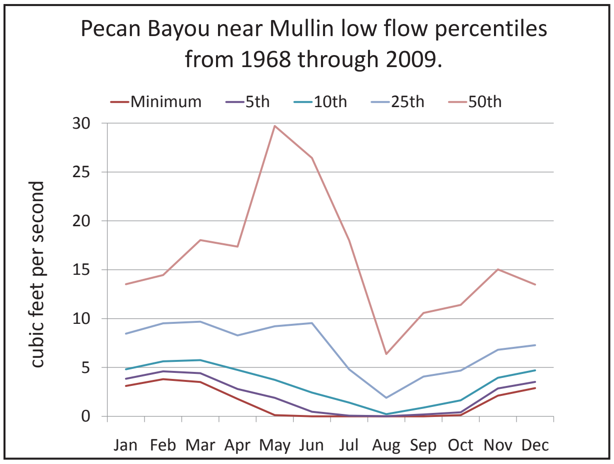
USGS Gage 08143600 Description

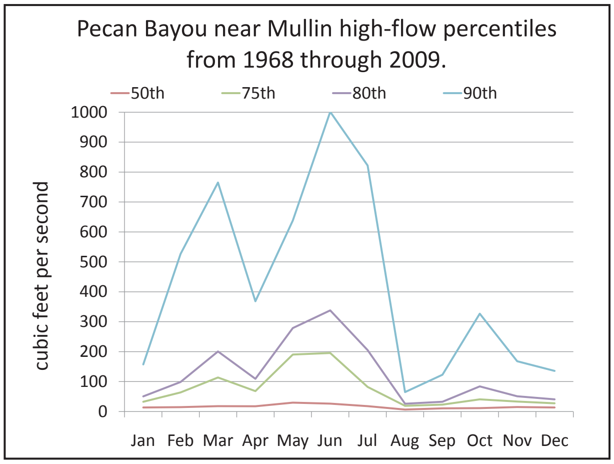
<table>
<tr><td>Mills County, Texas</td><td>Hydrologic Unit Code: 12090107</td><td>Latitude: 31°31’02”, Longitude: 98°44’25” NAD27</td></tr>
<tr><td>Drainage area: 2,073 square miles</td><td colspan="2">Contributing drainage area: 2,073 square miles</td></tr>
<tr><td>Gage datum: 1,202.93 feet above sea level NGVD29</td><td colspan="2">Flood stage occurs at 40 ft above the USGS gage elevation (NOAA 2010).</td></tr>
</table>

Summary of Historical USGS Flow Records at Pecan Bayou near Mullin



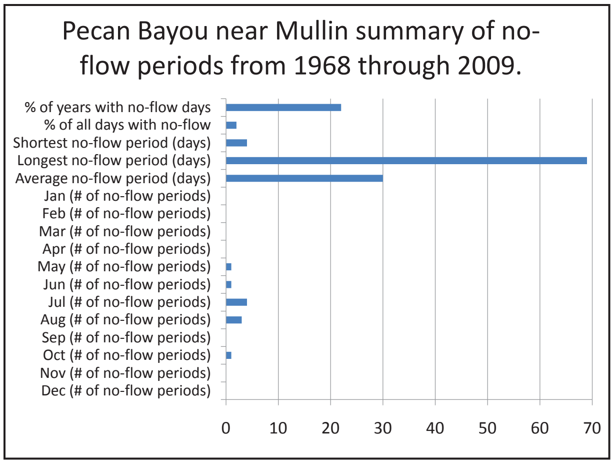


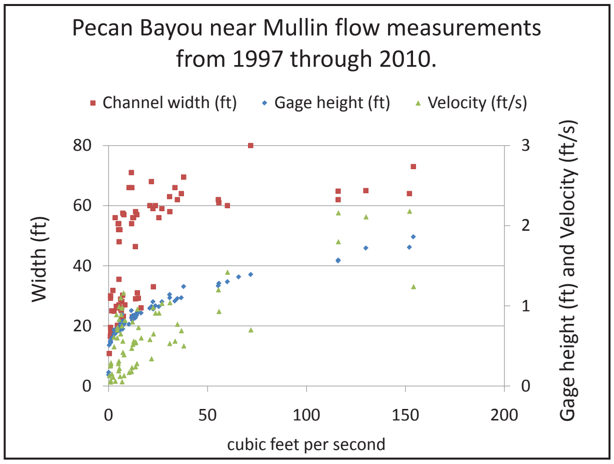




	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	2,860	5,079	3,475	4,757	3,639	6,396	4,349	1,813	1,655	2,439	3,277	4,898
Average	117	227	226	191	255	369	654	64	72	140	127	157
Minimum	3	4	4	2	0.1	0	0	0	0	0.1	2	3
5th	4	5	4	3	2	0.5	0.1	0	0.2	0.4	3	4
10th	5	6	6	5	4	2	1	0.2	1	2	4	5
20th	7	8	8	7	7	8	4	1	3	4	6	7
25th	8	10	10	8	9	10	5	2	4	5	7	7
50th	14	14	18	17	30	26	18	6	11	11	15	13
75th	32	64	114	68	190	196	82	19	23	41	33	27
80th	51	99	201	109	279	338	205	26	32	84	51	41
90th	157	527	765	368	638	1,001	822	65	123	327	168	136
95th	688	1,321	1,421	704	1,984	2,349	4,140	285	398	1,182	632	522

Pecan Bayou near Mullin flow percentiles in cubic feet per second





Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases, two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5^{th}, 25^{th}, 50^{th}, 75^{th}, 80^{th}, and 90^{th} percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured.

Historical Hydrology

An intensive survey of Pecan Bayou in 1979 (Buzan 1982) found:

- Flows downstream of Brownwood for about 10 river miles ranged from about 9 to 27 cfs
- Stream widths ranged from 26 to 52 ft while depths ranged from 0.7 to 4 ft deep
- Stream velocity based on time-of-travel studies in this reach averaged 0.13 fps
- Habitats: Series of riffles and pools downstream of Pecan Bayou's confluence with Willis Creek in Brownwood, followed by a series of long, deep pools

During a 1974 special study (TWQB 1974), flow at the USGS gage near Mullin was 9.8 cfs, average stream width was 46 ft, average depth was 2.2 ft, and the time-of-travel was about 0.08 fps. The bayou had little flow from Lake Brownwood downstream to Brownwood.

A U.S. Army Corps of Engineers study (1964) reported the average streambed slope of Pecan Bayou in its lower 18 miles was 2.9 ft per mile and the prevailing channel capacity was 30,000 cfs.

Site Description

- Review of aerial photography with Google Earth
  - 5 mile reach downstream of USGS gage at County Road 574 to its confluence with the Colorado River
  - Flows for each aerial photography date
    - January 26, 1995: 55 cfs
    - October 21, 2005: 7.2 cfs
    - October 30, 2008: 2.9 cfs
  - Habitat (based on October 30, 2008 aerial photography)
    - Most common mesohabitats: Relatively short runs (approximately 15) between pools (about 9), with perhaps 2 riffles
    - One tributary joins Pecan Bayou in this reach
    - One patch of boulders observed in the bayou
    - Flow appeared to be perennial in this reach at the different flows that occurred on the aerial photography dates
    - Much of the bayou in this reach has relatively steep banks
    - Oxbows not observed
- Field observations on September 1, 2010 when the USGS provisional flow was 0.99 cfs

Soil Types

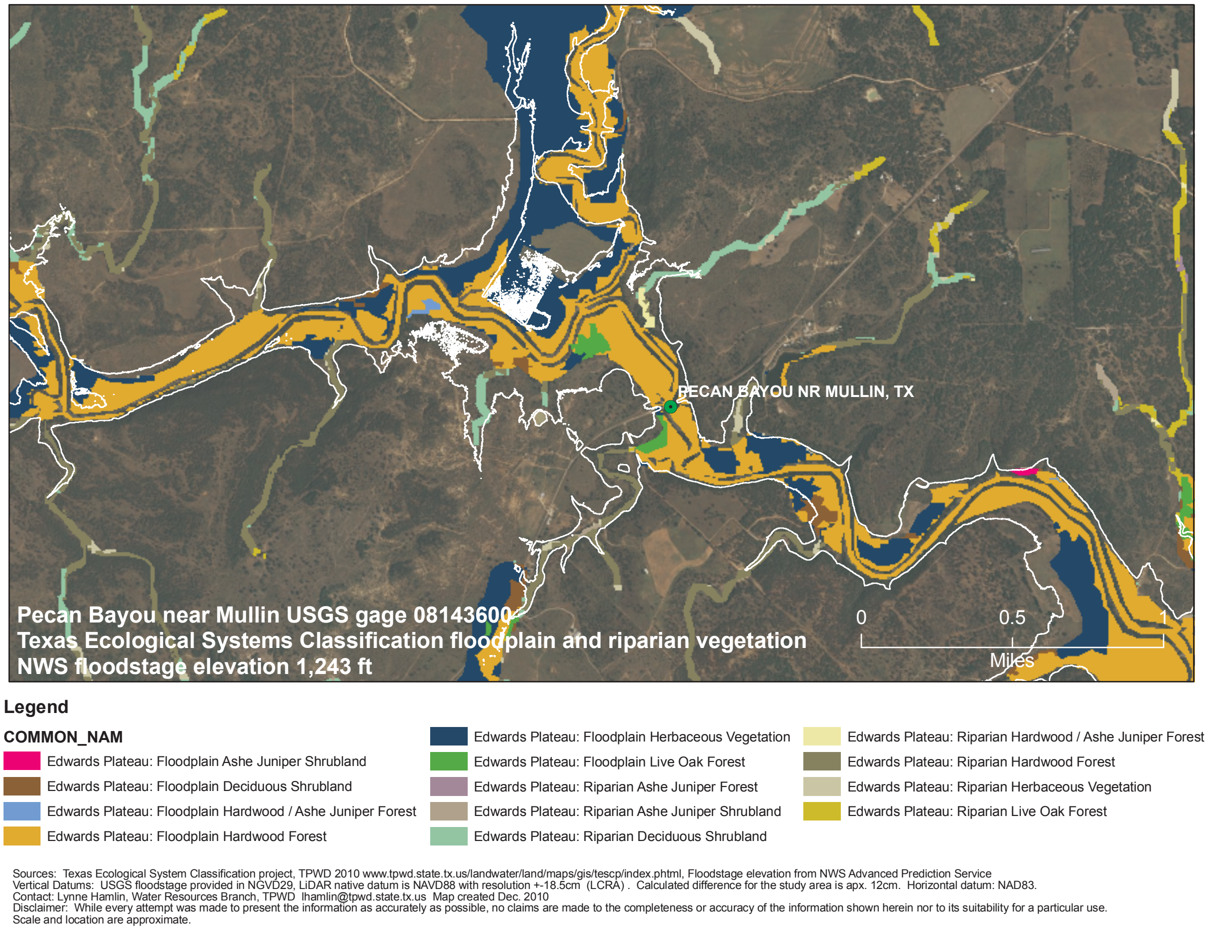
Soil data were obtained from the Natural Resource Conservation Service for a 4-mile stretch along the bayou near the gage (NRCS 2010).

Soil	Setting	Slope %	Wetland Potential	Flood Frequency
Frio silty clay loam	Floodplains	0-1	Well-drained	5-50 times per 100 years

Riparian/Flood Plain Vegetation

Texas Ecological Systems Classification of flood plain and riparian vegetation was reviewed for about 13 miles around the USGS gage (German et al. 2009). Vegetative communities included:

- Edwards Plateau floodplain hardwoods
- Ashe juniper and herbaceous vegetation communities
- Patches of the Edwards Plateau deciduous shrub vegetative community also present.



Texas Ecological Systems Classification of Riparian and Floodplain Vegetation for Pecan Bayou near Mullin. The white line represents the calculated NWS flood stage elevation.

Wetlands

Review of the National Wetland Inventory (USFWS 2010) for about 3.5 miles of river near this site indicates the absence of wetlands immediately adjacent to the bayou or which otherwise would be expected to be hydrologically connected to the bayou on a frequent basis. The bayou is classified as a lower perennial stream with a low gradient and velocity, and some flow throughout the year.

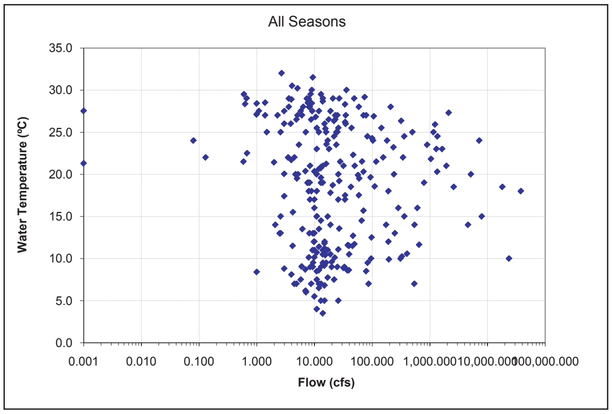
Biology

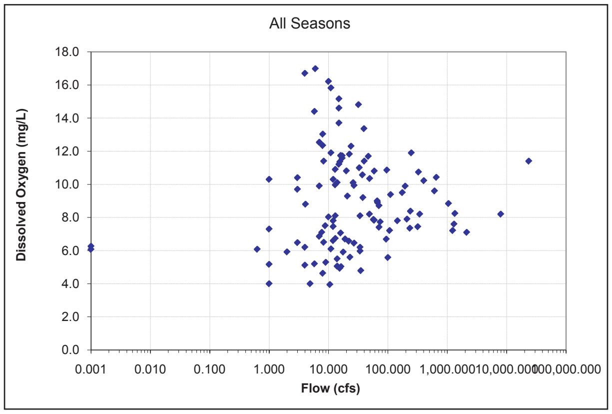
Source	Location	Biology	Observations
USFWS 1960	Pecan Bayou		Bayou supports local recreational fishery for species like largemouth bass, channel catfish, flathead catfish, and bluegill
Buzan 1982	Pecan Bayou in, and downstream of Brownwood	Macrophytes, *Potamogeton*, *Lemna*, and *Ludwigia* along with the algae, *Cladophora* and *Hydrodictyon* were present. 31 taxa of benthic macroinvertebrates were collected in a sample with a diversity of 3.60 about 9 miles downstream of Brownwood.	
LCRA 2009	Pecan Bayou	Evaluations of water quality data indicated the bayou supports its designated aquatic life use. 32 species of fish collected.	Assessments based on 2008 information.

Water Quality

- The water quality period of record for this gage
- 9/23/1964 to 2/22/2010
- Relationships between flow and water quality parameters
  - Specific conductance decreases with increasing flow.
  - pH shows no correlation.
  - NO2+NO3–Nitrogen shows no correlation.
  - Total phosphorus shows no correlation.
  - Chlorides decrease with increasing flow.
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in the Water Quality Segment 1417, Lower Pecan Bayou. The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the desig-

nated high aquatic life use.
  - The segment of river where this gage site is located is not listed on the 303(d) list.
- Relationship between temperature and flow
  - No correlation was observed between water temperature and flow.
  - The highest temperature was 32.0 °C (flow: 9.4 cfs; dissolved oxygen: not measured).
  - The lowest temperature was 3.5 °C (flow: 14 cfs; dissolved oxygen: not measured).
  - The lowest flow was 0 cfs.
  - The highest flow was 37,900 cfs (temperature: 18 °C; dissolved oxygen: not measured).
- Relationship between dissolved oxygen and flow
  - No correlation was observed between dissolved oxygen and flow.
  - The highest dissolved oxygen was 17.0 mg/L (flow: 6 cfs; temperature: 9.1 °C).
  - The lowest dissolved oxygen was 4.0 mg/L (flow of 4.9 cfs; temperature: 26.5 °C).
  - The lowest flow was 0 cfs.
  - The highest flow was 37,900 cfs (temperature: 18 °C; dissolved oxygen: not measured).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - The maximum observed for chloride was 470 mg/L, which is above the TSWQS of 310 mg/L.
  - The minimum and maximum pH were 6.8 and 9.4, which exceeds the upper limit of the TSWQS range of 6.5-9.0.
  - The highest observed instantaneous temperature was 32.0 °C, which meets the TSWQS of 32°C.
  - The minimum observed dissolved oxygen concentration was 4.0 mg/L, which is below the TSWQS of 5.0 mg/L.





This reach of Pecan Bayou includes three designated water quality segments, segment 1417, Lower Pecan Bayou from its confluence with the Colorado River upstream into Brown County; segment 1431, Middle Pecan Bayou, extending upstream from Lower Pecan Bayou to just downstream of the City of Brownwood; and segment 1432, Upper Pecan Bayou, from below Brownwood upstream to the dam on Lake Brownwood. The LCRA's 2009 Basin Highlights Report (LCRA 2009) describes water quality as generally supporting water quality standards and designated aquatic life uses with concerns for elevated nitrate and chlorophyll levels in Lower Pecan Bayou and elevated nitrogen and phosphorus in Middle Pecan Bayou.

Geomorphology

Geomorphological analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77-93% of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows.

Flow Interpretations

No-flow periods: About 2% of the days from 1968 through 2009 exhibited no flow. Change in the frequency and duration of no-flow periods from the historical patterns is expected to affect the aquatic ecosystem. Increased frequency and duration of no-flow periods is not expected to beneficially affect the bayou ecosystem.

Subsistence flows: Upstream-downstream connectivity was provided at flows of 2.9 cfs. The National Weather Service lowest flow for 7 days with the likelihood of occurring at least once every 2 years is 1.2 cfs.

Base flows: Presence of a variety of benthic macroinvertebrates and macrophytes and recent assessments of achievement of its aquatic life use designation indicate the existence of a perennial water body.

Pulses and overbank flows: Soils adjacent to the river indicate flooding may occur once every 2 to 20 years. The relatively widely scattered riparian and floodplain vegetation combined with the absence of numerous plants that require continuously wet conditions in the riparian community indicates flooding is probably infrequent.

HEFR/Hydrologic Regime

	Winter (Nov, Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct)
High Flow Pulses	Qp: 13,862 cfs with Average Frequency 1 per 5 years Regressed Volume is 59,844 to 260,617 (124,885) Regressed Duration is 7 to 43 (18)			
High Flow Pulses	Qp: 6,706 cfs with Average Frequency 1 per 2 years Regressed Volume is 25,929 to 112,737 (54,066) Regressed Duration is 6 to 33 (14)			
High Flow Pulses	Qp: 3,530 cfs with Average Frequency 1 per year Regressed Volume is 12,380 to 53,765 (25,799) Regressed Duration is 4 to 26 (11)			
High Flow Pulses	Qp: 243 cfs with Average Frequency 1 per season Regressed Volume is 676 to 3,436 (1,524) Regressed Duration is 2 to 14 (6)	Qp: 2,120 cfs with Average Frequency 1 per season Regressed Volume is 6,251 to 27,830 (13,190) Regressed Duration is 3 to 17 (7)	Qp: 104 cfs with Average Frequency 1 per season Regressed Volume is 229 to 854 (442) Regressed Duration is 2 to 7 (3)	Qp: 258 cfs with Average Frequency 1 per season Regressed Volume is 657 to 2,157 (1,191) Regressed Duration is 2 to 9 (5)
High Flow Pulses	Qp: 52 cfs with Average Frequency 2 per season Regressed Volume is 103 to 525 (233) Regressed Duration is 1 to 7 (3)	Qp: 707 cfs with Average Frequency 2 per season Regressed Volume is 1,701 to 7,563 (3,587) Regressed Duration is 2 to 10 (4)	Qp: 21 cfs with Average Frequency 2 per season Regressed Volume is 38 to 141 (73) Regressed Duration is 1 to 4 (2)	Qp: 36 cfs with Average Frequency 2 per season Regressed Volume is 61 to 202 (111) Regressed Duration is 1 to 3 (2)
Base Flows (cfs) – High	12(43.0%)	19(43.4%)	8.4(39.2%)	12(39.5%)
Base Flows (cfs) – Medium	6.5(59.7%)	8.6(60.6%)	3.8(53.2%)	6.5(52.7%)
Base Flows (cfs) – Low	2.9(76.7%)	2.7(78.4%)	1(67.4%)	2.6(66.6%)
Subsistence Flows (cfs)	0.25(96.1%)	0.37(95.8%)	0(100.0%)	0(100.0%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:

1. Period of Record used : 1/1/1940 to 12/31/2009.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 0.125 cfs.

Recommended Environmental Flow Regime

Pecan Bayou near Mullin, USGS Gage 08143600, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1968-2009	0 periods Max duration: 0 days	2 periods Max duration: 69 days	7 periods Max duration: 54 days	1 periods Max duration: 9 days
Subsistence	2 cfs	2 cfs	2 cfs	2 cfs
Base Low	3 cfs	3 cfs	2 cfs	3 cfs
Base Medium	7 cfs	9 cfs	4 cfs	7 cfs
Base High	12 cfs	19 cfs	8 cfs	12 cfs
2 Pulses per season	Trigger: 52 cfs Volume: 230 af Duration: 7 days	Trigger: 710 cfs Volume: 3,600 af Duration: 10 days	Trigger: 21 cfs Volume: 73 af Duration: 4 days	Trigger: 36 cfs Volume: 110 af Duration: 3 days
1 Pulse per season	Trigger: 250 cfs Volume: 1,500 af Duration: 14 days	Trigger: 2,100 cfs Volume: 13,200 af Duration: 17 days	Trigger: 100 cfs Volume: 440 af Duration: 7 days	Trigger: 250 cfs Volume: 1,200 af Duration: 9 days
1 Pulse per year	Trigger: 3,500 cfs Volume: 25,800 af Duration: 26 days			
1 Pulse per 2 years	Trigger: 6,700 cfs Volume: 54,100 af Duration: 33 days			
1 Pulse per 5 years	Trigger: 13,900 cfs Volume: 124,900 af Duration: 43 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second
af = acre-feet

2.2.5 San Saba River at San Saba — USGS 08146000


Riffle in San Saba River at SH 16 bridge in San Saba on September 1, 2010 (left). San Saba River at SH 16 in San Saba. View towards the upstream from the SH 16 bridge on September 1, 2010 (right).

San Saba River at SH 16 in San Saba. View downstream from SH 16 bridge on September 1, 2010.

General Area Description (USGS 2010; Griffith et al. 2004, Parsons Engineering, Inc 1999)

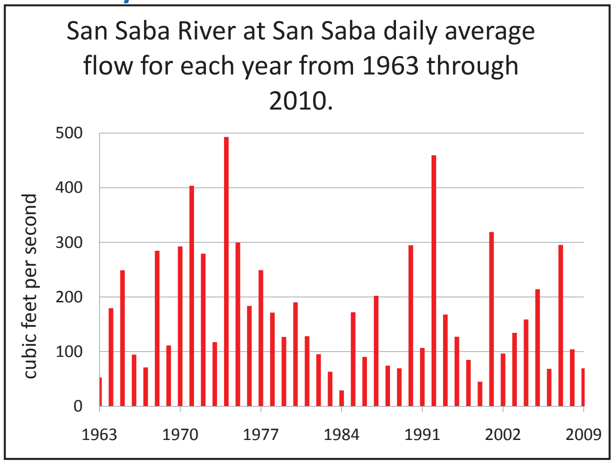
- Gage is 16.8 miles upstream from confluence with Colorado River
- TCEQ Water Quality Segment 1416
- Upper reach of the San Saba River crosses the Edwards Plateau ecoregion and the lower reach of the San Saba River is located in the Cross Timbers, EPA Level III, ecoregion
- Edwards Plateau ecoregion: mostly a dissected limestone plateau; Region contains a sparse network of perennial streams that are relatively clear and cool because of the karst topography and resultant underground drainage
- Originally covered by juniper-oak savanna and mesquite-oak savanna: most of the region used for grazing beef cattle, sheep, goats, and wildlife
- This part of the Cross Timbers ecoregion has sandstone ridges with a gentle dip slope on one side and a steeper scarp on the other

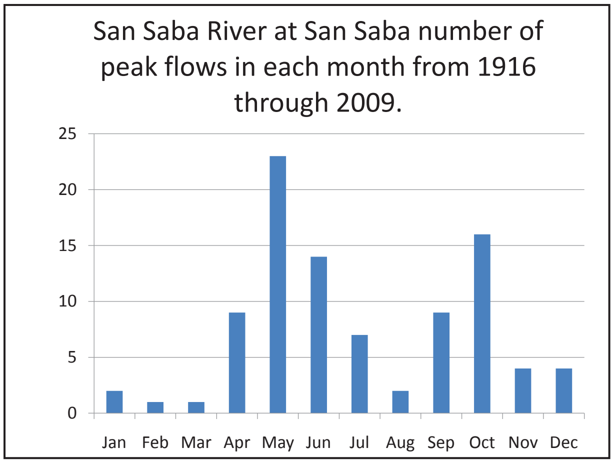
- Mostly fine sandy loams soils with clay subsoils that retain water
- Dominant trees: post oak and blackjack oak with an understory of greenbriar, little bluestem, and purpletop grasses
- Edwards-Trinity Aquifer is the source of springs and baseflow in the San Saba River

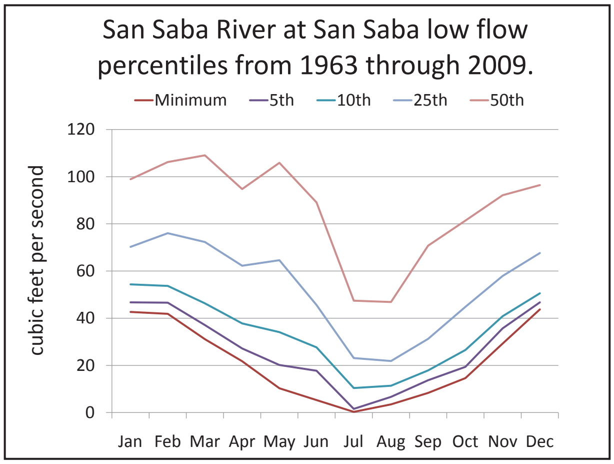
USGS Gage 08146000 Description

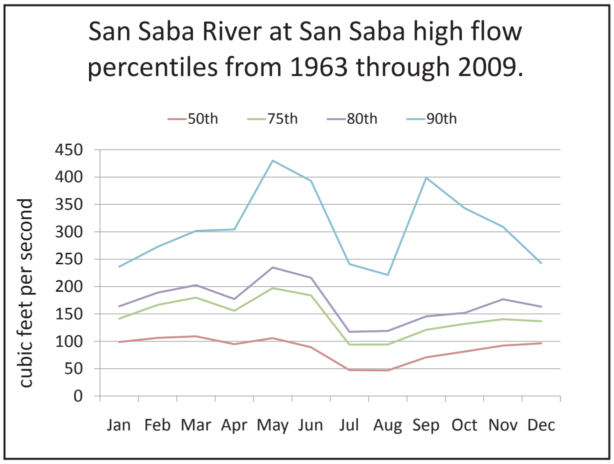
San Saba County, Texas	Hydrologic Unit Code: 12090109	Latitude: 31°12'47", Longitude: 98°43'09" NAD27
Drainage area: 3,046 square miles	Contributing drainage area: 3,039 square miles	
Gage datum: 1,162.16 feet above sea level NGVD29	Flood stage occurs at 24 ft above the USGS gage elevation (NOAA 2010).	

Summary of Historical USGS Flow Records at San Saba River at San Saba



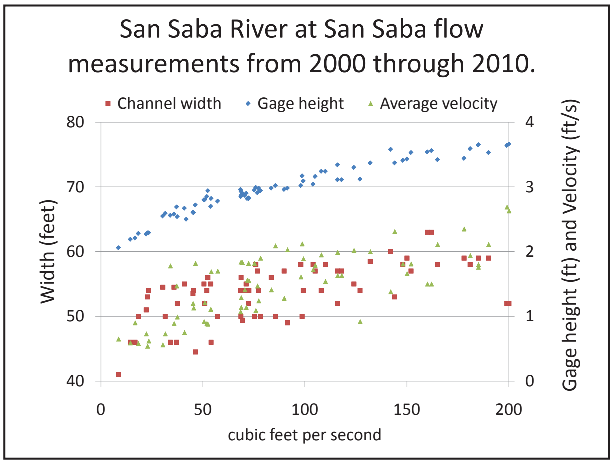






	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	1,521	1,638	999	1,244	1,953	2,049	3,000	3,171	4,797	3,272	2,889	1,485	2,335
Average	148	166	157	150	195	183	154	155	268	194	186	146	175
Minimum	43	42	31	22	10	5	0.3	3	8	15	29	44	21
5th	47	47	37	27	20	18	2	7	14	19	36	47	27
10th	54	54	46	38	34	28	10	11	18	27	41	51	34
20th	66	68	67	57	55	42	20	19	26	39	54	62	48
25th	70	76	72	62	65	46	23	22	31	45	58	68	53
50th	99	106	109	95	106	89	47	47	71	81	92	96	87
75th	141	167	180	156	197	184	94	94	121	132	140	137	145
80th	164	189	203	177	235	216	117	119	146	152	177	163	171
90th	236	273	302	304	430	393	241	221	399	343	309	243	308
95th	323	454	491	502	728	744	712	693	2,233	747	462	347	703

San Saba River at San Saba flow percentiles in cubic feet per second



Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases, two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5th, 25th, 50th, 75th, 80th, and 90th percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured.

Site Descriptions

- Review of aerial photography with Google Earth
  - 17 river-mile reach from the USGS gage downstream to confluence with the Colorado River
  - Flows for aerial photography dates; No apparent dry reaches between pools
    - January 26, 1995: 2.8 cfs
    - October 21, 2005: 78 cfs
    - October 30, 2008: 51 cfs
  - Habitats
    - Relatively abundant riparian vegetation obscures much of the river from aerial view
    - Wide pools are probably not a dominant mesohabitat and riffles and runs appear common
    - Split channels or oxbows not observed
- Field observations on September 1, 2010; USGS provisional flow was 38 cfs
  - Riffle upstream of SH 16, followed by a run to a cobble-boulder riffle under the SH 16 bridge and a run to a third riffle about 600 ft downstream of the SH 16 bridge
  - Mayfly nymphs abundant in the riffle and hellgrammites found
  - Water moccasin and pond slider turtle observed
  - Mosquitofish, unidentified minnows, and common carp observed. Live Asiatic clams collected along with shells of three species of mussels including the state-threatened, Texas pimpleback
- Field observations by TPWD and TWDB on September 23, 2010; USGS provisional flow was 61 cfs
  - Water willow, an aquatic plant, observed in the river
  - Herbaceous riparian vegetation: purple bindweed, ragweed, bermudagrass, sedge, wild grapevines, greenbriar, dewberry, horse herb, mist flower, castor bean, and cocklebur
  - Trees and shrubs further above the water's edge: pecans, oak, chinaberry, mulberry, sugar hackberry, black willow, American and cedar elm. Numerous mature trees and sapling

Soil Types

Soil data were obtained from the Natural Resource Conservation Service for a 5-mile stretch along the river (NRCS 2010).

Soil	Setting	Slope %	Wetland Potential	Flood Frequency
Frio silty clay loam, occasionally flooded	Floodplains, floodplains on draws	0-2	Well-drained	5-50 times per 100 years
Frio soils, frequently flooded	Floodplains, floodplains on draws	0-2	Well-drained	More than 50 times per 100 years
Nuvalde Shep complex	Stream terraces	1-5	Well-drained	None

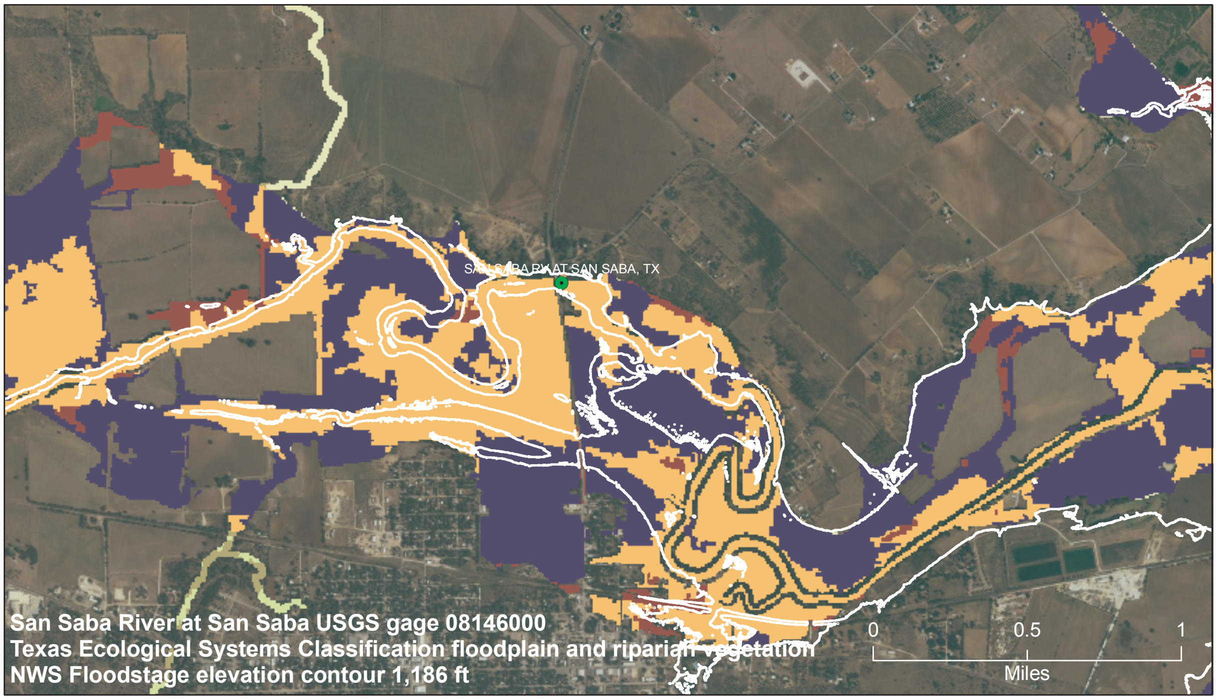
Wetlands

Review of the National Wetland Inventory (USFWS 2010) for about 3.5 miles of river near this site indicates widely scattered, relatively small areas adjacent to the river, which appear to be forested wetlands. These areas are expected to flood on an occasional basis. The river is classified as a lower perennial stream with a low gradient and velocity, and some flow throughout the year.

Riparian/Floodplain Vegetation

Analysis of Texas Ecological Systems Classification of vegetative communities was prepared for about 20 river miles along the San Saba River, most of which is upstream of the city of San Saba (German et al. 2009).

- Majority of the vegetation communities within the riparian and flood plain are Edwards Plateau floodplain hardwood forest and floodplain herbaceous
- Patches of Edwards Plateau floodplain deciduous shrubland are present.



Legend

COMMON_NAM

- Edwards Plateau: Floodplain Deciduous Shrubland
- Edwards Plateau: Floodplain Hardwood Forest
- Edwards Plateau: Floodplain Herbaceous Vegetation
- Edwards Plateau: Riparian Deciduous Shrubland
- Edwards Plateau: Riparian Hardwood Forest
- Edwards Plateau: Riparian Herbaceous Vegetation

Sources: Texas Ecological System Classification project, TPWD 2010 www.tpwd.state.tx.us/landwater/land/maps/gis/tescp/index.phtml, Floodstage elevation from NWS Advanced Prediction Service
Vertical Datums: USGS floodstage provided in NGVD29, LiDAR native datum is NAVD88 with resolution +-18.5cm (LCRA). Calculated difference for the study area is apx. 12cm. Horizontal datum: NAD83.
Contact: Lynne Hamlin, Water Resources Branch, TPWD lhamlin@tpwd.state.tx.us Map created Dec. 2010
Disclaimer: While every attempt was made to present the information as accurately as possible, no claims are made to the completeness or accuracy of the information shown herein nor to its suitability for a particular use.
Scale and location are approximate.

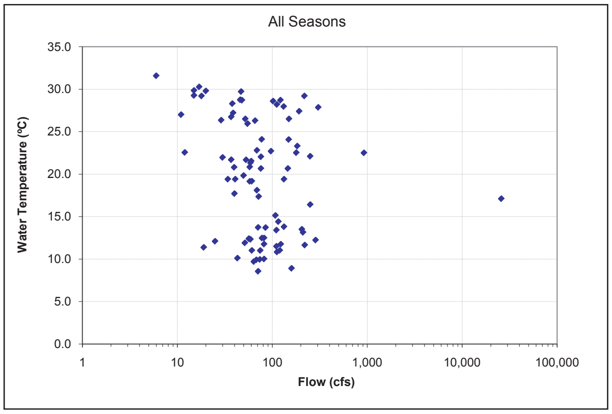
Texas Ecological Systems Classification of Riparian and Floodplain Vegetation for the San Saba River at San Saba. The white line represents the calculated NWS flood stage elevation.

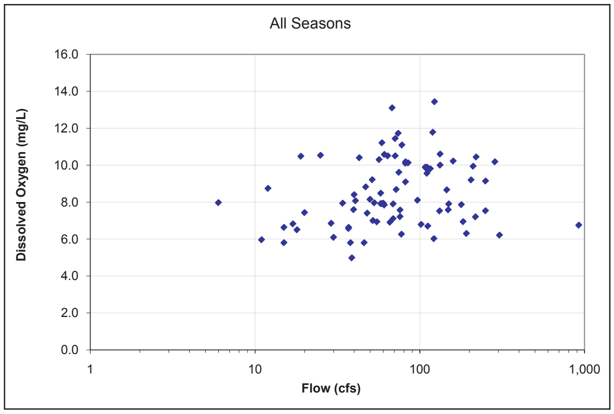
Biology

Source	Location	Biology	Observations
LCRA 2009	San Saba River	San Saba River meets its designated high aquatic life use for fish and benthic macroinvertebrates.	Assessment based on 2008 information
TPWD 2010	San Saba River	There are no reports in the TPWD database of fish kills in the San Saba River during the period from 1970 through 2009.	

Water Quality

- The water quality period of record for this gage is 9/1/1962–6/9/2010
- Relationships between flow and water quality parameters
    - Specific conductance decreases with increasing flow.
    - pH shows no correlation.
    - NO2+NO3-Nitrogen increases with increasing flow.
    - Total phosphorus increases with increasing flow.
    - Chloride decreases with increasing flow.
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in the Water Quality Segment 1416, San Saba River. The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated high aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
    - The segment of river where this gage site is located is not listed on the 303(d) list.
- Relationship between temperature and flow
    - No correlation was observed between water temperature and flow.
    - The highest temperature was 31.6 °C (flow: 6.0 cfs; dissolved oxygen: 8.0 mg/L).
    - The lowest temperature was 8.6 °C (flow: 71 cfs; dissolved oxygen: 11.4 mg/L).
    - The lowest flow was 1.0 cfs (temperature: not measured; dissolved oxygen: not measured).
    - The highest flow was 25,800 cfs (temperature: 17.1 °C; dissolved oxygen: not measured).
- Relationship between dissolved oxygen and flow
    - No correlation was observed between dissolved oxygen and flow.
    - The highest dissolved oxygen was 13.4 mg/L (flow: 123 cfs; temperature: 11.7 °C).
    - The lowest dissolved oxygen was 5.0 mg/L (flow of 38.7 cfs; temperature: 27.2 °C).
    - The lowest flow was 1.0 cfs (temperature: not measured; dissolved oxygen: not measured).
    - The highest flow was 25,800 cfs (temperature: 17.1 °C; dissolved oxygen: not measured).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
    - The maximum observed chloride was 54 mg/L, which is above the TSWQS of 50 mg/L.
    - The minimum and maximum pH were 6.7 and 8.4, which are within the TSWQS range of 6.5-9.0.
    - The highest observed instantaneous temperature was 31.6 °C, which is below the TSWQS of 32 °C.
    - The minimum observed dissolved oxygen concentration was 5.0 mg/L, which is at the TSWQS of 5.0 mg/L.





Geomorphology

Geomorphological analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77-93% of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows.

Flow Interpretations

No-flow periods: About 0.5% of the days over the period from 1916 through 1992 exhibited no flow. Increased frequency and duration of no-flow periods is not expected to improve ecosystem health.

Subsistence flows: Upstream-downstream connectivity in the immediate vicinity of the gage was provided at flows of 2.8 cfs. An extended reach of the river upstream of San Saba may lose its upstream-downstream connectivity at flows of 2.8 cfs because there is an extended reach where the channel is braided and water flows through several channels in limestone bedrock. The National Weather Service lowest flow for 7 days with the likelihood of occurring at least once every 2 years is 21.1 cfs.

Base flows: Fish and benthic communities that exhibit a high aquatic life use are present and are likely to require a range of flows to produce adequate diversity of habitat.

Pulses and overbank flows: Soils adjacent to the river indicate flooding may occur once every 2 to 20 years. The relatively dense riparian and floodplain vegetation in locations indicates flooding may be common along the riparian zone.

HEFR/Hydrologic Analysis

	Winter	Spring	Summer	Fall
Overbank Flows	Qp: 14,900 cfs with Average Frequency 1 per 5 years Regressed Volume is 36,667 to 155,389 (75,483) Regressed Duration is 3 to 27 (10)			
High Flow Pulses	Qp: 8,980 cfs with Average Frequency 1 per 2 years Regressed Volume is 22,021 to 93,163 (45,294) Regressed Duration is 3 to 24 (8)			
	Qp: 5,460 cfs with Average Frequency 1 per year Regressed Volume is 13,341 to 56,364 (27,422) Regressed Duration is 3 to 21 (7)			
	Qp: 334 cfs with Average Frequency 1 per season Regressed Volume is 910 to 5,660 (2,269) Regressed Duration is 1 to 18 (5)	Qp: 1,990 cfs with Average Frequency 1 per season Regressed Volume is 4,907 to 17,302 (9,214) Regressed Duration is 2 to 12 (5)	Qp: 214 cfs with Average Frequency 1 per season Regressed Volume is 531 to 2,111 (1,059) Regressed Duration is 1 to 9 (3)	Qp: 504 cfs w Average Freque 1 per seaso Regressed Vol is 1,168 to 4, (2,272) Regressed Dura is 1 to 12 (
	Qp: 146 cfs with Average Frequency 2 per season Regressed Volume is 392 to 2,452 (980) Regressed Duration is 1 to 14 (4)	Qp: 805 cfs with Average Frequency 2 per season Regressed Volume is 1,919 to 6,756 (3,600) Regressed Duration is 2 to 9 (4)		Qp: 137 cfs w Average Freque 2 per seaso Regressed Vol is 307 to 1, (599) Regressed Dura is 1 to 8 (
Base Flows (cfs)	107 (43.4%)	115 (42.7%)	62 (38.0%)	87 (40.8%)
	81 (61.3%)	81 (60.2%)	46 (50.5%)	64 (56.2%)
	57 (78.9%)	55 (77.5%)	32 (63.5%)	40 (72.2%)
Subsistence Flows (cfs)	29 (95.0%)	22 (95.1%)	3.2 (95.0%)	13 (95.6%)
	Nov, Dec, Jan, Feb	Mar, Apr, May, Jun	Jul, Aug	Sep, O

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Recommended Environmental Flow Regime

San Saba River at San Saba, USGS Gage 08146000, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1916-1992	0 periods Max duration: 0 days	2 periods Max duration: 3 days	13 periods Max duration: 46 days	0 periods Max duration: 0 days
Subsistence	29 cfs	22 cfs	22 cfs	22 cfs
Base Low	56 cfs	56 cfs	32 cfs	40 cfs
Base Medium	81 cfs	81 cfs	46 cfs	64 cfs
Base High	110 cfs	110 cfs	62 cfs	87 cfs
2 Pulses per season	Trigger: 150 cfs Volume: 980 af Duration: 14 days	Trigger: 810 cfs Volume: 3,600 af Duration: 9 days	Not applicable	Trigger: 150 cfs Volume: 600 af Duration: 8 days
1 Pulse per season	Trigger: 330 cfs Volume: 2,300 af Duration: 18 days	Trigger: 2,000 cfs Volume: 9,200 af Duration: 12 days	Trigger: 210 cfs Volume: 1,100 af Duration: 9 days	Trigger: 500 cfs Volume: 2,300 af Duration: 12 days
1 Pulse per year	Trigger: 5,500 cfs Volume: 27,400 af Duration: 21 days			
1 Pulse per 2 years	Trigger: 9,000 cfs Volume: 45,300 af Duration: 24 days			
1 per 5 years (Overbank)	Trigger: 14,900 cfs Volume: 75,500 af Duration: 27 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second
af = acre-feet

2.2.6 Llano River at Llano

USGS Gage 08151500


Typical view of Llano River at Llano, facing southeast at the highway crossing (left photo) and downstream (right photo) (Google Earth 2010).


Typical view of Llano City Lake dam, facing north (left photo) and south (right photo) (Google Earth 2010).

General Area Description (USGS 2009, USEPA 2003, Griffith et al. 2007, TPWD 2010)

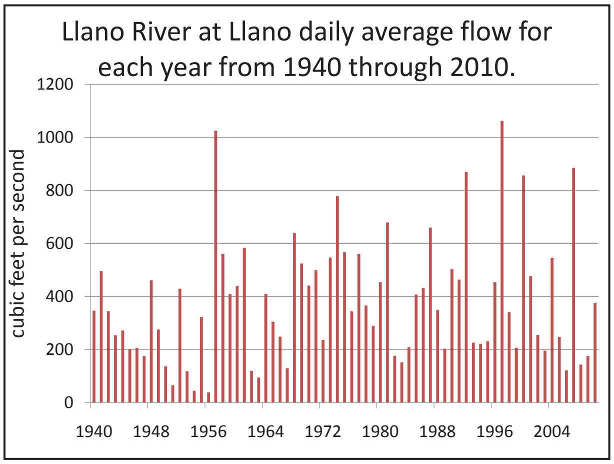
- Located in the city of Llano, downstream of Llano City Lake, at the crossing of Highway 71 in Llano County
- Edwards Plateau, EPA Level III ecoregion of Texas
- Llano Uplift, Level IV ecoregion of Texas
- Streams: low to moderate gradients with cobble, boulder, and sandy substrates
- Many springs give rise to the Llano River, and several creeks contribute to the river upstream of the gage
- Pecan Creek, Johnson Creek, San Fernando Creek, and Hickory Creek flow into the Llano River upstream of the gage
- A section of Llano River upstream of Llano City Lake is designated as an ecologically signifi-

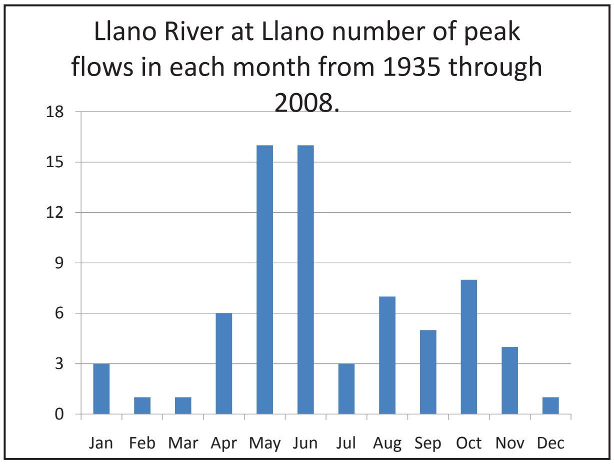
cant stream segment, where it has high water quality, exceptional aquatic life, high aesthetic value, and supports a genetic refuge for Guadalupe bass
- Though there is a dam on the river in the city of Llano, it is a simple barricade with no power-generating capacity
- No major diversions on this river
- Primary land cover and use: woodland, shrubland, grassland and rock outcrops, with some cattle ranching and cropland
- Meanders with multiple channels, granite boulders, and sandy shoals
- Part of the flow of the Llano River disappears into various formations or faults upstream of this gage
- Riparian areas support elms, willows, American sycamore, and non-native saltcedar (*Tamarix* spp.)
- Other native woody vegetation in the region: plateau live oak, post oak, blackjack oak, cedar elm, and black hickory

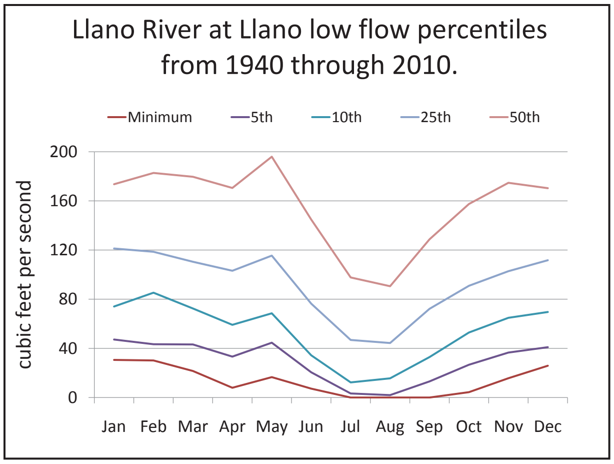
Summary of Historical USGS Gage Stream Flow Records (USGS 2010, NOAA 2010)

Llano County, Texas,	Hydrologic Unit: 12090204	Latitude 30°45'04", Longitude 98°40'10" NAD27
Drainage area: 4,197 square miles	Contributing drainage area: 4,192 square miles,	
Datum of gage: 970.01 feet above sea level NGVD29	Flood stage occurs at 10 ft above the USGS gage elevation (NWS 2010)	

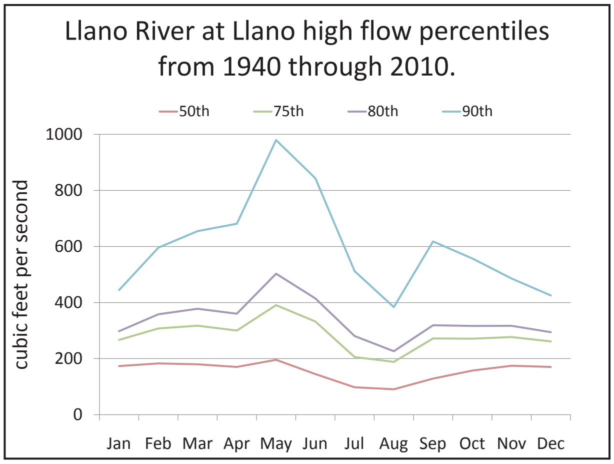
Summary of Historical USGS Flow Records at Llano River at Llano







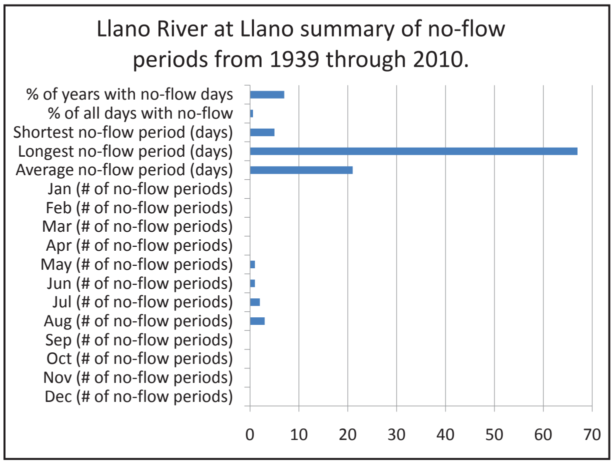
Llano River at Llano low flow percentiles from 1940 through 2010.



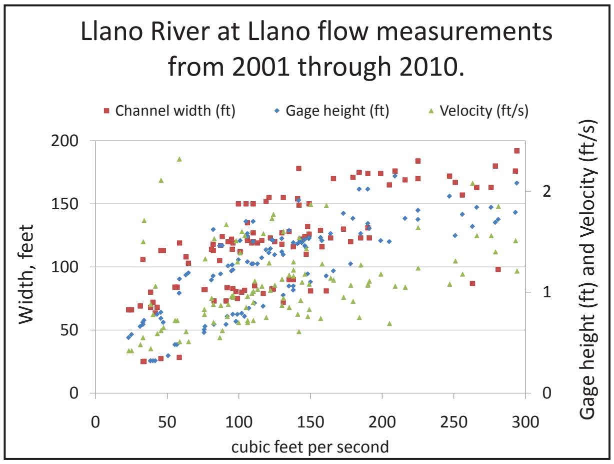
Llano River at Llano high flow percentiles from 1940 through 2010.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	4,379	6,854	4,521	6,288	8,550	15,317	4,661	9,866	11,632	14,415	10,260	5,665	8,534
Average	278	372	331	373	509	562	250	302	406	499	384	285	379
Minimum	31	30	22	8	17	7	0	0	0	4	16	26	13
5th	47	43	43	33	45	21	3	2	13	27	37	41	30
10th	74	85	72	59	69	34	12	16	33	53	65	70	54
20th	111	107	99	93	101	66	37	35	62	81	91	100	82
25th	121	119	110	103	115	76	47	44	72	91	103	112	93
50th	174	183	180	171	196	145	98	91	129	157	175	170	156
75th	267	308	317	300	391	332	206	188	272	271	277	261	283
80th	298	358	378	360	503	415	280	226	319	317	317	294	339
90th	444	596	655	681	979	843	512	384	618	557	486	425	598
95th	653	1,267	1,105	1,424	2,170	2,233	858	801	1,215	1,660	976	589	1,246

Llano River at Llano flow percentiles in cubic feet per second



Llano River at Llano summary of no-flow periods from 1939 through 2010.



Llano River at Llano flow measurements from 2001 through 2010.

Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases,two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5th, 25th,50th, 75th, 80th, and 90th percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured.

Site Description

- Review of aerial photography with Google Earth
  - Reviewed approximately 10 miles of river, from 5 miles upstream of the USGS gage to 5 miles downstream of the gage
  - Flows for each aerial photography date
    - January 5, 1995/January 26, 1995: 347/229 cfs
    - December 30, 1997: 281 cfs
    - December 30, 2002: 203 cfs
    - October 21, 2005: 126 cfs
    - April 29, 2006: 181 cfs
    - February 28, 2008: 160 cfs
    - October 30, 2008: 87 cfs
  - Habitats
    - Long, straight, reaches of shallow glides and pools
    - Llano City Lake is an approximately 1-mile stretch of the Llano River that has been dammed near the bridge at State Highway 16, upstream of the gage
    - Downstream of Llano City Lake, the river channel has several braided flow channels

across rock outcrop and sand substrates
- Development of the city of Llano extends to the north and south banks of the river one mile upstream of the gage and one-half mile downstream of the gage

Soil Types

Information about soils for an approximately 2-mile portion of this reach was obtained from NRCS (2009).

Soil*	Setting	Slope (%)	Wetland Potential	Flood Frequency
Riverwash-Rock outcrop complex	Streambed and channel of the Llano River	0	-	Flooded >50 times in 100 years
Fieldcreek fine sandy loam	Low terraces and on flood plains along streams and creeks	0	Moderately rapid permeability; well drained	Flooded about once in 15 years
Boerne fine sandy loam	Second-level flood plain of the Llano River	0	Moderately rapid permeability; well drained	Flooded 1 to 5 times in 100 years
Katemcy sandy loam	Foot slopes	1 to 5	Moderately slow permeability	Moderate water and wind erosion hazard

Wetlands

The section of the river downstream of the gage has many sandbars within the channel and a few series of braided stream segments within the channel. The main features identified on the National Wetland Inventory map (USFWS 2010) along this reach included:

- Llano River channel (R2RBH/R2UBH; riverine, lower perennial, permanently flooded)
- Channels of tributaries (PFO1A; broad-leaf deciduous forested palustrine feature, temporarily flooded)
- Several small upland ponds

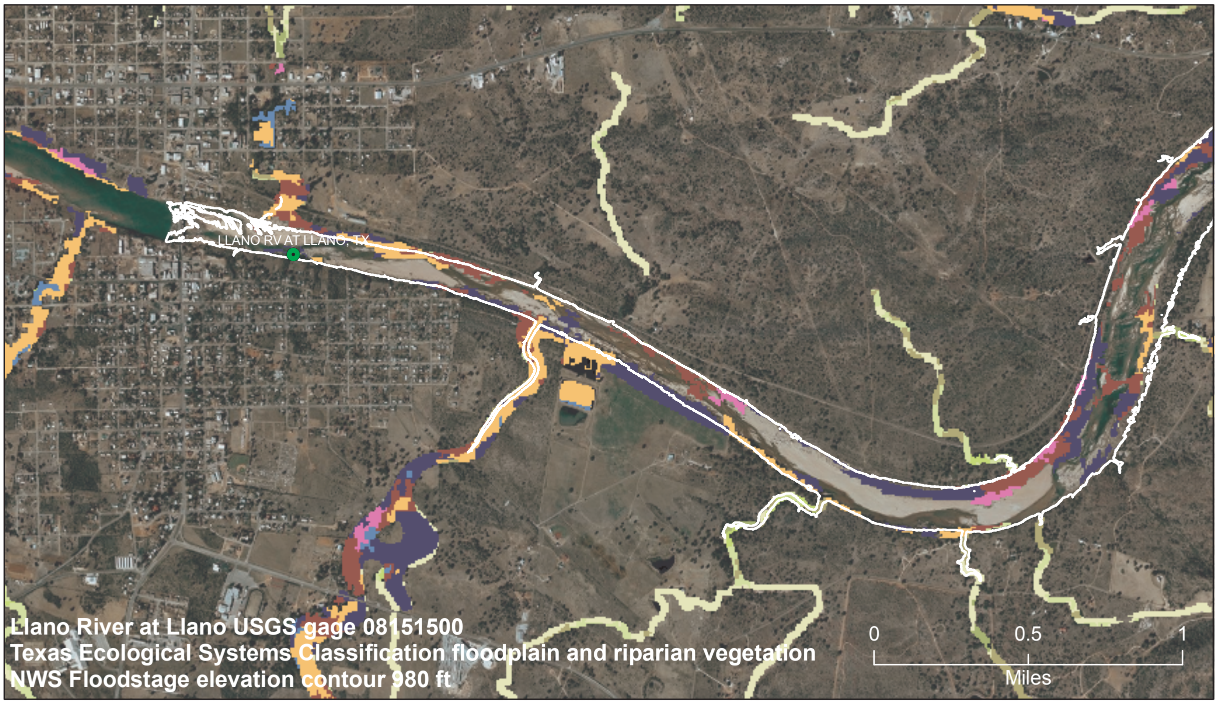
Riparian/Floodplain Vegetation

Texas Ecological System Classification of vegetation communities indicates the floodplain and riparian vegetation communities in this reach are generally confined to the stream banks and a narrow floodplain along tributaries of the Llano River. These communities consist of mainly four vegetation types in the "Edwards Plateau" region (see Riparian Vegetation Map below; German et al. 2009):

- Floodplain herbaceous vegetation
    - Typically grasslands that may include bermudagrass, King Ranch bluestem, switchgrass, bushy bluestem, Virginia wildrye, Texas wintergrass, little barley, eastern gamagrass, and Lindheimer muhly
- Floodplain ashe-juniper shrubland
    - A disturbance evergreen shrubland commonly a mix of ashe juniper, live oak, and mesquite
- Floodplain deciduous shrubland

  - Contain various shrublands, and mesquite, cedar elm, and plateau live oak (scattered trees or shrubs) common components
  - Huisache, western soapberry, little walnut, sugar hackberry, Ashe juniper, and common buttonbush may be components
- Floodplain hardwood forest
  - Mainly deciduous forest commonly with cedar elm, American elm, pecan, plateau live oak, bur oak, western soapberry, Arizona walnut, green ash, and plateau live oak
  - Understory species may include gum bumelia, roughleaf dogwood, red mulberry, Texas persimmon, and possumhaw

Floodplain riparian communities both upstream and downstream of the gage are made up of a similar assemblage of these four vegetation communities. The herbaceous vegetation along the river, including native bushy bluestem, switchgrass, Virginia wildrye, and eastern gamagrass are flood-tolerant, typically wetland species that benefit from base flows and pulse flows that provide moist soil conditions. The smaller, scattered communities of floodplain shrublands with buttonbush, which requires nearly continuous wet conditions, and floodplain hardwood forest with species such as green ash, American elm, cedar elm, and pecan that require wet conditions a fair amount of time, indicate that the riparian zone has developed with periodic pulse and overbank flows that allow these flood tolerant species to become established. Maintaining the seasonal variability in pulse and overbank flows is also important to allow seed dispersal, germination and recruitment of seedlings of these obligate wetland and facultative plant species.



Legend

COMMON_NAM

- Edwards Plateau: Floodplain Ashe Juniper Shrubland
- Edwards Plateau: Floodplain Deciduous Shrubland
- Edwards Plateau: Floodplain Hardwood / Ashe Juniper Forest
- Edwards Plateau: Floodplain Hardwood Forest
- Edwards Plateau: Floodplain Herbaceous Vegetation
- Edwards Plateau: Riparian Deciduous Shrubland
- Edwards Plateau: Riparian Hardwood / Ashe Juniper Forest
- Edwards Plateau: Riparian Hardwood Forest
- Edwards Plateau: Riparian Herbaceous Vegetation
- Edwards Plateau: Riparian Live Oak Forest

Sources: Texas Ecological System Classification project, TPWD 2010 www.tpwd.state.tx.us/landwater/land/maps/gis/tescp/index.phtml, Floodstage elevation from NWS Advanced Prediction Service
Vertical Datums: USGS floodstage provided in NGVD29, LiDAR native datum is NAVD88 with resolution +-18.5cm (LCRA). Calculated difference for the study area is apx. 12cm. Horizontal datum: NAD83.
Contact: Lynne Hamlin, Water Resources Branch, TPWD lhamlin@tpwd.state.tx.us Map created Dec. 2010
Disclaimer: While every attempt was made to present the information as accurately as possible, no claims are made to the completeness or accuracy of the information shown herein nor to its suitability for a particular use.
Scale and location are approximate.

Texas Ecological Systems Classification of Riparian and Floodplain Vegetation for the Llano River. The white line represents the calculated NWS flood stage elevation.

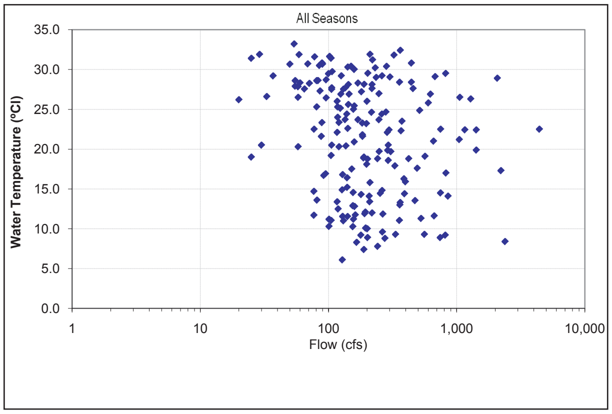
Biology

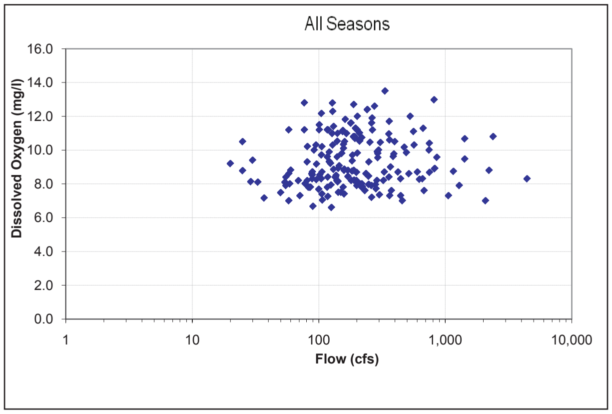
Source	Location	Biology	Observations
LCRA 2001	Llano River	Most abundant fish species from sampling in 2000 include shiners (blacktail, weed, sand, and mimic shiners), central stoneroller, sunfish (redbreast, green, longear, and orange-spotted sunfish), smallmouth buffalo, bluegill, and Guadalupe bass	High to Exceptional aquatic life Index of Biotic Integrity values
LCRA Database (unpublished data, 2000-2010)	Llano River watershed	Most abundant fish species from 2000-2010 include blacktail shiner, mimic shiner, Texas shiner, mosquitofish, orangethroat darter, redbreast sunfish, longear sunfish, Guadalupe bass, and central stoneroller	Total of 31 fish species collected in the Llano River
Perkin et al. 2010	Pedernales and Llano Rivers	Guadalupe bass study found these fish use shaded pool habitat under normal flow conditions, and move to eddy mesohabitats during flood events to resist downstream displacement.	Habitat degradation is the most significant threat to the persistence of Guadalupe bass.

Water Quality

- The water quality period of record for this gage
- 02/15/1984 - 06/09/2010
- Relationships between flow and water quality parameters
  - NO2+NO3–N increases with increasing flow.
  - Total phosphorus increases with increasing flow.
  - Chloride decreases with increasing flow.
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in the Water Quality Segment 1415, Llano River. The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated high aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
  - The segment of river where this gage site is located is not listed on the 303(d) list.

- Relationship between temperature and flow
  - No correlation was observed between water temperature and flow.
  - The highest temperature was 33.2 °C (flow: 54 cfs; dissolved oxygen: 8.1 mg/L).
  - The lowest temperature was 6.1 °C (flow: 128 cfs; dissolved oxygen: 12.79 mg/L).
  - The lowest flow was 20 cfs (temperature: 26.2 °C; dissolved oxygen: 9.2 mg/L).
  - The highest flow was 4430 cfs (temperature: 22.5 °C; dissolved oxygen: 8.3 mg/L).
- Relationship between dissolved oxygen and flow
  - No correlation was observed between dissolved oxygen and flow.
  - The highest dissolved oxygen was 13.5 mg/L (flow: 334 cfs; temperature: 9.3 °C).
  - The lowest dissolved oxygen was 6.6 mg/L (flow of 126 cfs; temperature: 29.2 °C).
  - The lowest flow was 20 cfs (temperature: 26.2 °C; dissolved oxygen: 9.2 mg/L).
  - The highest flow was 4,430 cfs (temperature: 22.5 °C; dissolved oxygen: 8.3 mg/L).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - The maximum observed chloride concentration was 48 mg/L.
  - The minimum and maximum pH values were 6.81 and 8.95.
  - The highest observed instantaneous temperature was 33.2 °C.
  - The minimum observed dissolved oxygen concentration was 6.6 mg/L. None of the dissolved oxygen measurements were less than 5 mg/L.





Geomorphology

Geomorphological analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77-93% of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows.

Flow Regime Interpretations

No-flow periods: A sound ecological environment in this reach of the Llano River may be maintained by preventing an increase in the frequency and duration of no-flow periods than have occurred in the past.

Subsistence flows: The TCEQ's critical low flow value is 55 cfs.

Base flows: Base flow is relatively low across the wide, incised stream channel over rock outcrop and sand substrate.

Pulses and overbank flows: Pulses and overbank flows are valuable; however, the frequency of occurrence is relatively low.

HEFR/Hydrologic Regime

	Winter (Nov, Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct)
Overbank Flows	Qp: 41,100 cfs with Average Frequency 1 per 5 years Regressed Volume is 110,353 to 415,060 (214,016) Regressed Duration is 4 to 27 (10)			
Overbank Flows	Qp: 17,400 cfs with Average Frequency 1 per 2 years Regressed Volume is 46,081 to 172,904 (89,262) Regressed Duration is 3 to 22 (8)			
High Flow Pulses	Qp: 9,090 cfs with Average Frequency 1 per year Regressed Volume is 23,820 to 89,252 (46,108) Regressed Duration is 3 to 18 (7)			
High Flow Pulses	Qp: 1,100 cfs with Average Frequency 1 per season Regressed Volume is 3,112 to 14,748 (6,774) Regressed Duration is 2 to 16 (5)	Qp: 4,790 cfs with Average Frequency 1 per season Regressed Volume is 13,046 to 41,397 (23,240) Regressed Duration is 2 to 13 (6)	Qp: 558 cfs with Average Frequency 1 per season Regressed Volume is 1,294 to 5,113 (2,572) Regressed Duration is 1 to 9 (3)	Qp: 1,380 cfs with Average Frequency 1 per season Regressed Volume is 3,403 to 11,736 (6,320) Regressed Duration is 1 to 11 (4)
High Flow Pulses	Qp: 391 cfs with Average Frequency 2 per season Regressed Volume is 1,143 to 5,430 (2,491) Regressed Duration is 1 to 13 (4)	Qp: 1,840 cfs with Average Frequency 2 per season Regressed Volume is 4,767 to 15,102 (8,485) Regressed Duration is 2 to 10 (4)		Qp: 369 cfs with Average Frequency 2 per season Regressed Volume is 880 to 3,044 (1,637) Regressed Duration is 1 to 8 (3)
Base Flows (cfs) – High	195(42.5%)	200(42.1%)	127(37.7%)	178(41.1%)
Base Flows (cfs) – Medium	150(60.5%)	143(59.2%)	92(50.5%)	122(57.4%)
Base Flows (cfs) – Low	109(77.5%)	98(76.0%)	67(63.0%)	87(73.5%)
Subsistence Flows (cfs)	44(95.4%)	36(95.1%)	3.3(95.0%)	20(95.3%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:
1. Period of Record used : 1/1/1940 to 12/31/2009.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 25 cfs.

Recommended Environmental Flow Regime

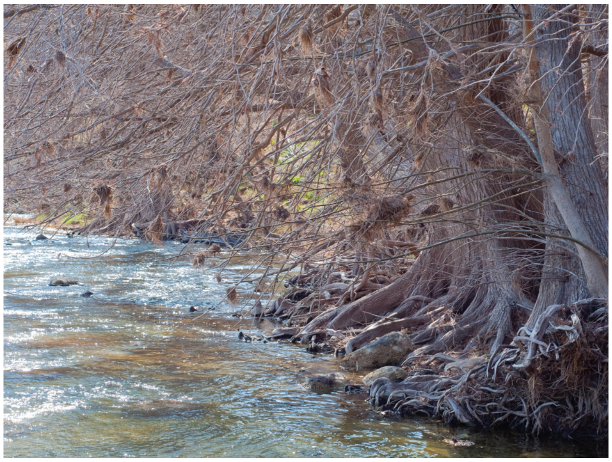
Llano River at Llano, USGS Gage 08151500, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1923-2009	0 periods Max duration: 0 days	2 periods Max duration: 67 days	5 periods Max duration: 31 days	0 periods Max duration: 0 days
Subsistence	55 cfs	55 cfs	55 cfs	55 cfs
Base Low	100 cfs	100 cfs	67 cfs	87 cfs
Base Medium	150 cfs	150 cfs	92 cfs	120 cfs
Base High	190 cfs	190 cfs	130 cfs	190 cfs
2 Pulses per season	Trigger: 390 cfs Volume: 2,500 af Duration: 13 days	Trigger: 1,800 cfs Volume: 8,500 af Duration: 10 days	Not applicable	Trigger: 370 cfs Volume: 1,600 af Duration: 8 days
1 Pulse per season	Trigger: 1,100 cfs Volume: 6,800 af Duration: 16 days	Trigger: 4,800 cfs Volume: 23,200 af Duration: 13 days	Trigger: 560 cfs Volume: 2,600 af Duration: 9 days	Trigger: 1,400 cfs Volume: 6,300 af Duration: 11 days
1 Pulse per year	Trigger: 9,100 cfs Volume: 46,100 af Duration: 18 days			
1 Pulse per 2 years (Overbank)	Trigger: 17,400 cfs Volume: 89,300 af Duration: 22 days			
1 Pulse per 5 years (Overbank)	Trigger: 41,100 cfs Volume: 214,000 af Duration: 27 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second
af = acre-feet

2.2.7 Pedernales River near Johnson City — USGS Gage 08153500


Typical view of the Pedernales River near Johnson City, facing upstream (left) and downstream (right) (Google Earth 2010).

Typical view of the Pedernales River at Pedernales Falls State Park, facing upstream (left) and a view of the bald cypress along the bank (right) (M. Fontenot, February 17, 2011).

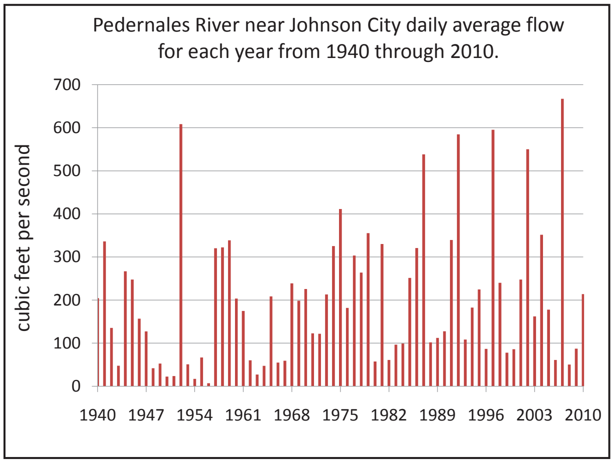
General Area Description (USGS 2010, USEPA 2003, Griffith et al. 2007, TPWD 2010)

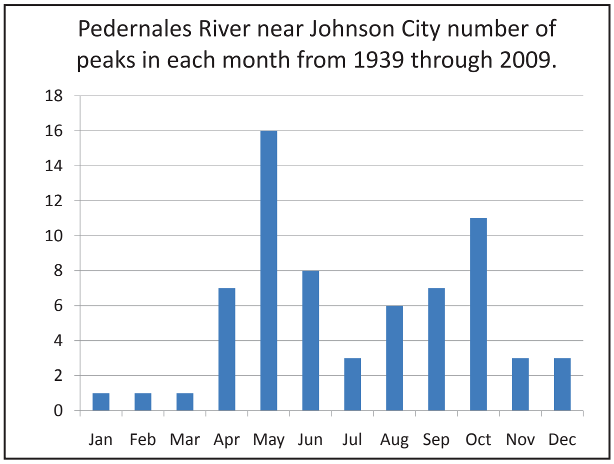
- Located north of Johnson City at the crossing of Highway 281 in Blanco County
- Edwards Plateau, EPA Level III ecoregion of Texas
- Edwards Plateau Woodland, Level IV ecoregion of Texas
- The entire Pedernales River listed as an ecologically significant stream
- Spring-fed system flowing over limestone substrate
- Characterized by rolling terrain and intervening broad valleys
- Streams: low to moderate gradients with mostly bedrock, cobble, gravel and sandy substrates
- Land cover includes woodland, grassland and pastureland
- Primary land use: livestock grazing
- Native riparian trees: sycamore, ash, black willow, little walnut, and eastern cottonwood; pecan, American elm, and plateau live oak occur in the floodplains of larger rivers

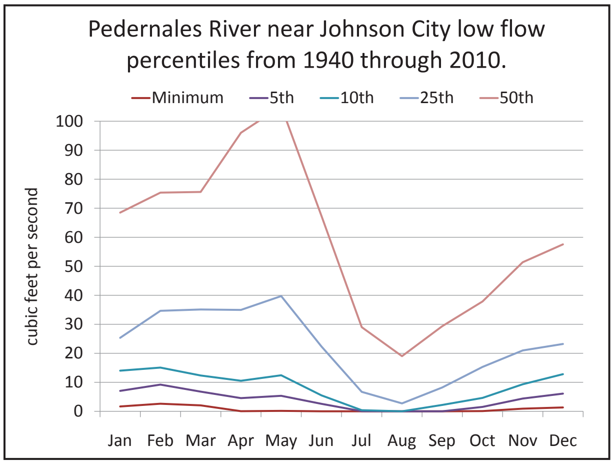
Summary of Historical USGS Gage Stream Flow Records (USGS 2010, NOAA 2010)

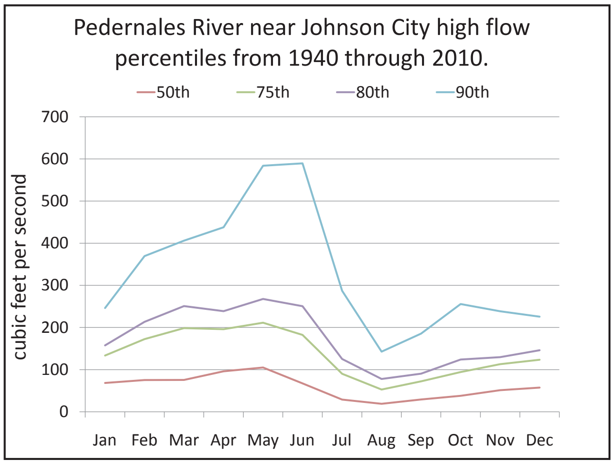
Blanco County, Texas	Hydrologic Unit: 12090206	Latitude 30°17’30” Longitude 98°23’57” NAD27
Drainage area: 901 square miles	Contributing drainage area: 901 square miles	
Datum of gage: 1,096.70 feet above sea level NGVD29	Flood stage occurs at 14 ft above the USGS gage elevation of 1096.7 ft.	

Summary of Historical USGS Flow Records at Pedernales River near Johnson City



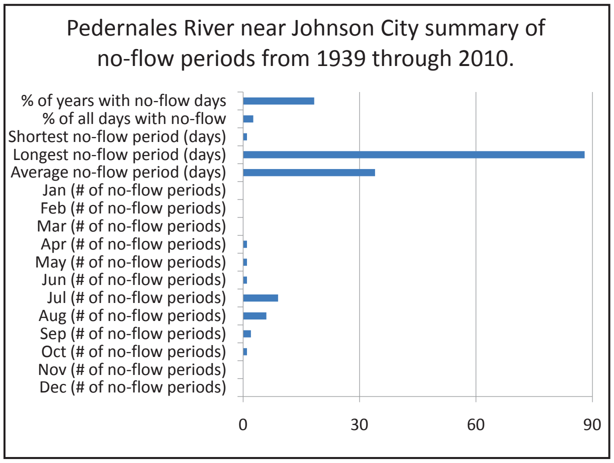


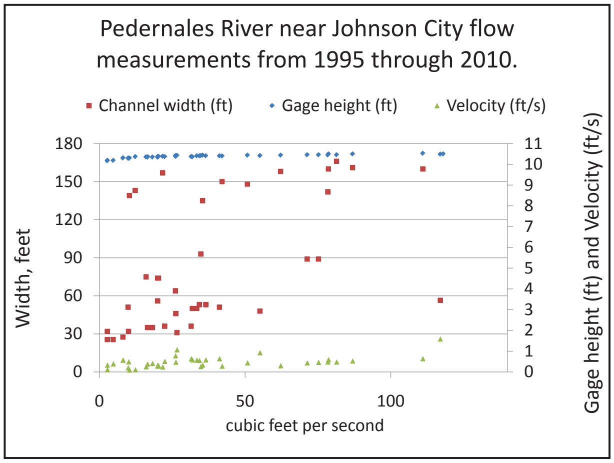




	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	1,871	3,945	3,231	5,426	7,281	7,985	5,828	5,665	8,595	7,149	2,764	4,788	5,377
Average	127	206	194	240	328	319	171	130	191	219	129	170	202
Minimum	2	3	2	0.1	0.2	0	0	0	0	0.1	1	1	1
5th	7	9	7	5	5	3	0.1	0	0	2	4	6	4
10th	14	15	12	11	12	5	0.4	0	2	5	9	13	8
20th	21	29	29	27	28	15	3	1	5	12	16	19	17
25th	25	35	35	35	40	22	7	3	8	15	21	23	22
50th	69	75	76	96	105	67	29	19	29	38	51	58	59
75th	134	172	199	196	211	183	90	53	72	94	113	123	137
80th	158	213	251	239	268	251	125	78	90	124	130	146	173
90th	246	369	406	438	584	590	287	143	185	256	239	226	331
95th	430	879	698	840	1,391	1,520	613	286	415	832	432	513	737

Pedernales River near Johnson City flow percentiles in cubic feet per second





Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases,two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5th, 25th,50th, 75th, 80th, and 90th percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured.

Site Description

- Review of aerial photography with Google Earth
  - 10 miles of the river, from 5 miles upstream of the gage down to Pedernales Hills Road crossing (approximately 5 miles downstream of the gage)
  - Flows for aerial photography dates:
    - January 8, 1995: 169 cfs
    - December 30, 1997: 86 cfs
    - December 30, 2002: 284 cfs
    - September 30, 2004: 48 cfs
    - October 21, 2005: 26 cfs
    - April 29, 2006: 730 cfs, following a peak of 1,560 cfs that day
    - February 28, 2008: 108 cfs
    - October 30, 2008: 9.9 cfs
  - Habitats
    - Long reaches of relatively straight glides separated by pools and occasional riffle-run reaches
    - Johnson City Lake is an approximately 1-mile section of the river that is a pool habitat created by a simple barricade, located immediately upstream of the gage
    - Two in-channel islands observed upstream of the gage in 2008 imagery
    - No oxbow channels observed in this reach
    - Based on 2009 aerial photography, the riparian vegetation within the floodplain appears to be sparse and confined to the banks of the Pedernales River and its tributaries

Soil Types

Information about soils for an approximately 2-mile portion of this reach was obtained from NRCS (2009).

Soil*	Setting	Slope	Wetland Potential	Flood Frequency
Riverwash	Along the sides of the Pedernales River channel	-	-	Frequently flooded (>50 times in 100 years)
Eckert-Rock outcrop association	Very shallow, loamy soils and rock outcrop on broad hills and uplands	Rolling, 5 to 16 %	Moderate permeability, well-drained	
Nebgen-Oben-Rock outcrop association	Shallow, stony loamy soils and rock outcrops on rolling uplands	5 to 16%	Moderate permeability, well-drained	
Hensley association	Shallow, stony, loamy soils underlain by limestone on rangeland	1 to 8%	Slow permeability, well-drained	

Wetlands

The main features identified on the National Wetland Inventory map (USFWS 2010) along this reach included:

- The perennial Pedernales River channel with unconsolidated to rock bottom substrate (R2UBH; R2RBH)
- Channels of intermittent tributaries (Flat Creek, Town Creek, Deer Creek)
- A few upland ponds

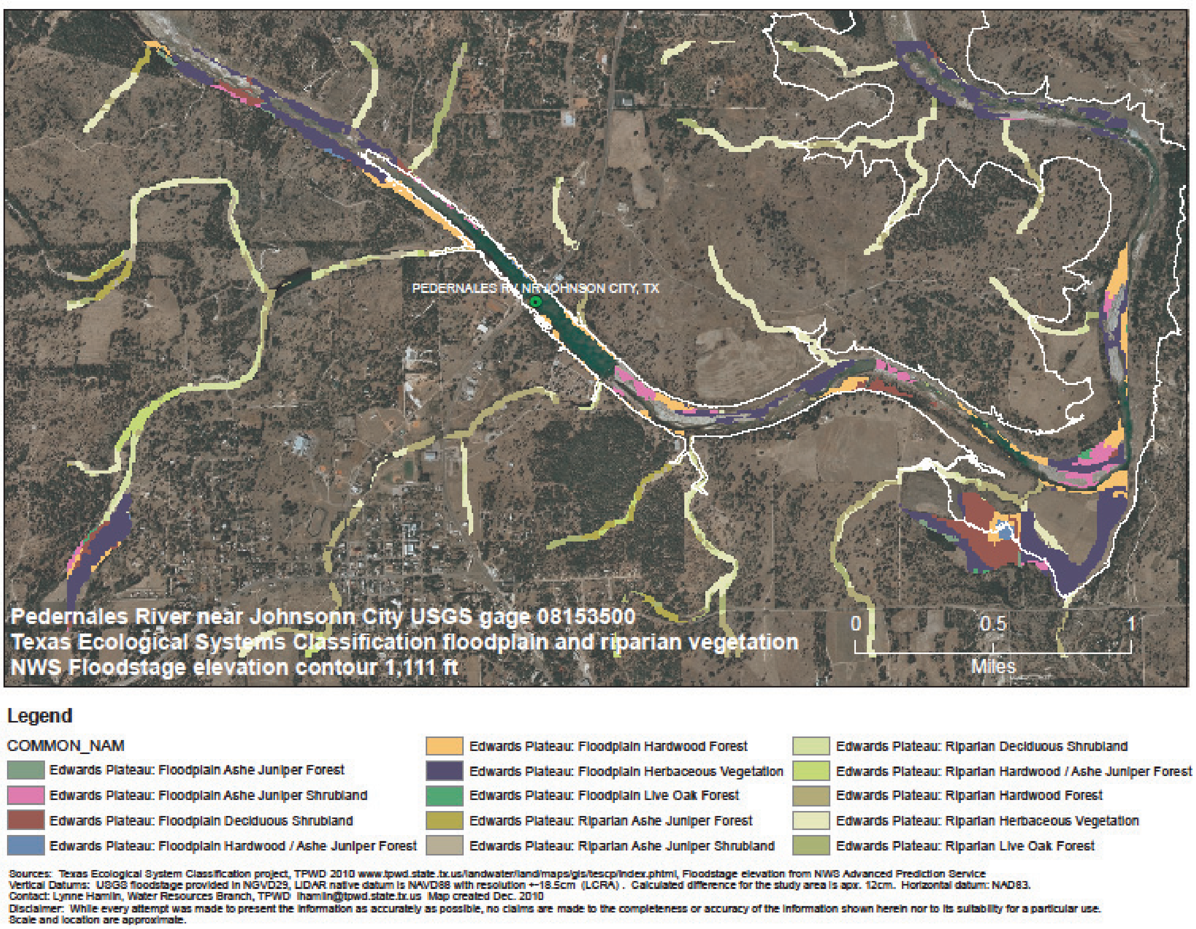
Riparian/Floodplain Vegetation

Texas Ecological System Classification of vegetation communities shown in the figure below indicate the riparian and floodplain communities in this reach occur in small pockets immediately adjacent to the river channel and tributary channels. The dominant communities consist mainly of three vegetation types in the "Edwards Plateau" region (German et al. 2009).

- Floodplain herbaceous vegetation
  - Typically grasslands that may include bermudagrass, King Ranch bluestem, switchgrass, bushy bluestem, Virginia wildrye, Texas wintergrass, little barley, eastern gamagrass, and Lindheimer muhly
- Floodplain hardwood forest
  - Commonly consists of cedar elm, American elm, pecan, plateau live oak, bur oak, western soapberry, Arizona walnut, and green ash; floodplain herbaceous vegetation dominated by bermudagrass or King Ranch bluestem
- Floodplain ashe-juniper shrubland
  - A disturbance evergreen shrubland commonly a mix of ashe juniper, live oak, and mesquite

Changes in the historical vegetation of the Pedernales River watershed have not been dramatic in this area, and communities are predominantly woodland stands of juniper and oak, with prairie and grassy areas common throughout the area (LCRA 2000). Along perennial stream banks, the vegetation is dominated by bald cypress, sycamore, and to a lesser extent black willow (Abbott and Woodruff 1986). Buttonbush is often conspicuous in the shrub stratum. Smaller floodplains and higher terraces are dominated by American elm, cedar elm, pecan, sugarberry, netleaf hackberry, and Texas ash (Beuchner 1944).

Similar to the Llano River, the floodplain herbaceous vegetation communities have developed with flood-tolerant wetland plants such as bushy bluestem, switchgrass, and eastern gamagrass. Floodplain hardwood communities both on the mainstem of the Pedernales River and along its tributaries (e.g., Hamilton Creek) have established with areas of bald cypress which requires nearly continuous wet conditions, and mixed communities of facultative tree and herbaceous species (e.g., Eastern gammagrass). These areas have likely had perennial water for bald cypress to persist, and maintaining seasonal variability in pulse and overbank flows is important for seed dispersal, germination, and recruitment for species including green ash, American sycamore, cedar elm, American elm, and pecan.



Texas Ecological Systems Classification of Riparian and Floodplain Vegetation for the Pedernales River near Johnson City. The white line represents the calculated NWS flood stage elevation.

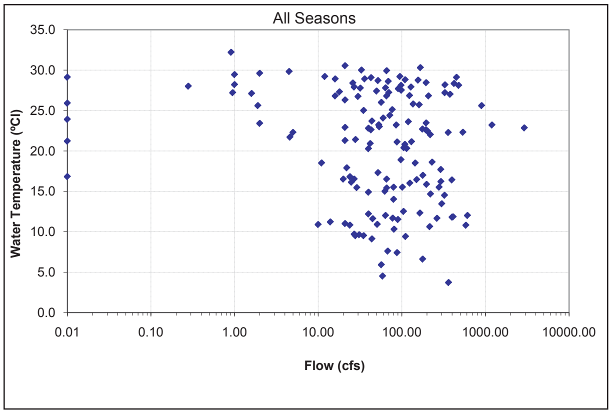
Biology

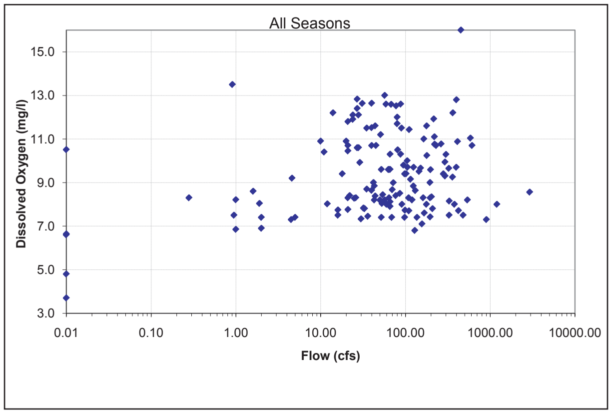
Source	Location	Biology	Observations
Perkin et al. 2010	Pedernales and Llano Rivers	Guadalupe bass study found these fish use shaded pool habitat under normal flow conditions, and move to eddy mesohabitats during flood events to resist downstream displacement.	Habitat degradation is the most significant threat to the persistence of Guadalupe bass.
LCRA Database (unpublished data, 2000-2010)	Pedernales River watershed	Most abundant fish species from 2000-2010 include blacktail shiner, red shiner, bluegill, mimic shiner, flathead catfish, longear sunfish, Texas shiner, redbreast sunfish, Texas logperch, central stoneroller, and Guadalupe bass.	Total of 32 fish species collected in the Pedernales River watershed.

Water Quality

- The water quality period of record for this gage is 02/15/1984 - 06/09/2010
- Relationships between flow and water quality parameters
  - Specific conductance decreases with increasing flow.
  - pH decreases with increasing flow.
  - Chloride decreases with increasing flow.
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in the Water Quality Segment 1414, Pedernales River. The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated high aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
  - The segment of river where this gage site is located is not listed on the 303(d) list.
- Relationship between temperature and flow:
  - No correlation was observed between water temperature and flow.
  - The highest temperature was 32.2 °C (flow: 0.91 cfs; dissolved oxygen: 13.5 mg/L).
  - The lowest temperature was 3.7 °C (flow: 363 cfs; dissolved oxygen: 12.2 mg/L).
  - The lowest flow was .01 cfs (temperature: 29.11 °C; dissolved oxygen: 10.11 mg/L).
  - The highest flow was 2924 cfs (temperature: 22.84 °C; dissolved oxygen: 8.56 mg/L).
- Relationship between dissolved oxygen and flow
  - No correlation was observed between dissolved oxygen and flow.
  - The highest dissolved oxygen was 16 mg/L (flow: 452 cfs; temperature: 29.1 °C).

  - The lowest dissolved oxygen was 3.7 mg/L (flow of .01 cfs; temperature: 21.2 °C).
  - The lowest flow was .01 cfs (temperature: 21.2 °C; dissolved oxygen: 3.7 mg/L).
  - The highest flow was 2924 cfs (temperature: 22.84 °C; dissolved oxygen: 8.56 mg/L).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - The maximum observed chloride concentration was 179 mg/L.
  - The minimum and maximum pH values were 7.51 and 9.5.
  - The highest observed instantaneous temperature was 32.2 °C.
  - The minimum observed dissolved oxygen concentration was 3.7 mg/L. Two of 147 dissolved oxygen measurements were less than 5 mg/L.





Geomorphology

Geomorphological analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77-93% of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows.

Flow Regime Interpretations

The hydrologic characteristics of the Pedernales River are closely linked to precipitation patterns in the river basin, especially the cycles of floods and droughts (LCRA 2000).

No-flow periods: A sound ecological environment in this reach of the Llano River may be maintained by preventing an increase in the frequency and duration of no-flow periods than have occurred in the past.

Subsistence flows: The TCEQ's critical low flow value is 4.2 cfs.

Base flows: Base flow is relatively low across the wide, incised stream channel over rock outcrop and sand substrate.

Pulses and overbank flows: Pulses and overbank flows are valuable; however, the frequency of occurrence is relatively low.

HEFR/Hydrologic Regime

	Winter (Nov, Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct)
Overbank Flows	Qp: 26,300 cfs with Average Frequency 1 per 5 years Regressed Volume is 58,539 to 198,859 (107,894) Regressed Duration is 3 to 21 (8)			
Overbank Flows	Qp: 10,900 cfs with Average Frequency 1 per 2 years Regressed Volume is 24,216 to 82,108 (44,591) Regressed Duration is 3 to 17 (7)			
High Flow Pulses	Qp: 6,960 cfs with Average Frequency 1 per year Regressed Volume is 15,447 to 52,334 (28,432) Regressed Duration is 2 to 15 (6)			
High Flow Pulses	Qp: 908 cfs with Average Frequency 1 per season Regressed Volume is 2,324 to 9,677 (4,742) Regressed Duration is 2 to 15 (6)	Qp: 3,710 cfs with Average Frequency 1 per season Regressed Volume is 8,173 to 25,259 (14,368) Regressed Duration is 2 to 10 (4)	Qp: 287 cfs with Average Frequency 1 per season Regressed Volume is 614 to 2,058 (1,124) Regressed Duration is 1 to 7 (3)	Qp: 803 cfs with Average Frequency 1 per season Regressed Volume is 1,796 to 4,873 (2,958) Regressed Duration is 2 to 8 (4)
High Flow Pulses	Qp: 267 cfs with Average Frequency 2 per season Regressed Volume is 651 to 2,715 (1,330) Regressed Duration is 1 to 9 (3)	Qp: 1,660 cfs with Average Frequency 2 per season Regressed Volume is 3,570 to 11,019 (6,272) Regressed Duration is 1 to 8 (3)		Qp: 160 cfs with Average Frequency 2 per season Regressed Volume is 375 to 1,018 (618) Regressed Duration is 1 to 6 (2)
Base Flows (cfs) – High	80(41.7%)	106(42.7%)	47(32.6%)	50(38.2%)
Base Flows (cfs) – Medium	45(61.1%)	60(59.9%)	28(46.0%)	29(54.6%)
Base Flows (cfs) – Low	23(78.6%)	29(77.6%)	15(59.6%)	17(70.7%)
Subsistence Flows (cfs)	7.2(95.0%)	4.4(95.0%)	0(100.0%)	0(100.0%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:

1. Period of Record used : 1/1/1940 to 12/31/2009.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 1 cfs.

Recommended Environmental Flow Regime

Pedernales River near Johnson City, USGS Gage 08153500, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1939-2009	0 periods Max duration: 0 days	3 periods Max duration: 37 days	15 periods Max duration: 88 days	3 periods Max duration: 33 days
Subsistence	7 cfs	4 cfs	4 cfs	4 cfs
Base Low	23 cfs	29 cfs	16 cfs	16 cfs
Base Medium	45 cfs	60 cfs	29 cfs	29 cfs
Base High	80 cfs	110 cfs	49 cfs	49 cfs
2 Pulses per season	Trigger: 270 cfs Volume: 1,300 af Duration: 9 days	Trigger: 1,700 cfs Volume: 6,300 af Duration: 8 days	Not Applicable	Trigger: 160 cfs Volume: 620 af Duration: 6 days
1 Pulse per season	Trigger: 860 cfs Volume: 4,700 af Duration: 15 days	Trigger: 3,700 cfs Volume: 14,400 af Duration: 10 days	Trigger: 290 cfs Volume: 1,100 af Duration: 7 days	Trigger: 860 cfs Volume: 3,000 af Duration: 8 days
1 Pulse per year	Trigger: 7,000 cfs Volume: 28,400 af Duration: 15 days			
1 Pulse per 2 years	Trigger: 10,900 cfs Volume: 44,600 af Duration: 17 days			
1 Pulse per 5 years	Trigger: 26,300 cfs Volume: 107,900 af Duration: 21 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second
af = acre-feet

2.2.8 Onion Creek near Driftwood

USGS Gage 08158700


Typical view of run habitat at Onion Creek near Driftwood, facing downstream (left) and pool habitat, facing upstream (right) on October 25, 2010.


Typical view of riffle habitat at Onion Creek near Driftwood, facing upstream (left) and facing downstream (right) on October 25, 2010.

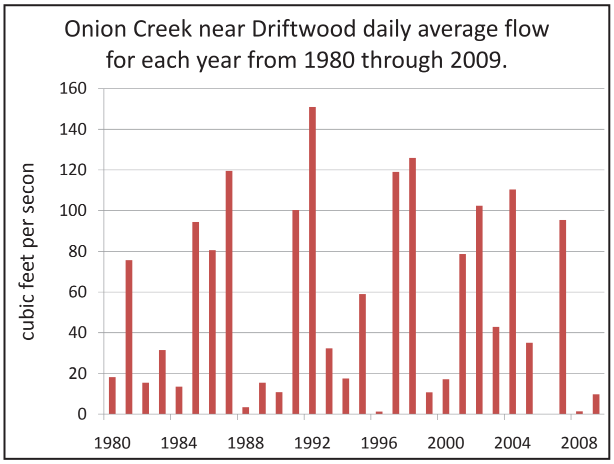
General Area Description (USGS 2010; USEPA 2003; Griffith et al. 2007)

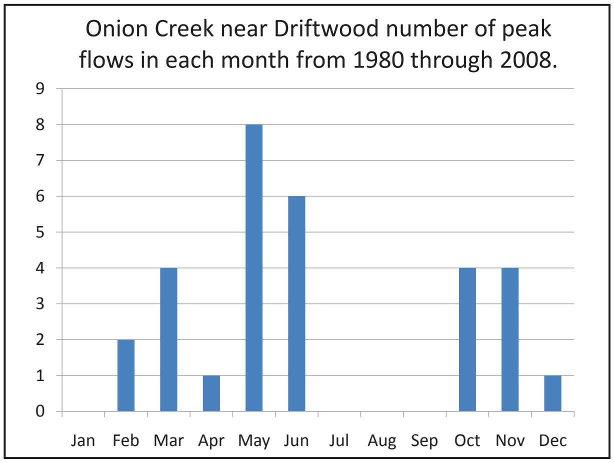
- Approximately 10 miles west of Buda, TX at the crossing of F.M. 150 in Hays County
- Edwards Plateau, EPA Level III ecoregion of Texas
- Balcones Canyonlands, Level IV ecoregion of Texas
- Primary land use: woodland and forest, with some shrubland and grassland and some cattle ranching and cropland
- Streams: moderate to high gradients with bedrock, cobble, and gravel substrates
- Regional stream flow and annual precipitation infiltrate sinkholes, fissures and caverns of the limestone substrate to recharge the Balcones Canyonlands' portion of the Edwards Aquifer
- Native riparian areas support bald cypress, American sycamore, black willow, slippery elm, Ohio buckeye, boxelder, bigtooth maple, and Carolina basswood

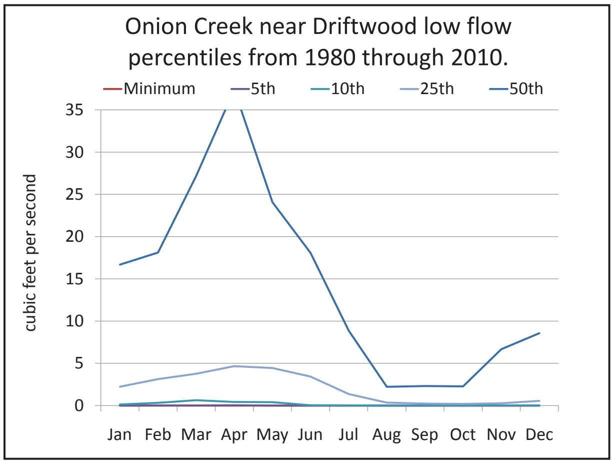
Summary of Historical USGS Gage Stream Flow Records (USGS 2010)

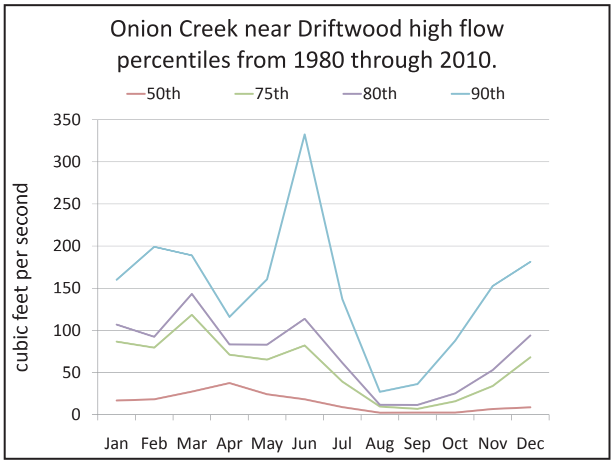
Hays County, Texas	Hydrologic Unit: 12090205	Latitude 30°04’58” Longitude 98°00’27” NAD27
Drainage area: 124 square miles	Contributing drainage area: 124 square miles	
Datum of gage: 878.13 feet above sea level NGVD29	The National Weather Service flood stage elevation is not indicated for this USGS gage (NOAA 2010)	

Summary of Historical USGS Flow Records at Onion Creek near Driftwood



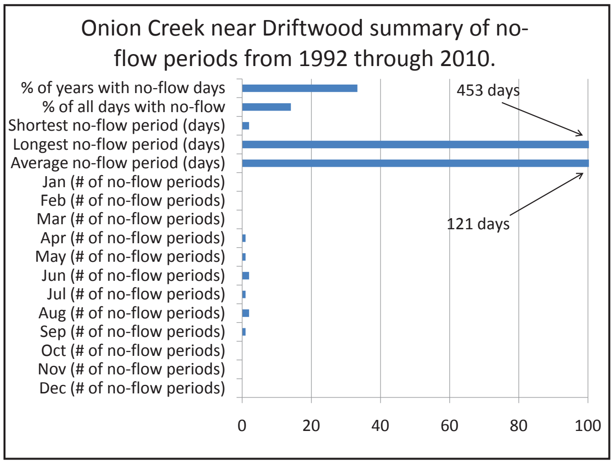


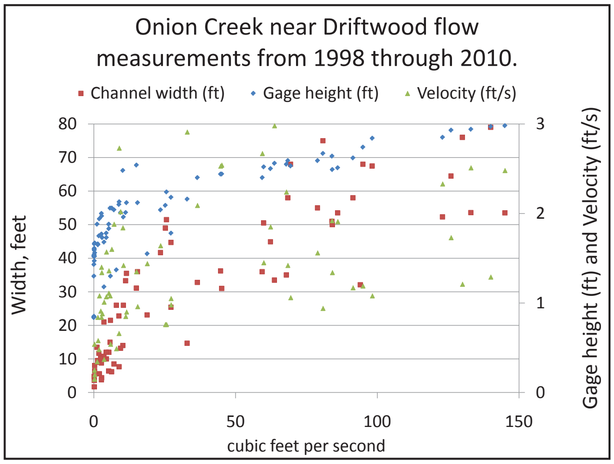




	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	347	582	477	297	635	1,421	692	134	212	484	819	711	568
Average	54	65	73	49	62	112	51	10	13	30	56	66	53
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0
5th	0	0	0	0	0	0	0	0	0	0	0	0	0
10th	0.1	0.3	1	0.4	0.4	0	0	0	0	0	0	0	0
20th	1	2	3	3	3	3	1	0.2	0.1	0.1	0.2	0.3	1
25th	2	3	4	5	4	3	1	0.4	0.2	0.2	0.3	1	2
50th	17	18	27	37	24	18	9	2	2	2	7	9	14
75th	87	79	118	71	65	82	39	9	7	16	34	68	56
80th	107	92	143	83	83	114	61	12	11	25	53	94	73
90th	160	199	189	116	160	333	137	27	36	88	153	181	148
95th	267	410	335	213	399	962	380	77	114	278	499	504	370

Onion Creek near Driftwood flow percentiles in cubic feet per second





Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases,two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5th, 25th,50th, 75th, 80th, and 90th percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured.

Site Description

- Review of aerial photography with Google Earth
  - Approximately 10 miles from 5 miles upstream of the USGS gage to 5 miles downstream of the gage
  - Flows that occurred on each of the aerial photography dates
    - January 26, 1995: 62 cfs; difficult to view the river in this black and white photograph
    - December 30, 2002: 153 cfs
    - October 21, 2005: 0.04 cfs
    - April 29, 2006: 0 cfs
    - February 28, 2008: 2.6 cfs
    - October 30, 2008: 0 cfs
    - February 27, 2009: 0 cfs
    - November 24, 2009: 69 cfs
  - Habitats
    - Perennial water bodies observed in all historical imagery in this reach, even in periods when no flow was recorded
    - An inundated oxbow channel located upstream of the gage approximately 2 miles
    - Long, straight reaches of glides and pools with two riffle areas downstream of the gage
    - Creek forms one large bend in this reach
    - Based on the 2009 aerial images, there is little development in the area, and the riparian corridor is continuous along the banks of the creek
    - Woody riparian vegetation is apparent along the banks of the river
- Field observations regarding cross-section information and riparian habitat were made on October 25, 2010 at a flow level of 11 cfs
  - Series of long, relatively straight pools and runs approximately 60 feet in width
  - Riffles with cobble and gravel substrates observed
  - Both banks lined with baldcypress, and American sycamore, American elm and pecan trees observed higher up on the banks; Trees, saplings, and seedlings of each of these species observed; Live oaks observed on the bluffs

Soil Types

Information on soils for an approximately 2-mile portion of this reach was obtained from NRCS (2009).

Soil*	Setting	Slope (%)	Wetland Potential	Flood Frequency
Orif soils	Floodplains of large creeks and rivers	<1	Rapid permeability; well drained	Flooded several times each year
Oakalla soils	Smooth to slightly undulating floodplains	Nearly level	Moderate permeability; well drained	Flooded more than once every 2 years
Sunev silty clay loam	Low stream terraces	0 to 1	Moderate permeability; well drained	
Sunev clay loam	Valley slopes and foot slopes of hills	1 to 3	Moderate permeability; well drained	This soil receives runoff from adjacent higher slopes
Brackett-Rock outcrop-Comfort complex	Uplands	Undulating	Moderately slow to slow permeability; well drained	
Brackett-Rock outcrop-Real complex	Uplands	Steep	Moderately slow to slow permeability; well drained	

Wetlands

The main features identified on the National Wetland Inventory maps (USFWS 2010) included:

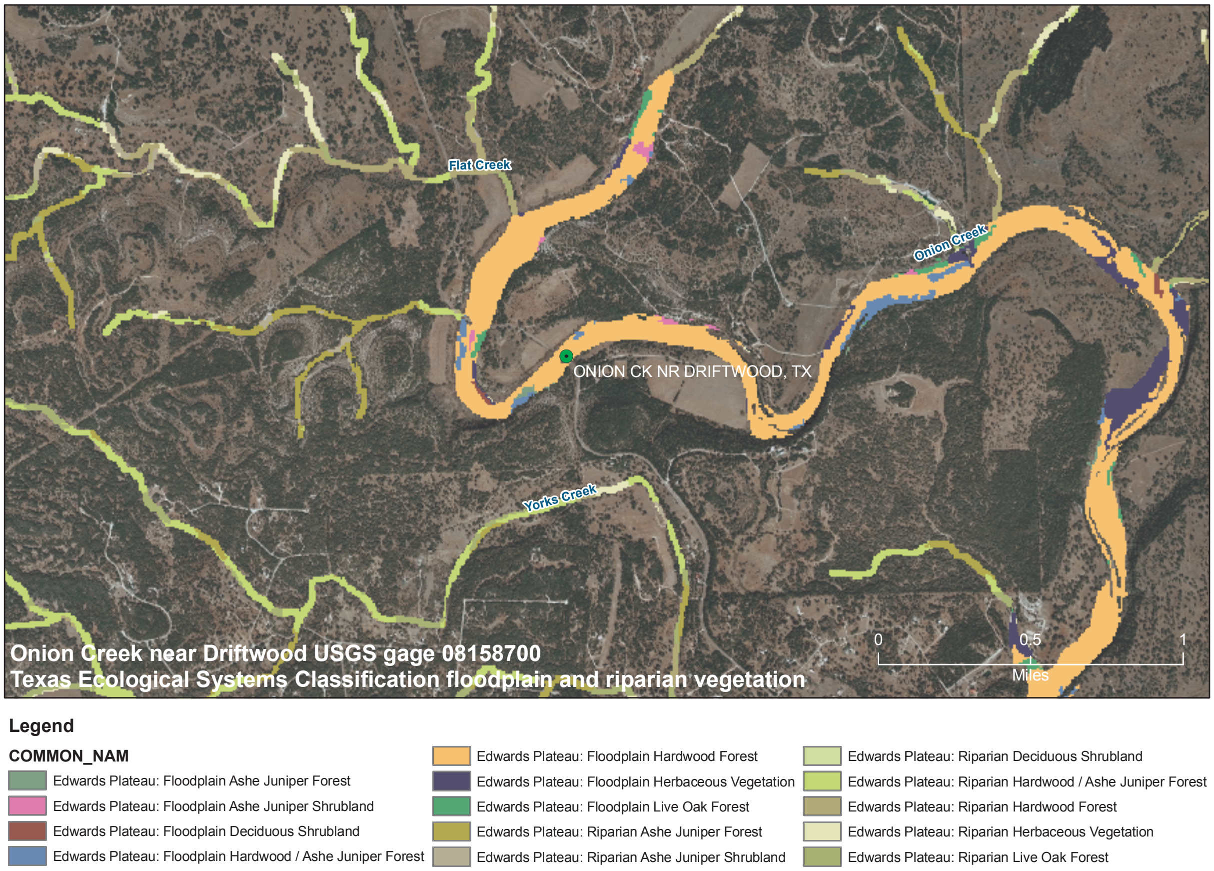
- The Onion Creek channel (R2OWH/R2UBH; riverine, lower perennial, permanently flooded)
- A permanently flooded impoundment upstream of the gage (POWHh/PUBHh; palustrine wetland, permanently flooded, impounded)
- The streambeds of associated tributaries (PFO1A; forested palustrine feature, broad-leaved deciduous, temporarily flooded)

Riparian/Floodplain Vegetation

The main Texas Ecological System Classification Program mapped riparian vegetation community shown in the figure below in this reach is Edwards Plateau floodplain hardwood forest, with some floodplain herbaceous vegetation, and very small patches of floodplain ashe juniper forest and floodplain live oak forest. The hardwood forest community extends across the channel and narrow floodplain of Onion Creek. This floodplain hardwood forest community is described as commonly consisting of cedar elm, American elm, pecan, plateau live oak, bur oak, western soapberry, Arizona walnut, and green ash (German et al. 2009).

Based on a field visit in October 2010, both banks were lined with bald cypress, and American sycamore, American elm and pecan trees were observed higher up on the banks. Trees, saplings, and seedlings of each of these species were observed. Live oaks were observed on the bluffs.

With the occurrence of mature bald cypress-lined banks in this reach of Onion Creek, and current recruitment of saplings and seedlings in the community, it is apparent that water is maintained in the channel perennially. Bald cypress seed germination is dependent on inundated or saturated soil conditions for 1-3 months, and is adapted to areas of frequent to permanent inundation. A base flow in this creek that maintains frequent inundation of bald cypress roots or perennial pools would allow this species to grow. High flow pulses in this region transport organic material, which is likely deposited on the bank side of the bald cypress trees, enriching the soil and maintaining the shoreline elevation. High flow pulses also transport seeds for sycamore, elm and pecan trees. Moist soil conditions from pulse flows and a shallow water table would allow germination and recruitment of these obligate wetland and facultative wetland plant species.



Sources: TPWD Texas Ecological System Classification project, TPWD 2010 www.tpwd.state.tx.us/landwater/land/maps/gis/tescp/index.phtml, Floodstage elevation from NWS Advanced Prediction Service
Vertical Datums: USGS floodstage provided in NGVD29, LiDAR native datum is NAVD88 with resolution +-18.5cm (LCRA). Calculated difference for the study area is apx. 12cm. Horizontal datum: NAD83.
Contact: Lynne Hamlin, Water Resources Branch, TPWD lhamlin@tpwd.state.tx.us Map created Dec. 2010
Disclaimer: While every attempt was made to present the information as accurately as possible, no claims are made to the completeness or accuracy of the information shown herein nor to its suitability for a particular use. Scale and location are approximate.

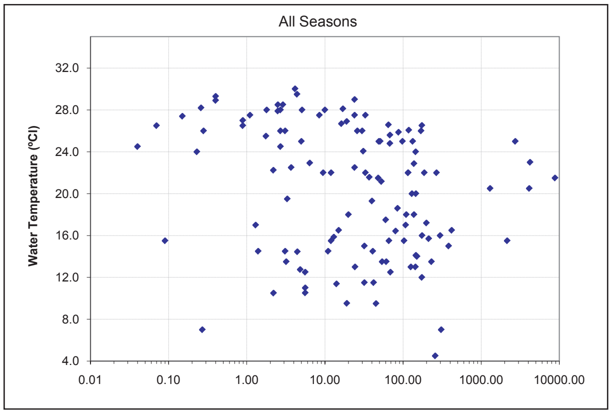
Texas Ecological Systems Classification of Riparian and Floodplain Vegetation for the Onion Creek near Driftwood

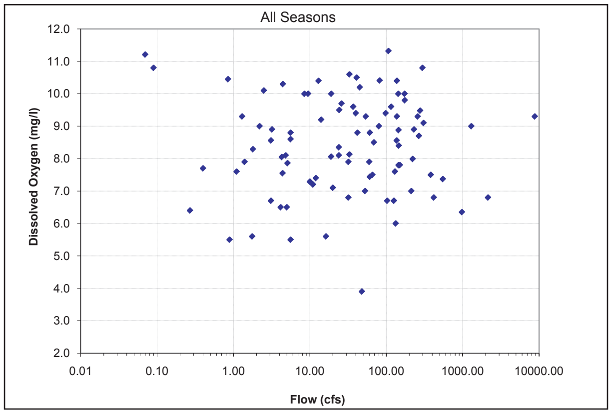
Biology

Source	Location	Biology	Observations
Walther and Palma 2005	Onion Creek	Fish species in Onion Creek include blacktail shiner, bluegill, channel catfish, green sunfish, largemouth bass, longear sunfish, redbreast sunfish, spotted bass, bullhead minnow, common carp, mosquitofish, red shiner, Rio Grande ciclid, sailfin molly, stoneroller, warmouth, channel catfish, green sunfish, orangethroat darter, and yellow bullhead catfish.	Onion Creeks supports a high aquatic life use based on Index of Biotic Integrity analysis.
Griffith 2007	Balcones Canyonlands	The broken, limestone topography supports diverse habitats including moist caves, where endemic fish, salamanders and bats occur; Crevice seeps and springs also support endemic and rare plant species including maidenhair fern (*Adiantium capillus-veneris*), tuber anemone (*Anemone edwardsiana*), and southern shield fern (*Thelypteris kunthii*).	
Griffith 2007	Balcones Canyonlands	Fire was once more prevalent in this region, and had confined Ashe juniper (*Juniperus asheii*) to the understory of woodland communities; Today, it has invaded former grasslands on ridgetops and benches in the region.	
Griffith 2007	Balcones Canyonlands	Some relicts of eastern swamp communities, such as baldcypress (*Taxodium distichum*), American sycamore (*Plantanus americanus*), and black willow (*Salix nigra*) occur along major stream courses in this region.	
TCEQ 2009	Onion Creek		Onion Creek supports a high aquatic life use.

Water Quality

- The water quality period of record for this gage is 04/22/1982 - 10/06/2010
- Relationship between flow and water quality parameters
  - No relationship between flow and water quality
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in the Water Quality Segment 1427, Onion Creek at Driftwood. The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated high aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
  - The segment of river where this gage site is located is not listed on the 303(d) list.
- Relationship between temperature and flow
  - No correlation was observed between water temperature and flow.
  - The highest temperature was 30.02 °C (flow: 4.15 cfs; dissolved oxygen: 8.35 mg/L).
  - The lowest temperature was 4.5 °C (flow: 258 cfs; dissolved oxygen: not collected).
  - The lowest flow was 0.04 cfs (temperature: 24.5 °C; dissolved oxygen: 5.5 mg/L).
  - The highest flow was 8800 cfs (temperature: 21.5 °C; dissolved oxygen: 8.8 mg/L).
- Relationship between dissolved oxygen and flow
  - No correlation was observed between dissolved oxygen and flow.
  - The highest dissolved oxygen was 11.32 mg/L (flow: 14 cfs; temperature: 11.38°C).
  - The lowest dissolved oxygen was 3.9 mg/L (flow of 0.07 cfs; temperature: 26.5°C).
  - The lowest flow was 0.04 cfs (temperature: 24.5°C; dissolved oxygen: 5.5 mg/L).
  - The highest flow was 8800 cfs (temperature: 21.5°C; dissolved oxygen: 8.8 mg/L).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - The maximum observed chloride concentration was 21 mg/L.
  - The minimum and maximum pH values were 7 and 9.83.
  - The highest observed instantaneous temperature was 30.02 °C.
  - The minimum observed dissolved oxygen concentration was 3.9 mg/L. One dissolved oxygen measurement was less than 5 mg/L.





Geomorphology

Geomorphological analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77-93% of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows.

Flow Regime Interpretations

No-flow periods: About 9% of the days over the period from 1979 through 2009 exhibited no flow. A prolonged drought period in central Texas resulted in a recent period of no flow for 484 days (ending October 9, 2009). It is assumed, based on the presence of perennial pools and baldcypress-dominated creek bank communities, that increased frequency and duration of no-flow periods would not have a beneficial impact on the system.

Subsistence flows: The TCEQ's critical low flow value is 0.19 cfs.

Base flows: Instream aquatic habitats include a variety of velocity and substrates within riffle, run and pool habitats.

Pulses and overbank flows: Riparian communities consisting of bald cypress and assorted hard-woods and documented recruitment indicate pulse and overbank flows are important to the seed dispersal and germination for the maintenance of these species.

HEFR/Hydrological Analysis

	Dec Jan Feb (Winter)	Mar Apr May Jun (Spring)	Jul Aug (Summer)	Sep Oct N (Fall)
High Flow Pulses	Qp: 3,550 cfs with Average Frequency 1 per 5 years Regressed Volume is 13,803 to 63,336 (29,568) Regressed Duration is 8 to 53 (20)			
	Qp: 2,350 cfs with Average Frequency 1 per 2 years Regressed Volume is 8,851 to 40,457 (18,923) Regressed Duration is 6 to 45 (17)			
	Qp: 1,150 cfs with Average Frequency 1 per year Regressed Volume is 4,096 to 18,625 (8,734) Regressed Duration is 5 to 34 (13)			
	Qp: 174 cfs with Average Frequency 1 per season Regressed Volume is 899 to 4,088 (1,917) Regressed Duration is 3 to 20 (8)	Qp: 615 cfs with Average Frequency 1 per season Regressed Volume is 1,910 to 7,311 (3,737) Regressed Duration is 3 to 19 (7)		Qp: 116 cfs with Avera Frequency 1 per seaso Regressed Volume is 290 1,092 (563) Regressed Duration is 2 11 (5)
		Qp: 198 cfs with Average Frequency 2 per season Regressed Volume is 568 to 2,175 (1,111) Regressed Duration is 2 to 11 (4)		Qp: 18 cfs with Avera Frequency 2 per seaso Regressed Volume is 36 136 (70) Regressed Duration is 1 (2)
Base Flows (cfs)	26(42.2%)	34(42.2%)	6.7(40.6%)	7.3(35.3%)
	6(58.6%)	12(59.6%)	2.4(55.9%)	2.7(52.5%)
	2(75.3%)	3.7(76.4%)	0.89(71.5%)	0.32(70.0%)
Subsistence Flows (cfs)	0(100.0%)	0(100.0%)	0(100.0%)	0(100.0%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:

1. Period of Record used : 1/1/1980 to 12/31/2009.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 0 cfs.

Recommended Environmental Flow Regime

Onion Creek near Driftwood, USGS Gage 08158700, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1992-2010	0 periods Max duration: 0 days	4 periods Max duration: 245 days	3 periods Max duration: 453 days	1 periods Max duration: 182 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	2 cfs	4 cfs	1 cfs	1 cfs
Base Medium	6 cfs	12 cfs	3 cfs	3 cfs
Base High	26 cfs	34 cfs	7 cfs	7 cfs
2 Pulses per season	Not applicable	Trigger: 200 cfs Volume: 1,100 af Duration: 11 days	Not applicable	Trigger: 18 cfs Volume: 70 af Duration: 5 days
1 Pulse per season	Trigger: 170 cfs Volume: 1,900 af Duration: 20 days	Trigger: 620 cfs Volume: 3,700 af Duration: 19 days	Not applicable	Trigger: 120 cfs Volume: 560 af Duration: 11 days
1 Pulse per year	Trigger: 1,200 cfs Volume: 8,700 af Duration: 34 days			
1 Pulse per 2 years	Trigger: 2,400 cfs Volume: 18,900 af Duration: 45 days			
1 Pulse per 5 years	Trigger: 3,600 cfs Volume: 29,600 af Duration: 53 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second
af = acre-feet

2.3 Lower Colorado

2.3.1 Colorado River at Bastrop — USGS Gage 08159200


Typical view of riffle habitat in the Colorado River near Bastrop, facing upstream (left) and across the river (right) (Courtesy of BIO-WEST, Inc.).

General Area Description (USGS 2010, BIO-WEST 2008)

- Along a bend in the river at the crossing of Highway 71 in Bastrop County
- Extends from below Longhorn Dam to Bastrop
- No records of days without flow at this gage
- Examined as part of an instream flow study in 2004-2007
- Instream habitat modeling conducted within this reach
- HECRAS modeling conducted within this reach
- Intensive biological and physical data collection activities conducted 2004-2007 (BIO-WEST, Inc. 2004, BIO-WEST, Inc. 2005, BIO-WEST, Inc. 2006, BIO-WEST, Inc. 2007)
- Biological sampling conducted within this reach; included blue sucker tagging and tracking
- Land use practices have altered the lateral extent of riparian communities along the river
- Native riparian areas support mixed bottomland hardwood species

USGS Gage 08159200 Description

Bastrop County, Texas	Hydrologic Unit: 12090301	Latitude 30°06'16", Longitude 97°19'09" NAD27
Drainage area: 39,979 square miles	Contributing drainage area: 28,576 square miles	
Datum of gage: 307.38 feet above sea level NGVD29	Flood stage occurs at 23 feet above the USGS gage elevation (NWS 2010)	

Site Description

- Review of aerial photography with Google Earth
  - 12 mile reach, from one mile upstream of the city of Bastrop to the crossing of Highway 95 in Smithville

- Flows dates
  - January 22, 1995: 452 cfs
  - January 8, 1996: 427 cfs
  - December 30, 1997: 673 cfs
  - December 30, 2002: 2,670 cfs
  - October 21, 2005: 598 cfs
  - April 29, 2006: 1,210 cfs
  - February 28, 2008: 616 cfs
  - October 30, 2008: 318 cfs
  - November 24, 2009: 753 cfs
- Habitats
  - Multiple in-channel islands and sand bank deposits along bends occurred downstream of the city of Bastrop
  - Lower terraces along bends had herbaceous vegetation
  - Significant portions of the riparian corridor cleared of woody vegetation up to the banks of the river in this reach
  - Only a few small areas of wooded riparian communities between the city of Bastrop and the city of Smithville

Wetlands

The main features identified on the National Wetland Inventory maps (USFWS 2010) included:

- Frequent areas adjacent to the river channel that are occasionally or seasonally inundated, some of which support herbaceous or woody vegetation
- Many features occur at bends in the river
- Numerous in-channel islands
- Numerous intermittent streams flow into the Colorado River

Riparian/Floodplain Vegetation

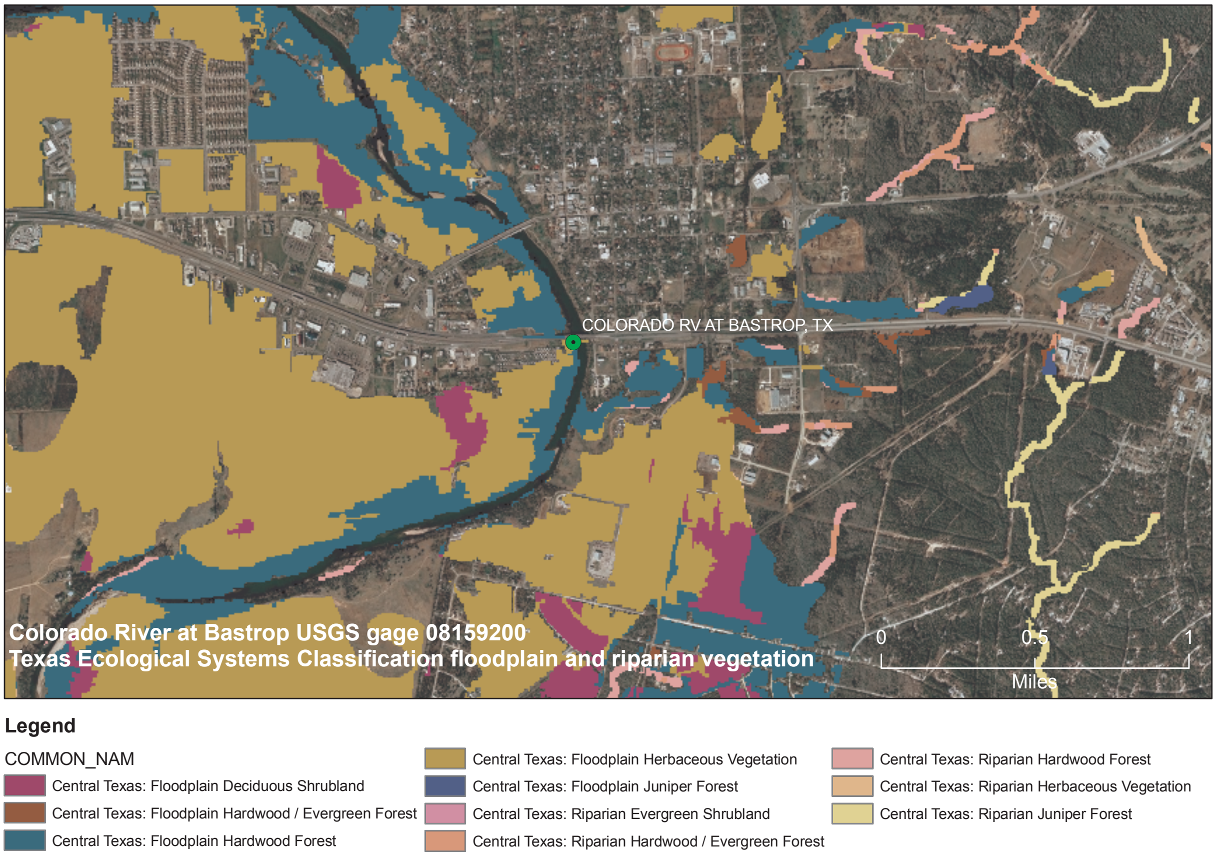
Riparian vegetation communities in this reach are generally wide on both sides of the river, with gradual slopes from a low terrace to an upper terrace. The cut bank side of the river has a narrow riparian corridor following a steep slope from the water's edge to the top of the bank. There is a narrow corridor of floodplain hardwood forest vegetation along most of the river in this reach, with wide bands of floodplain herbaceous vegetation outside of the wooded corridors on the low floodplain terraces. These communities consist of two main vegetation types in the "Central Texas" region (see Riparian Vegetation Map below; German et al. 2009):

- Floodplain hardwood forest
  - Mainly deciduous trees such as pecan, white ash, cedar elm, American elm, sugar hackberry, willows, and eastern cottonwood
- Floodplain herbaceous vegetation
  - Non-native grass species such as bermudagrass and Johnsongrass may frequently dominate this vegetation type

  - Scattered shrubs such as mesquite and juniper common
  - Eastern gamagrass or switchgrass may dominate some lowland sites
- Field survey of the riparian zone in this reach in 2005 observed
  - Black willow and green ash trees along the water's edge, and American elm, sugar hackberry, Chinese tallow, American sycamore, and Eastern cottonwood on the banks (BIO-WEST unpublished data)

HECRAS results and TESCP riparian vegetation communities were evaluated along the Bastrop reach (see figures below). The water's edge lines for the 2-year and 5-year flow events follow the Colorado River and tributary channels. The 10-year event appears to inundate most of the floodplain hardwood forest communities along the main stem of the Colorado River and floodplain herbaceous vegetation along lower terraces. There are wide sections of floodplain herbaceous vegetation communities that are inundated only at the 500-year flow event, although much of this area is pastureland.

The black willow and green ash trees present along the banks within this reach indicate that base flows are important to the riparian community, as both of these species are shallow-rooted and would require a shallow depth to the water table during the growing season. Black willow trees are also not drought tolerant. The distribution of American elm, American sycamore and cottonwood on the banks indicate that pulse flows are also important. Sycamore and cottonwood seeds are typically dispersed by water, and moist soils are necessary to prevent desiccation and allow germination. Cottonwood seeds require specific germination sites of freshly scoured, moist mineral substrates within 1–2 weeks of seeding, and recruitment likely does not occur every year. The pulse flows that occur every 5–10 years likely maintain the germination sites for cottonwood, and maintaining these pulse flows in the environmental flow regime would likely allow the persistence of this species in the community.



Sources: Texas Ecological System Classification project, TPWD 2010 www.tpwd.state.tx.us/landwater/land/maps/gis/tescp/index.phtml,
Horizontal datum: NAD83.
Contact: Lynne Hamlin, Water Resources Branch, TPWD lhamlin@tpwd.state.tx.us Map created Jan. 2011
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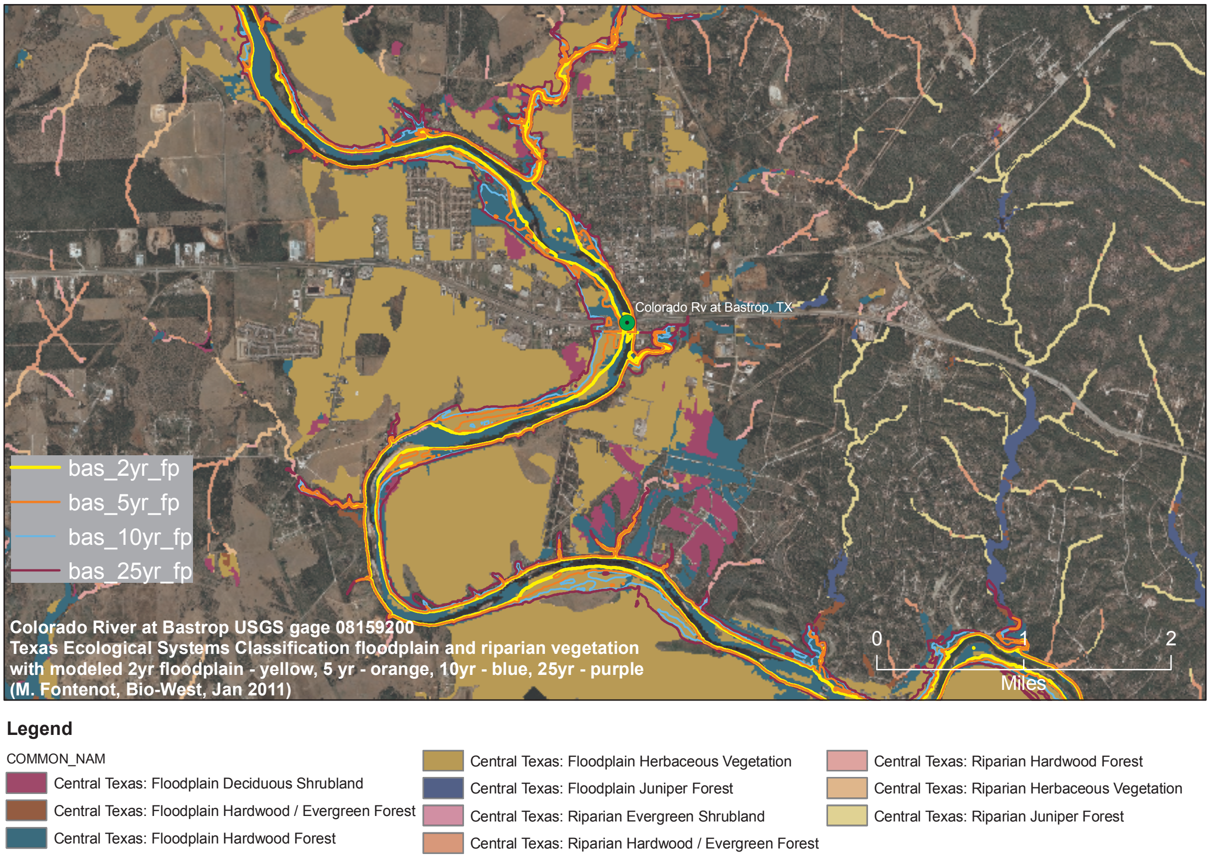
Texas Ecological Systems Classification of Riparian and Floodplain Vegetation for the Colorado River at Bastrop



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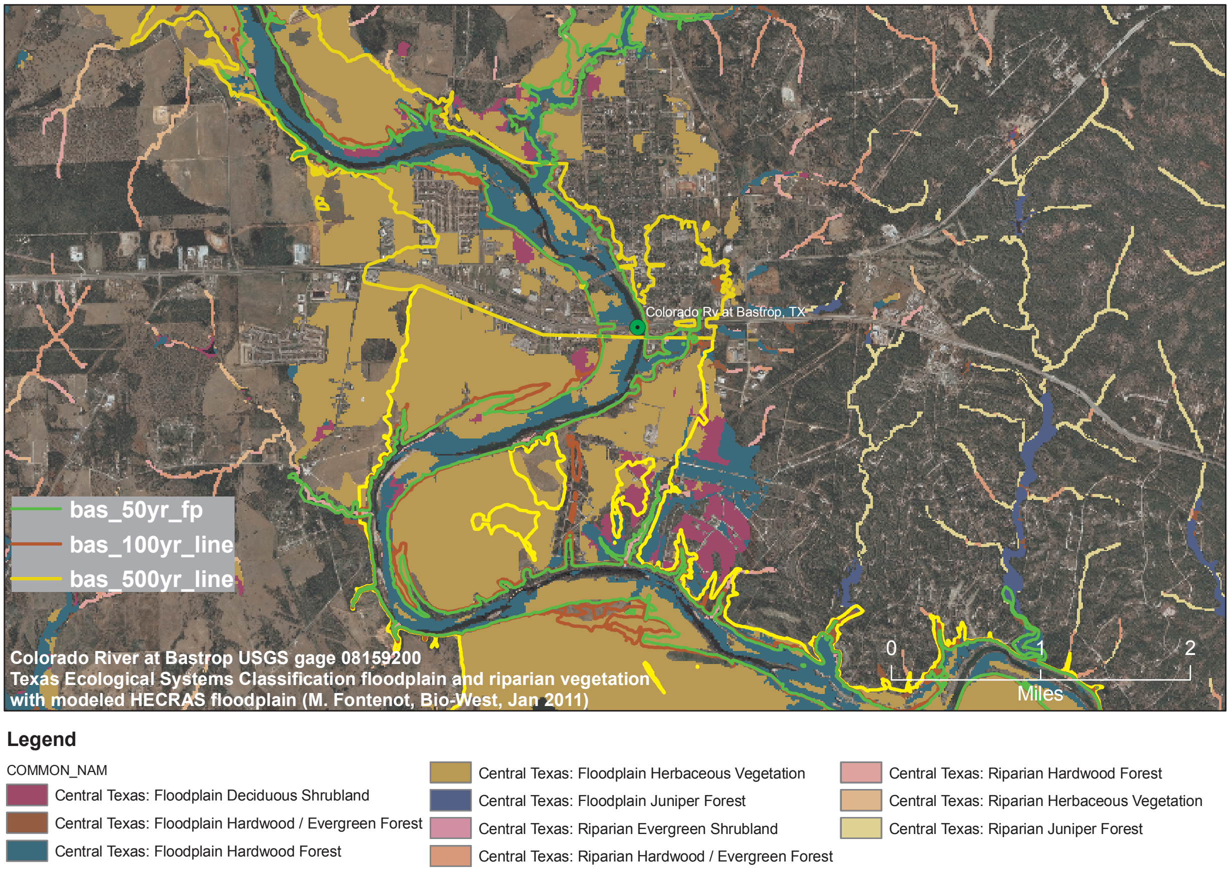
HECRAS model results near the Bastrop gage for the 2-year, 5-year, 10-year, and 25-year flow events



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Scale and location are approximate.

HECRAS model results near the Bastrop gage for the 50-year, 100-year, and 500-year flow events

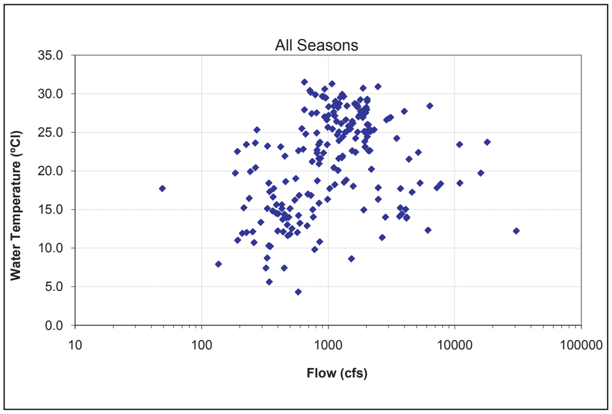
Biology

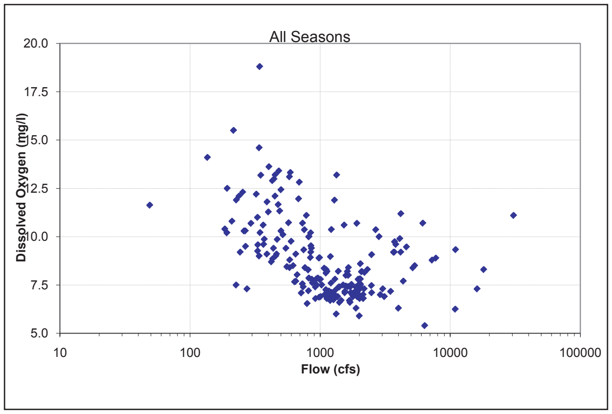
Aquatic habitat use data were collected at 10 sites from Longhorn Dam to Wharton in 2004–2007 using various fish sampling techniques including seining, backpack electrofishing, barge electrofishing, and boat electrofishing. 50 species of fish collected. A habitat guild approach was used to assess aquatic habitat modeled over a range of flows using River2D models at each site (BIO-WEST, Inc. 2008). Life-history information, a radio telemetry study to identify adult habitat, and field confirmation of spawning habitat for blue suckers was used to supplement the fish guild approach.

Water Quality

- The water quality period of record for this gage is 10/07/82 – 06/09/2010
- Relationships between flow and water quality parameters
  - NO2+NO3–N decreases with increasing flow.

    - Total phosphorus decreases with increasing flow.
    - Specific conductance decreases with increasing flow.
    - pH decreases with increasing flow.
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in the Water Quality Segment 1434, Colorado River at Bastrop. The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated exceptional aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
    - The segment of river where this gage site is located is not listed on the 303(d) list.
- Relationship between temperature and flow
    - No correlation was observed between water temperature and flow.
    - The highest temperature was 31.49 °C (flow: 650 cfs; dissolved oxygen: 7.69 mg/L).
    - The lowest temperature was 4.3 °C (flow: 581 cfs; dissolved oxygen: 13.1 mg/L).
    - The lowest flow was 49 cfs (temperature: 17.7 °C; dissolved oxygen: 11.63 mg/L).
    - The highest flow was 30,700 cfs (temperature: 12.2 °C; dissolved oxygen: 11.1 mg/L).
- Relationship between dissolved oxygen and flow
    - No correlation was observed between dissolved oxygen and flow.
    - The highest dissolved oxygen was 18.8 mg/L (flow: 343 cfs; temperature: 5.6 °C).
    - The lowest dissolved oxygen was 5.4 mg/L (flow of 6367 cfs; temperature: 28.4 °C).
    - The lowest flow was 49 cfs (temperature: 17.7 °C; dissolved oxygen: 11.63 mg/L).
    - The highest flow was 30,700 cfs (temperature: 12.2 °C; dissolved oxygen: 11.1 mg/L).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
    - The maximum observed chloride concentration was 204 mg/L.
    - The minimum and maximum pH values were 7.14 and 9.
    - The highest observed instantaneous temperature was 31.49 °C.
    - The minimum observed dissolved oxygen concentration was 5.4 mg/L. Two dissolved oxygen measurements were less than 6 mg/L.





Geomorphology

Two sites along the lower Colorado River were modeled for sediment transport and effective discharge in the LSWP study: La Grange and Columbus. It was found that the greatest proportion of total sediment is transported by low flows (at both sites). At La Grange, the peak occurs at the discharge increment of about 1,700 cfs, when sand-sized particles are being transported while little to no gravel is mobile. At La Grange, a strong secondary peak is evident at the discharge increment between about 26,000-29,000 cfs, which is the effective discharge for gravel at the site. This gravel-based effective discharge is important for channel (and riffle) maintenance, and flows of this size reach the top of the banks. Flows of this size are equaled or exceeded between 0.5% to 2% of the time (BIO-WEST, Inc. 2008).

The geomorphic analyses conducted by the LSWP study utilize different terminology and are related to different aspects of the river's geomorphology than the geomorphic analyses conducted by the BBEST at other gages in the basin.

Flow Regime Interpretations

The instream flow study conducted as part of the LCRA SAWS Water Project (LSWP) identified four components of the hydrologic regime to integrate as part of the environmental flow regime: subsistence flows, base flows, high flow pulses, and overbank flows. The following description of the integration of these aspects of the hydrological record and ecological responses is provided from BIO-WEST, Inc. (2008).

Subsistence flows: Infrequent, seasonal periods of low flows. The primary objective of this component is to maintain water quality criteria. The secondary objectives are to provide important low flow life cycle cues or refugia habitat. The 95th percent habitat exceedence level was evaluated, and the 95th percent exceedence flow was the recommended subsistence flow.

Base flows: Normal flow conditions between storm events. The objective of this component is to ensure adequate habitat conditions, including variability, to support the natural biological community.

Pulse flows: Short-duration, within channel, high flow events following storm events. The objective of this component is to maintain important physical habitat features and provide longitudinal connectivity along the river channel.

Overbank flows: Infrequent, high flow events that exceed the normal channel. The objective of this component is to maintain riparian areas and provide lateral connectivity between the river channel and active floodplain.

HEFR/Hydrologic Regime

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 106,619 cfs with Average Frequency 1 per 5 years Regressed Volume is 381,163 to 1,298,125 (703,418) Regressed Duration is 3 to 18 (8)			
Overbank Flows	Qp: 66,456 cfs with Average Frequency 1 per 2 years Regressed Volume is 224,971 to 764,817 (414,803) Regressed Duration is 3 to 16 (7)			
Overbank Flows	Qp: 41,716 cfs with Average Frequency 1 per year Regressed Volume is 133,810 to 454,273 (246,549) Regressed Duration is 3 to 14 (6)			
High Flow Pulses	Qp: 4,648 cfs with Average Frequency 1 per season Regressed Volume is 13,857 to 56,670 (28,023) Regressed Duration is 2 to 12 (5)	Qp: 30,744 cfs with Average Frequency 1 per season Regressed Volume is 90,493 to 286,757 (161,088) Regressed Duration is 2 to 10 (5)	Qp: 11,179 cfs with Average Frequency 1 per season Regressed Volume is 33,699 to 106,072 (59,787) Regressed Duration is 2 to 10 (5)	Qp: 23,084 cfs with Average Frequency 1 per season Regressed Volume is 73,319 to 239,946 (132,637) Regressed Duration is 2 to 12 (5)
High Flow Pulses	Qp: 1,573 cfs with Average Frequency 2 per season Regressed Volume is 3,845 to 15,865 (7,810) Regressed Duration is 1 to 7 (3)	Qp: 20,082 cfs with Average Frequency 2 per season Regressed Volume is 55,554 to 175,756 (98,813) Regressed Duration is 2 to 8 (4)	Qp: 2,495 cfs with Average Frequency 2 per season Regressed Volume is 6,221 to 19,688 (11,067) Regressed Duration is 1 to 6 (3)	Qp: 10,558 cfs with Average Frequency 2 per season Regressed Volume is 29,468 to 96,240 (53,254) Regressed Duration is 2 to 10 (4)
Base Flows (cfs) — High	717(42.2%)	1511(43.1%)	990(39.4%)	963(42.1%)
Base Flows (cfs) — Medium	495(59.8%)	870(59.9%)	642(54.0%)	562(56.8%)
Base Flows (cfs) — Low	342(76.9%)	495(76.6%)	387(68.4%)	372(72.0%)
Subsistence Flows (cfs)	207(95.1%)	202(95.1%)	81(95.0%)	137(95.1%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:

1. Period of Record used : 12/31/1899 to 12/31/1939.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 159 cfs.

Recommended Environmental Flow Regime

Two flow record periods were evaluated during the LSWP study: the existing condition (1975–2004) and pre-1940 (1898–1939). An evaluation of the hydrology, habitat time series modeling results, sediment transport analyses, and water quality results indicated that the pre-1940 flow regime is different from the existing flow regime. To maintain natural habitat diversity, hydrologic character, and water quality, the pre-1940 time period was selected for the development of instream flow guidelines (BIO-WEST, Inc. 2008).

The recommended environmental flow regime for the Colorado River at Bastrop includes monthly regimes for subsistence and two levels of base flow, and periodic pulse flows, channel maintenance flows and overbank flows. It should be noted that the pulse, channel maintenance and overbank flow recommendations are the same amongst the Bastrop, Columbus, and Wharton gages.

Colorado River at Bastrop, USGS Gage 08159200, Recommended Environmental Flow Regime

Flow	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Subsistence	208	274	274	184	275	202	137	123	123	127	180	186
Base – Dry	313	317	274	287	579	418	347	194	236	245	283	311
Base - Average	433	497	497	635	824	733	610	381	423	433	424	450
Pulse flow -Base	Magnitude (2,000 to 3,000 cfs); Frequency (8-10 times annually); Duration (3-5 days)											
Pulse flow - High	Magnitude (8,000 cfs); Frequency (2 events in a 3-year period); Duration (2-3 days)											
Channel Maintenance	Magnitude (27,000 to 30,000 cfs); Frequency (1 event in 3 year period); Duration (3 days)											
Overbank	Magnitude (>30,000 cfs); Frequency and Duration (naturally driven)											

2.3.2 Colorado River at Columbus — USGS Gage 08161000

Aerial view of the Colorado River near Columbus (left), and a view of the river facing downstream (right) (Courtesy of BIO-WEST, Inc.).

General Area Description (USGS 2010, BIO-WEST, Inc. 2008)

- Located along a bend in the river at the crossing of Highway 71 in Bastrop County
- Extends from downstream of Bastrop to Columbus
- No records of days without flow at this gage
- Examined as part of an instream flow study in 2004-2007
- Instream habitat modeling conducted within this reach
- HECRAS modeling conducted within this reach
- Intensive biological and physical data collection activities conducted 2004–2007 (BIO-WEST, Inc. 2004, BIO-WEST, Inc. 2005, BIO-WEST, Inc. 2006, BIO-WEST, Inc. 2007)
- Biological sampling conducted within this reach; included blue sucker tagging and tracking
- Riparian vegetation community described during a field effort in 2005
- Land use practices have altered the lateral extent of riparian communities along the river

The Colorado River gage at Columbus is located in Colorado County, Texas (Columbus Quad) east of the city of Bastrop at the crossing of Highway 90. The gage is located downstream of the confluence of Cummins Creek with the Colorado River and downstream of a large U-bend in the river with several in-channel islands. This region is primarily used as pastureland for cattle, and there is not a wide riparian corridor along this reach of the river; cattle grazing occurs up to the bank on both sides of the river. Some development has occurred along the right riverbank upstream and downstream of the gage within the city of Bastrop. Downstream of the gage approximately 1.5 miles, strip-mining activity has occurred along both sides of the river. Further downstream approximately 2.5 miles from the gage, one oxbow and one remnant oxbow occur along the right bank of the river. The existing oxbow is permanently flooded and is associated with a wide wooded riparian community, surrounded by areas of pastureland and cropland. The floodplain in this reach of the Colorado River is wider than at the sites upstream of this gage.

USGS Gage 08161000 Description

Colorado County, Texas	Hydrologic Unit: 12090301	Latitude: 29°42’22” Longitude: 96°32’12” NAD27
Drainage area: 41,640 square miles	Contributing drainage area: 30,237 square miles	
Datum of gage: 145.52 feet above sea level NGVD29	Flood stage occurs at 34 feet above the USGS gage elevation (NOAA 2010)	

Site Description

- Review of aerial photography with Google Earth
  - Approximately 10-mile reach, from one mile upstream of the USGS gage to 9 miles downstream of the gage
  - Flow for each aerial photography date
    - February 19, 1995/January 23, 1996: 615/533 cfs
    - October 21, 2005: 834 cfs
    - April 11, 2007: 1,710 cfs
    - October 30, 2008: 368 cfs
  - Habitats
    - Dominated by long straight runs, with occasional in-channel islands
    - Sandbars common around bends in the river
    - Banks and upper terraces: wooded riparian vegetation, with lower terraces dominated by herbaceous vegetation

Wetlands

The main features identified on the National Wetland Inventory maps (USFWS 2010) included:

- Frequent areas adjacent to the river channel that are occasionally or seasonally inundated, some of which support herbaceous or woody vegetation
- Many features occur at bends in the river
- Numerous in-channel islands
- Numerous intermittent streams flow into the Colorado River
- Occasional oxbow channels, some which are likely connected to the river during high flows

Riparian/Floodplain Vegetation

Texas Ecological System Classification of vegetation communities indicates the floodplain and riparian vegetation communities in this reach are generally wide on both sides of the river. These communities consist of two main vegetation types in the “Central Texas” region (see Riparian Vegetation Map below; German et al. 2009):

- Floodplain hardwood forest
  - Occurs on the cut bank side of the river and within tributary drainages (e.g. Cummins Creek)
  - Mainly deciduous trees such as pecan, white ash, cedar elm, American elm, sugar hackberry, willows, and eastern cottonwood

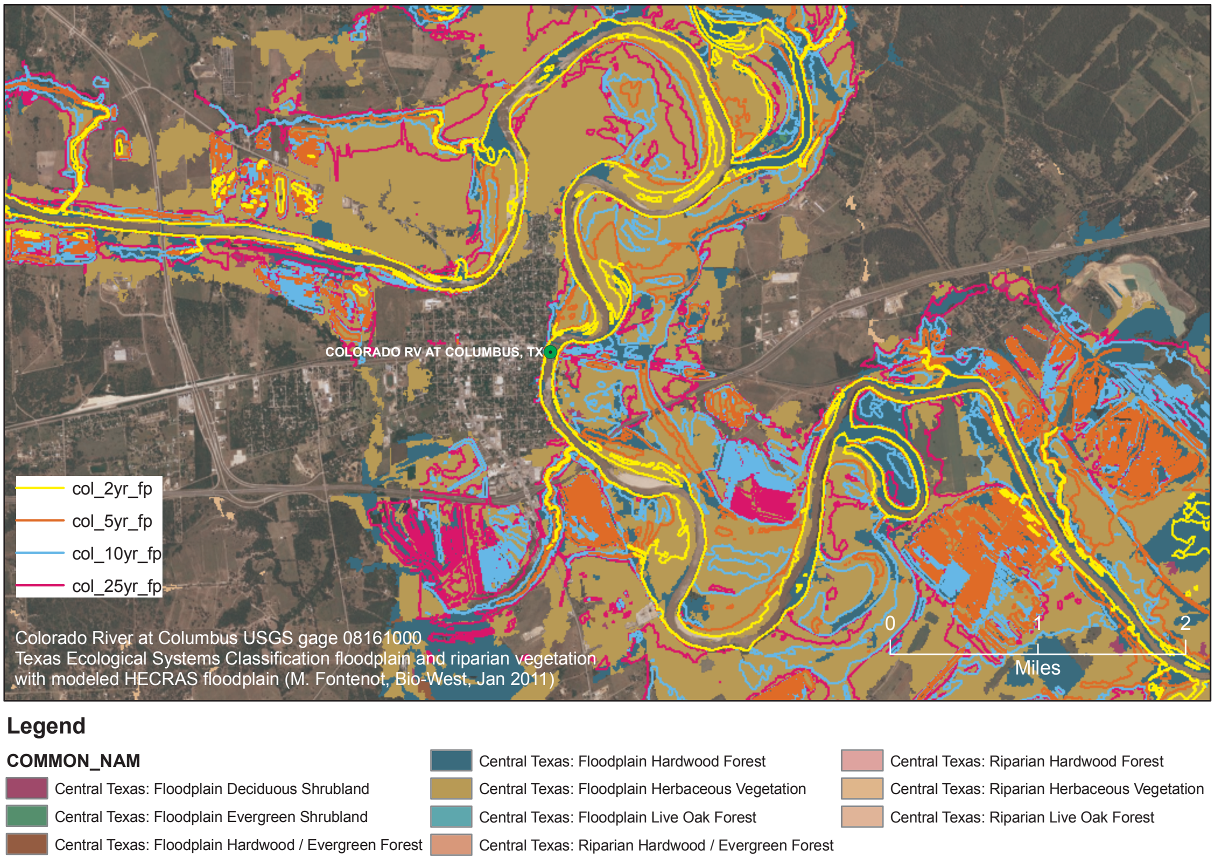
- Floodplain herbaceous vegetation
  - Occurs on the low floodplain terraces around river bends and in areas surrounding hardwood forests
  - Non-native grass species such as bermudagrass and Johnsongrass may frequently dominate
  - Scattered shrubs such as mesquite and juniper common
  - Eastern gamagrass or switchgrass may dominate some lowland sites
- Field survey of the riparian zone in this reach in 2005 observed
  - Right river bank in this reach of the river: primarily used as pastureland
  - Riparian vegetation community occurred along the inside of a bend in the river, with a gentle slope along the bank from the lower terrace to the upper terrace
  - Lower terrace on the right bank: primarily herbaceous vegetation, with bermudagrass, cocklebur, giant ragweed and slim aster
  - Upper terrace: wooded with species including American sycamore, black willow, green ash, box elder, sugar hackberry, western soapberry and several Eastern cottonwood trees

HECRAS results and TESCP riparian vegetation communities were evaluated along the Columbus reach (see maps below). The floodplain herbaceous community is the dominant vegetation community along this reach, and includes both actively managed and unmanaged areas of herbaceous plant communities. The water's edge line for the 2-year flow event follows the Colorado River channel and inundates the lower river terraces with floodplain herbaceous vegetation, as well as the tributary channels. The 5-year event also follows the river channel and inundates some of the riparian zone outside the channel of tributaries. Both the 2-year and 5-year events allow the connection of a recent oxbow channel with a floodplain hardwood forest community downstream of the Columbus gage. The 10-year event allows the connection of a second, older oxbow and inundates most of the floodplain hardwood forest communities outside the channel of the main stem Colorado River, especially along bends in the river. The 25-year event appears to inundate the majority of the riparian and floodplain communities adjacent to the Colorado River, which includes large areas of pastureland. The 50-year, 100-year, and 500-year events all appear to inundate approximately the same amount of area within this reach, all slightly outside the 25-year event area.

The presence of box elder, black willow, and green ash along the banks within this reach indicates, similar to the Bastrop reach, that base flows are important to the floodplain hardwood forest community. Base flows maintain a shallow water table during the growing season for these species, which have shallow root systems and do not tolerate drought well. Pulse flows are also important in providing a mechanism for seed dispersal and soil moisture for recruitment of the American sycamore, cottonwood, and elm species in the community. Pulse flow events that occur every 2–5 years likely scour seedbeds and disperse seed, regulating herbaceous plant species distribution in the lower and upper terraces with floodplain herbaceous vegetation communities.

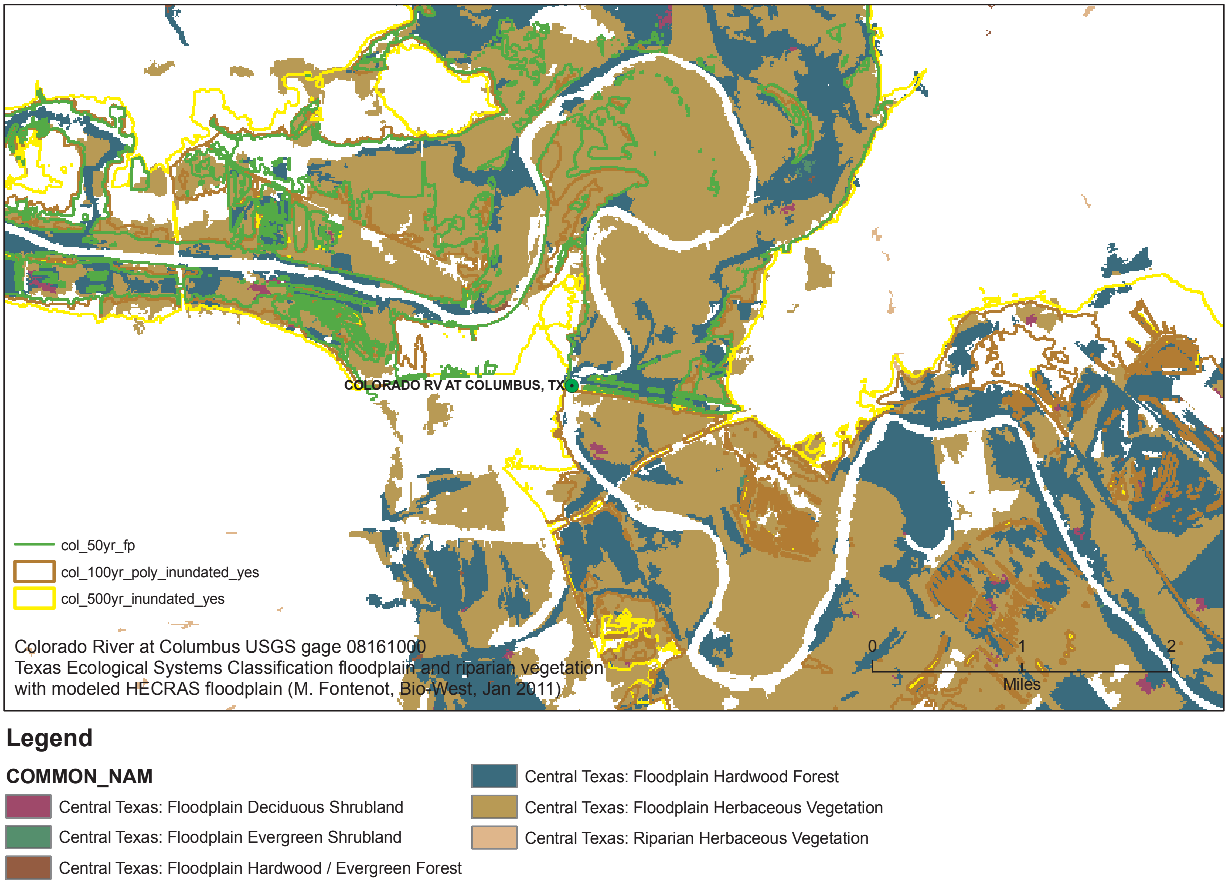
Sources: Texas Ecological System Classification project, TPWD 2010 www.tpwd.state.tx.us/landwater/land/maps/gis/tescp/index.phtml,
Horizontal datum: NAD83.
Contact: Lynne Hamlin, Water Resources Branch, TPWD lhamlin@tpwd.state.tx.us Map created Dec. 2010
Disclaimer: While every attempt was made to present the information as accurately as possible, no claims are made to the completeness or accuracy of the information shown herein nor to its suitability for a particular use.
Scale and location are approximate.

Texas Ecological Systems Classification of Riparian and Floodplain Vegetation for the Colorado River at Columbus



Sources: Texas Ecological System Classification project, TPWD 2010 www.tpwd.state.tx.us/landwater/land/maps/gis/tescp/index.phtml,
Horizontal datum: NAD83, Vertical datum: NAVD88
Contact: Lynne Hamlin, Water Resources Branch, TPWD lhamlin@tpwd.state.tx.us Feb. 2011
Disclaimer: While every attempt was made to present the information as accurately as possible, no claims are made to the completeness or accuracy of the information shown herein nor to its suitability for a particular use.
Scale and location are approximate.

HECRAS Model Results with Riparian/Floodplain Vegetation Maps



Sources: Texas Ecological System Classification project, TPWD 2010 www.tpwd.state.tx.us/landwater/land/maps/gis/tescp/index.phtml,
Horizontal datum: NAD83, Vertical datum: NAVD88
Contact: Lynne Hamlin, Water Resources Branch, TPWD lhamlin@tpwd.state.tx.us Map created Jan. 2011
Disclaimer: While every attempt was made to present the information as accurately as possible, no claims are made to the completeness or accuracy of the information shown herein nor to its suitability for a particular use.
Scale and location are approximate.

HECRAS Model Results with Riparian/Floodplain Vegetation Maps

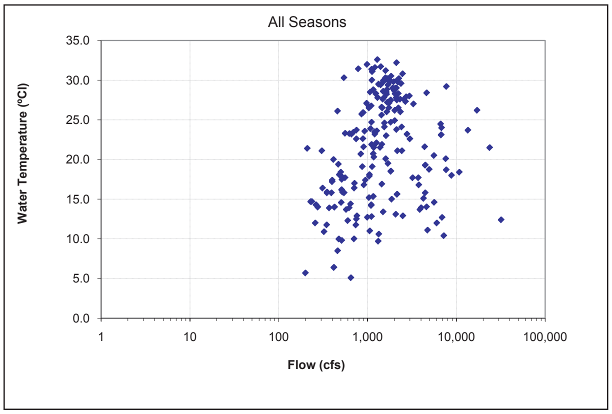
Biology

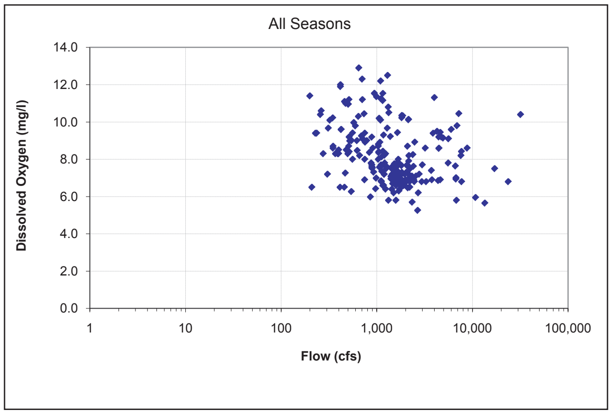
Aquatic habitat use data were collected at 10 sites from Longhorn Dam to Wharton in 2004–2007 using various fish sampling techniques including seining, backpack electrofishing, barge electrofishing, and boat electrofishing. A habitat guild approach was used to assess aquatic habitat modeled over a range of flows using River2D models at each site (BIO-WEST, Inc. 2008). Life-history information, a radio telemetry study to identify adult habitat, and field confirmation of spawning habitat for blue suckers was used to supplement the fish guild approach.

Water Quality

- The water quality period of record for this gage is 10/04/1982 - 06/2/2010
- Relationships between flow and water quality parameters

  - Specific conductance decreases with increasing flow.
  - pH increases with increasing flow.
  - NO2+NO3–N decreases with increasing flow.
  - Total phosphorus decreases with increasing flow.
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in Water Quality Segment 1402, Colorado River below La Grange. The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated high aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
  - The segment of river where this gage site is located is not listed on the 303(d) list.
- Relationship between temperature and flow
  - No correlation was observed between water temperature and flow.
  - The highest temperature was 32.59 °C (flow: 1,290 cfs; dissolved oxygen: 9.67 mg/L).
  - The lowest temperature was 5.1 °C (flow: 650 cfs; dissolved oxygen: 12.9 mg/L).
  - The lowest flow was 200 cfs (temperature: 5.7 °C; dissolved oxygen: 11.4mg/L).
  - The highest flow was 31,900 cfs (temperature: 12.4 °C; dissolved oxygen: 10.4 mg/L).
- Relationship between dissolved oxygen and flow
  - No correlation was observed between dissolved oxygen and flow.
  - The highest dissolved oxygen was 12.9 mg/L (flow: 650 cfs; temperature: 5.1 °C).
  - The lowest dissolved oxygen was 5.26 mg/L (flow of 2,680 cfs; temperature: 27.3 °C).
  - The lowest flow was 200 cfs (temperature: 5.7 °C; dissolved oxygen: 11.4mg/L).
  - The highest flow was 31,900 cfs (temperature: 12.4° C; dissolved oxygen: 10.4 mg/L).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - The maximum observed chloride concentration was 154 mg/L, which exceeded the TSWQS of 100 mg/L.
  - The minimum and maximum pH values were within the TSWQS range of 6.5-9.0.
  - The highest temperature was below the TSWQS of 35 °C.
  - The minimum dissolved oxygen concentration was above the TSWQS of 5.0 mg/L.





Geomorphology

Two sites along the lower Colorado River were modeled for sediment transport and effective discharge: La Grange and Columbus. It was found that the greatest proportion of total sediment is transported by low flows (at both sites). At Columbus, the peak occurs at the discharge increment of about 2,000 cfs, when sand-sized particles are being transported while little to no gravel is mobile. At Columbus, minor secondary peaks can be seen at about 21,500 cfs and 31,500 cfs when gravel would be in transport at the site. This gravel-based effective discharge is important for channel (and riffle) maintenance, and flows of this size reach the top of the banks. Flows of this size are equaled or exceeded between 0.5% to 2% of the time (BIO-WEST, Inc. 2008).

The geomorphic analyses conducted by the LSWP study utilize different terminology and are related to different aspects of the river's geomorphology than the geomorphic analyses conducted by the BBEST at other gages in the basin.

Flow Regime Interpretations

The instream flow study conducted as part of the LCRA SAWS Water Project (LSWP) identified four components of the hydrologic regime to integrate as part of the environmental flow regime: subsistence flows, base flows, high flow pulses, and overbank flows. The following description of the integration of these aspects of the hydrological record and ecological responses is provided from BIO-WEST, Inc. (2008).

Subsistence flows: Infrequent, seasonal periods of low flows. The primary objective of this component is to maintain water quality criteria. The secondary objectives are to provide important low flow life cycle cues or refugia habitat. The 95^{th} percent habitat exceedence level was evaluated, and the 95^{th} percent exceedence flow was the recommended subsistence flow.

Base flows: Normal flow conditions between storm events. The objective of this component is to ensure adequate habitat conditions, including variability, to support the natural biological community.

Pulse flows: Short-duration, within channel, high flow events following storm events. The objective of this component is to maintain important physical habitat features and provide longitudinal connectivity along the river channel.

Overbank flows: Infrequent, high flow events that exceed the normal channel. The objective of this component is to maintain riparian areas and provide lateral connectivity between the river channel and active floodplain.

HEFR/Hydrologic Regime

<table>
<tr><td rowspan="3">Overbank Flows</td><td colspan="11">Qp: 101,000 cfs with Average Frequency 1 per 5 years
Regressed Volume is 479,526 to 1,578,581 (870,040)
Regressed Duration is 4 to 22 (10)</td></tr>
<tr><td colspan="11">Qp: 55,900 cfs with Average Frequency 1 per 2 years
Regressed Volume is 233,020 to 764,061 (421,949)
Regressed Duration is 3 to 17 (8)</td></tr>
<tr><td colspan="11">Qp: 48,500 cfs with Average Frequency 1 per year
Regressed Volume is 195,937 to 641,979 (354,666)
Regressed Duration is 3 to 16 (7)</td></tr>
<tr><td rowspan="2">High Flow Pulses</td><td colspan="3">Qp: 12,200 cfs with Average Frequency 1 per season
Regressed Volume is 44,883 to 146,329 (81,041)
Regressed Duration is 3 to 12 (6)</td><td colspan="4">Qp: 37,900 cfs with Average Frequency 1 per season
Regressed Volume is 144,282 to 436,751 (251,028)
Regressed Duration is 3 to 12 (6)</td><td colspan="2">Qp: 5,580 cfs with Average Frequency 1 per season
Regressed Volume is 15,965 to 57,482 (30,293)
Regressed Duration is 2 to 9 (4)</td><td colspan="2">Qp: 38,800 cfs with Average Frequency 1 per season
Regressed Volume is 132,042 to 439,814 (240,985)
Regressed Duration is 2 to 13 (5)</td></tr>
<tr><td colspan="3">Qp: 4,800 cfs with Average Frequency 2 per season
Regressed Volume is 12,476 to 40,889 (22,586)
Regressed Duration is 1 to 6 (3)</td><td colspan="4">Qp: 23,800 cfs with Average Frequency 2 per season
Regressed Volume is 79,829 to 240,717 (138,623)
Regressed Duration is 2 to 10 (5)</td><td colspan="2">Qp: 2,030 cfs with Average Frequency 2 per season
Regressed Volume is 4,244 to 15,495 (8,110)
Regressed Duration is 1 to 5 (2)</td><td colspan="2">Qp: 11,700 cfs with Average Frequency 2 per season
Regressed Volume is 31,887 to 105,493 (57,999)
Regressed Duration is 1 to 9 (4)</td></tr>
<tr><td rowspan="3">Base Flows (cfs)</td><td colspan="3">1310 (41.8%)</td><td colspan="4">2410 (42.8%)</td><td colspan="2">1240 (39.6%)</td><td colspan="2">1480 (41.7%)</td></tr>
<tr><td colspan="3">908 (58.7%)</td><td colspan="4">1530 (60.0%)</td><td colspan="2">888 (54.0%)</td><td colspan="2">950 (56.7%)</td></tr>
<tr><td colspan="3">624 (75.3%)</td><td colspan="4">950 (77.1%)</td><td colspan="2">608 (68.4%)</td><td colspan="2">613 (72.0%)</td></tr>
<tr><td>Subsistence Flows (cfs)</td><td colspan="3">340 (95.1%)</td><td colspan="4">352 (95.1%)</td><td colspan="2">193 (95.0%)</td><td colspan="2">222 (95.0%)</td></tr>
<tr><td></td><td>Dec</td><td>Jan</td><td>Feb</td><td>Mar</td><td>Apr</td><td>May</td><td>Jun</td><td>Jul</td><td>Aug</td><td>Sep</td><td>Oct</td></tr>
<tr><td></td><td colspan="3">Winter</td><td colspan="4">Spring</td><td colspan="2">Summer</td><td colspan="3">Fall</td></tr>
</table>

Note: the month row also includes "Nov" as the last column under Fall.

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:

1. Period of Record used : 1/1/1917 to 12/31/1939.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 301 cfs.

Recommended Environmental Flow Regime

Two flow record periods were evaluated during the LSWP study: the existing condition (1975–2004) and pre-1940 (1898–1939). An evaluation of the hydrology, habitat time series modeling results, sediment transport analyses, and water quality results indicated that the pre-1940 flow regime is different from the existing flow regime. To maintain natural habitat diversity, hydrologic character, and water quality, the pre-1940 time period was selected for the development of instream flow guidelines (BIO-WEST, Inc. 2008).

The recommended environmental flow regime for the Colorado River at Columbus includes monthly regimes for subsistence and two levels of base flow, and periodic pulse flows, channel maintenance flows and overbank flows that were adopted from the LSWP study (BIO-WEST 2008). It should be noted that the pulse, channel maintenance and overbank flow recommendations are the same amongst the Bastrop, Columbus, and Wharton gages.

Colorado River at Columbus, USGS Gage 08161000, Recommended Environmental Flow Regime

Flow	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Subsistence	340	375	375	299	425	534	342	190	279	190	202	301
Base – Dry	487	590	525	554	966	967	570	310	405	356	480	464
Base - Average	828	906	1036	1011	1397	1512	906	522	617	749	764	746
Pulse flow -Base	Magnitude (2,000 to 3,000 cfs); Frequency (8-10 times annually); Duration (3-5 days)											
Pulse flow - High	Magnitude (8,000 cfs); Frequency (2 events in a 3-year period); Duration (2-3 days)											
Channel Maintenance	Magnitude (27,000 to 30,000 cfs); Frequency (1 event in 3 -year period); Duration (3 days)											
Overbank	Magnitude (>30,000 cfs); Frequency and Duration (naturally driven)											

2.3.3 Colorado River at Wharton

USGS Gage 08162000

Typical view of the Colorado River near Wharton, facing upstream (left photo) and downstream (right photo) (Courtesy of BIO-WEST, Inc.).

General Area Description (USGS 2010, BIO-WEST, Inc. 2008)

- Located in Wharton County on the south side of the city of Wharton at the crossing of Highway 59-Business
- Examined as part of an instream flow study in 2004–2007
- Instream habitat modeling conducted within this reach
- HECRAS modeling conducted within this reach
- Intensive biological and physical data collection activities conducted 2004–2007 (BIO-WEST, Inc. 2004, BIO-WEST, Inc. 2005, BIO-WEST, Inc. 2006, BIO-WEST, Inc. 2007)
- Biological sampling conducted within this reach, although blue sucker habitat not observed and no blue suckers tagged
- Riparian vegetation community described during a field effort in 2005
- Land use practices have altered the lateral extent of riparian communities along the river

USGS Gage 08162000 Description

Wharton County, Texas	Hydrologic Unit: 12090302	Latitude: 29°18'32" Longitude: 96°06'13" NAD27
Drainage area: 42,003 square miles	Contributing drainage area: 30,600 square miles	
Datum of gage: 52.42 feet above sea level NGVD29	Flood stage occurs at 39 feet above the USGS gage elevation (NOAA 2010)	

Site Description

- Review of aerial photography with Google Earth
  - Approximately 10-mile river reach, from one mile upstream of the USGS gage to 9 miles downstream of the gage
  - Flow dates
    - February 19, 1995: 615 cfs

        - January 23, 1996: 533 cfs
        - October 21, 2005: 834 cfs
        - April 11, 2007: 1,710 cfs
        - October 30, 2008: 368 cfs
    - Habitats
        - Dominated by long straight runs, with occasional in-channel islands
        - Sandbars common around bends in the river
        - Banks of the river and upper terraces: wooded riparian vegetation, with lower terraces dominated by herbaceous vegetation
        - Two old oxbow lakes associated with the channel in this reach, one located just over 2 miles upstream and one located just over 2 miles downstream of the gage

Wetlands

The main features identified on the National Wetland Inventory maps (USFWS 2010) included:

- Frequent wetlands adjacent to the river channel that are occasionally or seasonally inundated, some of which support herbaceous or woody vegetation (R2USA/R2USC)
- Many wetlands occur at bends in the river
- Numerous in-channel islands
- Numerous intermittent streams flow into the Colorado River
- Occasional oxbow channels are present, and likely connect to the river during high flows

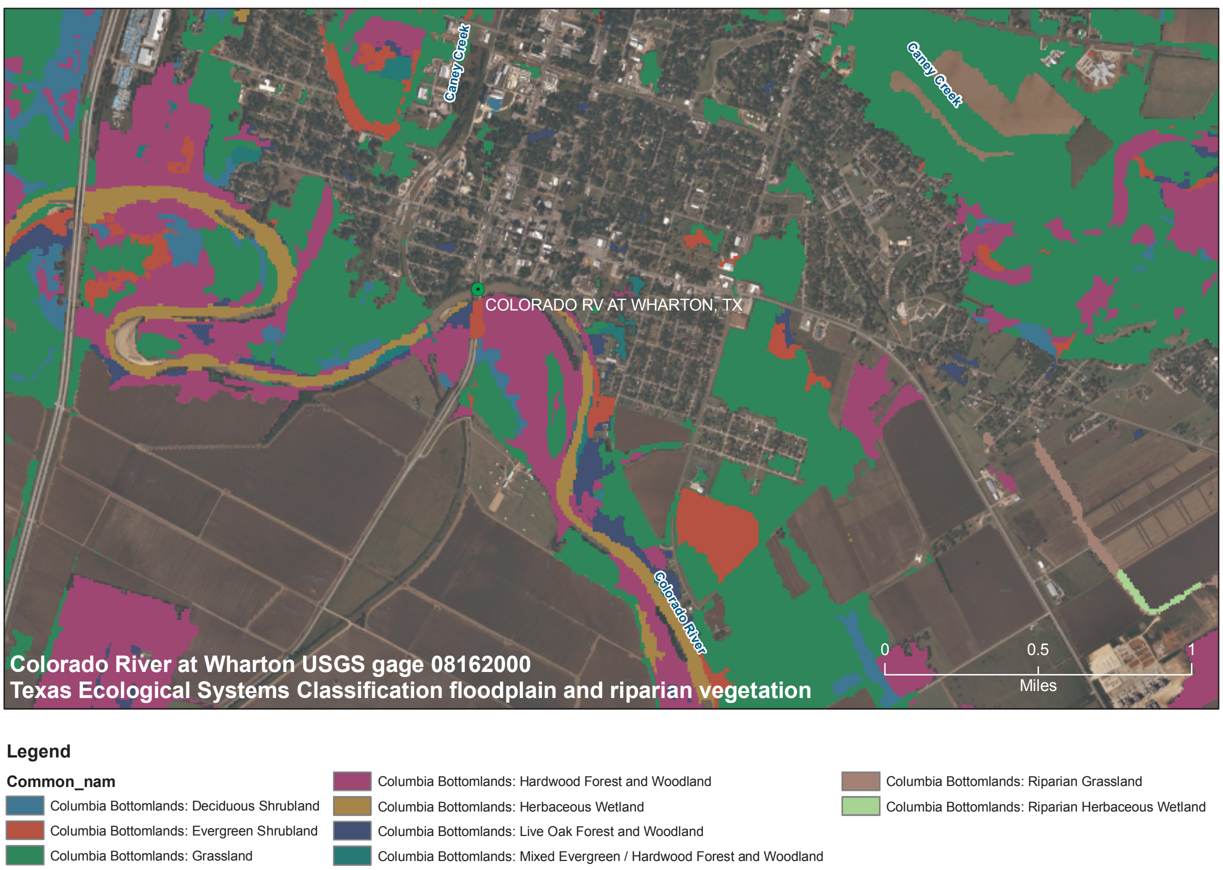
Riparian/Floodplain Vegetation

Texas Ecological System Classification of vegetation communities indicates the floodplain and riparian vegetation communities in this reach are within a wide floodplain, and consist of mainly two communities in the "Columbia Bottomlands" region (see Riparian Vegetation Map below; German et al. 2009):

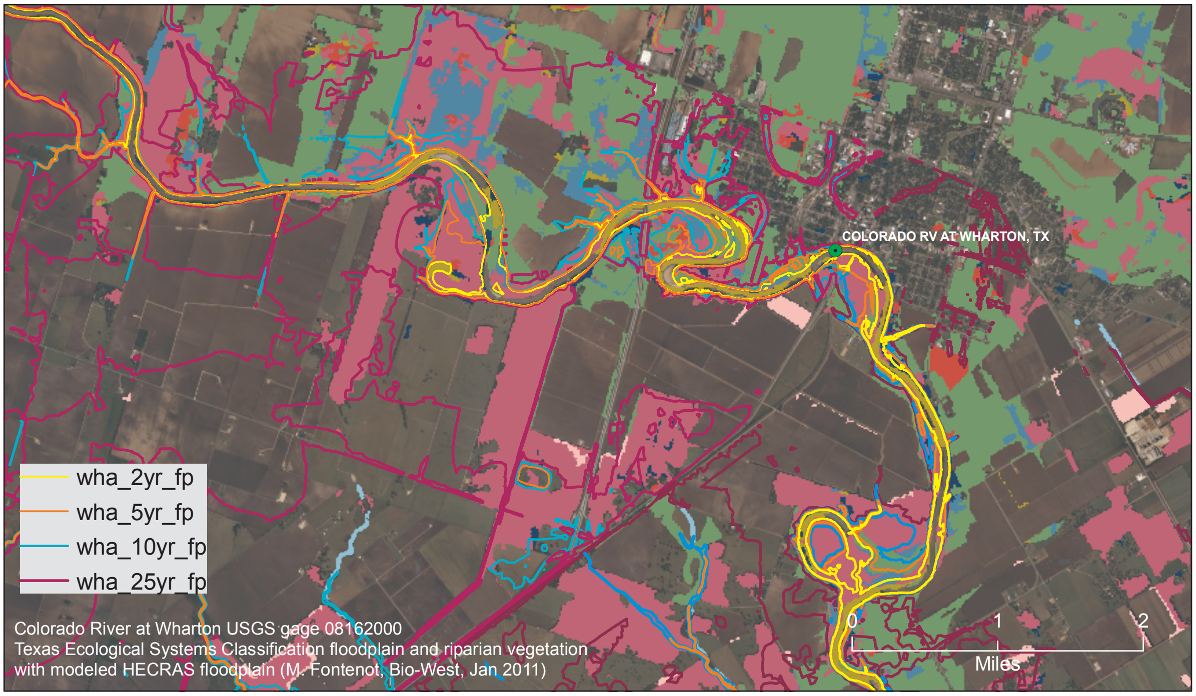
- Grassland
    - Mostly managed grasslands dominated by grasses including bermudagrass, bahiagrass, and Italian ryegrass
- Hardwood forest and woodland
    - May contain species such as water oak, sugar hackberry, cedar elm, green ash, American elm, water hickory, and less commonly, coastal live oak
- Small patches of deciduous shrubland and evergreen shrubland
- Field survey of the riparian zone in this reach in 2005 found a mix of wooded riparian vegetation and cropland along the banks
    - Woody species included sugar hackberry, green ash, Eastern cottonwood, box elder and scattered cedar elm, American elm, pecan, gum bumelia, and western soapberry
    - Black willow and American sycamore growing along the banks

HECRAS results and TESCP riparian vegetation communities were evaluated along the Wharton reach (see maps below). Along most of the Wharton reach, the floodplain extends north of the river. The 2-year and 5-year flow events primarily stay in-channel, and inundate two oxbow channels near the gage. The 5-year flow event fully connects the two oxbow channels to the river and inundates small tributaries in the reach. The 10-year flow event inundates a portion of the lower river terraces and hardwood forest and woodland community, and the 25-year event fully inundates these terraces and also appears to inundate a large portion of the floodplain including grasslands and shrublands. The 50-year, 100-year and 500-year events all appear to inundate the surrounding river floodplain and cropland areas.

The hardwood forest and woodland communities are comprised of water hickory which requires near continuous wet conditions, and green ash, water oak, American elm, cedar elm, and pecan which tolerate common to frequent wet conditions. A relatively shallow water table or frequent periods of inundation would be important to the species with shallow root systems which would otherwise be outcompeted by more upland species (e.g., hackberry, live oak). Similar to the Bastrop and Columbus sites, sufficient base flows would support these species along the riverbanks and oxbows. Pulse flows would be important to this community for seed dispersal, germination, and ultimately recruitment of these species in the future.



Texas Ecological Systems Classification of Riparian and Floodplain Vegetation for the Colorado River at Wharton



Legend

Common_nam

- Columbia Bottomlands: Deciduous Shrubland
- Columbia Bottomlands: Evergreen Shrubland
- Columbia Bottomlands: Grassland
- Columbia Bottomlands: Hardwood Forest and Woodland
- Columbia Bottomlands: Herbaceous Wetland
- Columbia Bottomlands: Live Oak Forest and Woodland
- Columbia Bottomlands: Riparian Grassland
- Gulf Coast: Coastal Prairie Pondshore

Sources: Texas Ecological System Classification project, TPWD 2010 www.tpwd.state.tx.us/landwater/land/maps/gis/tescp/index.phtml,
Horizontal datum: NAD83, Vertical datum: NAVD88
Contact: Lynne Hamlin, Water Resources Branch, TPWD lhamlin@tpwd.state.tx.us Map created Jan. 2011
Disclaimer: While every attempt was made to present the information as accurately as possible, no claims are made to the completeness or accuracy of the information shown herein nor to its suitability for a particular use.
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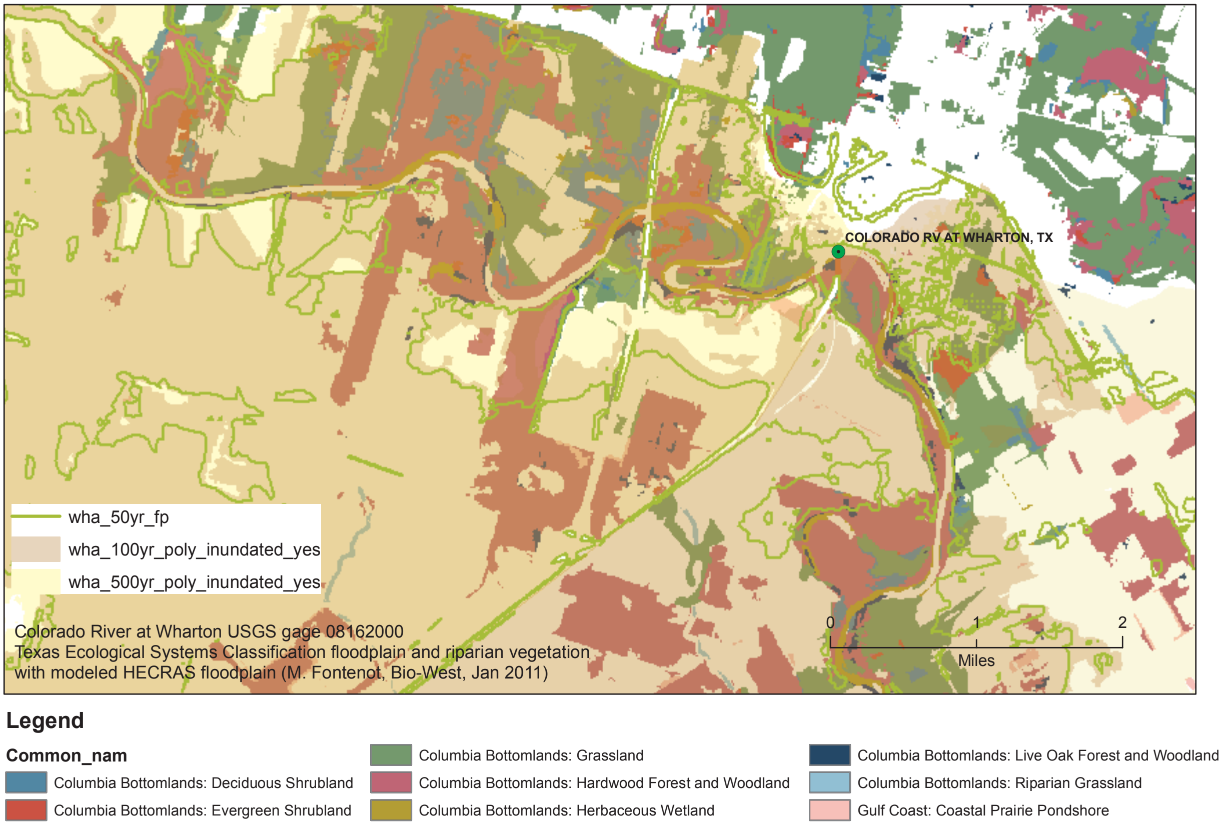


Sources: Texas Ecological System Classification project, TPWD 2010 www.tpwd.state.tx.us/landwater/land/maps/gis/tescp/index.phtml,
Horizontal datum: NAD83, Vertical datum: NAVD88
Contact: Lynne Hamlin, Water Resources Branch, TPWD lhamlin@tpwd.state.tx.us Map created Jan. 2011
Disclaimer: While every attempt was made to present the information as accurately as possible, no claims are made to the completeness or accuracy of the information shown herein nor to its suitability for a particular use.
Scale and location are approximate.

HECRAS Model Results with Riparian/Floodplain Vegetation Maps

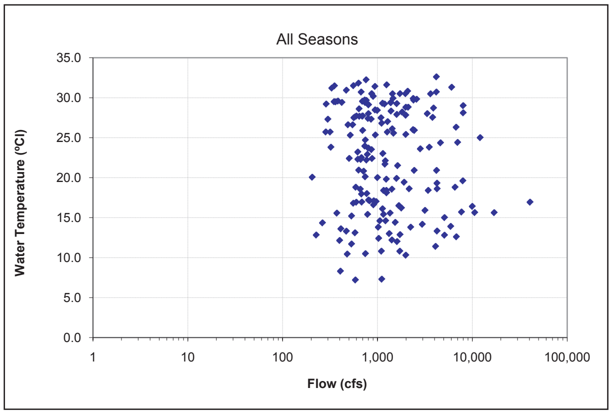
Biology

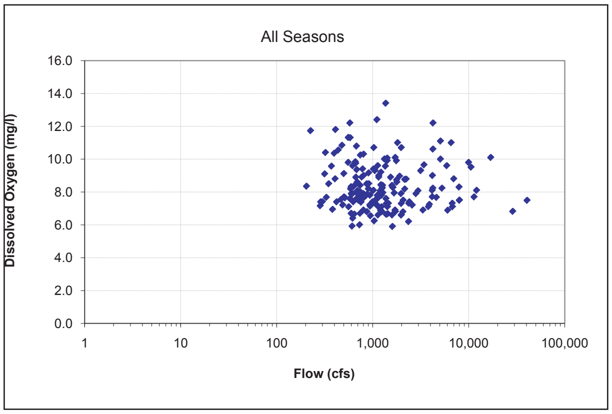
Aquatic habitat use data were collected at 10 sites from Longhorn Dam to Wharton in 2004–2007 using various fish sampling techniques including seining, backpack electrofishing, barge electrofishing, and boat electrofishing. A habitat guild approach was used to assess aquatic habitat modeled over a range of flows using River2D models at each site (BIO-WEST 2008). While blue sucker data was included for habitat assessment at more upstream locations, blue suckers were not sampled at the Wharton site, nor was habitat for the blue sucker observed.

Water Quality

- The water quality period of record for this gage is 10/01/1982 - 06/02/2010
- Relationships between flow and water quality parameters
  - Water temperature decreases with increasing flow during the warmer months (May – October).
  - Chloride decreases with increasing flow.

- According to the 2008 Texas Water Quality Inventory, this gaging station is located in Water Quality Segment 1402, Colorado River below La Grange. The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated high aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
  - The segment of river where this gage site is located is <u>not</u> listed on the 303(d) list.
- Relationship between temperature and flow
  - No correlation was observed between water temperature and flow during cooler months (November–April) or when all months were included in the analysis.
  - A slight inverse correlation (r2=0.061) was observed between flow and temperature during warmer months (May–October).
  - The highest temperature was 32.6 °C (flow: 4,180 cfs; dissolved oxygen: 8.1 mg/L).
  - The lowest temperature was 7.2 °C (flow: 585 cfs; dissolved oxygen: 11.3 mg/L).
  - The lowest flow was 205 cfs (temperature: 20.05 °C; dissolved oxygen: 8.35 mg/L).
  - The highest flow was 40,600 cfs (temperature: 16.93 °C; dissolved oxygen: 7.49 mg/L).
- Relationship between dissolved oxygen and flow
  - No correlation was observed between dissolved oxygen and flow.
  - The highest dissolved oxygen was 13.4 mg/L (flow: 1,370 cfs; temperature: not measured).
  - The lowest dissolved oxygen was 5.9 mg/L (flow of 1,610 cfs; temperature: 12.0 °C).
  - The lowest flow was 205 cfs (temperature: 20.05 °C; dissolved oxygen: 8.35 mg/L).
  - The highest flow was 40,600 cfs (temperature: 16.93 °C; dissolved oxygen: 7.49 mg/L).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - The maximum observed chloride concentration was 148 mg/L, which exceeded the TSWQS of 100 mg/L.
  - The minimum and maximum pH values were within the TSWQS range of 6.5-9.0.
  - The highest temperature was below the TSWQS of 35 °C.
  - The minimum dissolved oxygen concentration was above the TSWQS of 5.0 mg/L.





Geomorphology

Two sites along the lower Colorado River were modeled for sediment transport and effective discharge: La Grange and Columbus. It was found that the greatest proportion of total sediment is transported by low flows (at both sites). At Columbus, the peak occurs at the discharge increment of about 2,000 cfs, when sand-sized particles are being transported while little to no gravel is mobile. At Columbus, minor secondary peaks can be seen at about 21,500 cfs and 31,500 cfs when gravel would be in transport at the site. This gravel-based effective discharge is important for channel (and riffle) maintenance, and flows of this size reach the top of the banks. Flows of this size are equaled or exceeded between 0.5% to 2% of the time (BIO-WEST, Inc. 2008).

The geomorphic analyses conducted by the LSWP study utilize different terminology and are related to different aspects of the river's geomorphology than the geomorphic analyses conducted by the BBEST at other gages in the basin.

Flow Regime Interpretations

The instream flow study conducted as part of the LCRA SAWS Water Project (LSWP) identified four components of the hydrologic regime to integrate as part of the environmental flow regime: subsistence flows, base flows, high flow pulses, and overbank flows. The following description of the integration of these aspects of the hydrological record and ecological responses is provided from BIO-WEST, Inc. (2008).

Subsistence flows: Infrequent, seasonal periods of low flows. The primary objective of this component is to maintain water quality criteria. The secondary objectives are to provide important low flow life cycle cues or refugia habitat. The 95^{th} percent habitat exceedence level was evaluated, and the 95^{th} percent exceedence flow was the recommended subsistence flow.

Base flows: Normal flow conditions between storm events. The objective of this component is to ensure adequate habitat conditions, including variability, to support the natural biological community.

Pulse flows: Short-duration, within channel, high flow events following storm events. The objective of this component is to maintain important physical habitat features and provide longitudinal connectivity along the river channel.

Overbank flows: Infrequent, high flow events that exceed the normal channel. The objective of this component is to maintain riparian areas and provide lateral connectivity between the river channel and active floodplain.

HEFR/Hydrologic Regime

<table>
<tr><td rowspan="3">Overbank Flows</td><td colspan="4">Qp: 102,213 cfs with Average Frequency 1 per 5 years
Regressed Volume is 481,207 to 1,569,489 (869,051)
Regressed Duration is 4 to 22 (9)</td></tr>
<tr><td colspan="4">Qp: 56,571 cfs with Average Frequency 1 per 2 years
Regressed Volume is 234,171 to 760,799 (422,087)
Regressed Duration is 3 to 17 (7)</td></tr>
<tr><td colspan="4">Qp: 49,082 cfs with Average Frequency 1 per year
Regressed Volume is 196,974 to 639,467 (354,906)
Regressed Duration is 3 to 16 (7)</td></tr>
<tr><td rowspan="2">High Flow Pulses</td><td>Qp: 12,346 cfs with Average Frequency 1 per season
Regressed Volume is 46,510 to 144,752 (82,051)
Regressed Duration is 3 to 12 (6)</td><td>Qp: 38,355 cfs with Average Frequency 1 per season
Regressed Volume is 142,888 to 437,353 (249,985)
Regressed Duration is 3 to 12 (6)</td><td>Qp: 5,870 cfs with Average Frequency 1 per season
Regressed Volume is 16,969 to 59,070 (31,660)
Regressed Duration is 2 to 9 (4)</td><td>Qp: 35,218 cfs with Average Frequency 1 per season
Regressed Volume is 121,055 to 408,845 (222,470)
Regressed Duration is 2 to 13 (5)</td></tr>
<tr><td>Qp: 4,890 cfs with Average Frequency 2 per season
Regressed Volume is 13,168 to 41,131 (23,272)
Regressed Duration is 2 to 6 (3)</td><td>Qp: 24,187 cfs with Average Frequency 2 per season
Regressed Volume is 79,907 to 243,671 (139,539)
Regressed Duration is 2 to 10 (4)</td><td>Qp: 2,166 cfs with Average Frequency 2 per season
Regressed Volume is 5,007 to 17,656 (9,402)
Regressed Duration is 1 to 6 (2)</td><td>Qp: 11,840 cfs with Average Frequency 2 per season
Regressed Volume is 31,601 to 106,078 (57,898)
Regressed Duration is 1 to 8 (3)</td></tr>
<tr><td rowspan="3">Base Flows (cfs)</td><td>1359(41.8%)</td><td>2419(42.6%)</td><td>1222(39.6%)</td><td>1528(41.3%)</td></tr>
<tr><td>932(58.6%)</td><td>1558(59.9%)</td><td>872(54.2%)</td><td>992(56.6%)</td></tr>
<tr><td>630(75.4%)</td><td>950(77.0%)</td><td>609(68.5%)</td><td>622(71.9%)</td></tr>
<tr><td>Subsistence Flows (cfs)</td><td>344(95.1%)</td><td>356(95.1%)</td><td>195(95.0%)</td><td>225(95.0%)</td></tr>
<tr><td></td><td>Dec Jan Feb</td><td>Mar Apr May Jun</td><td>Jul Aug</td><td>Sep Oct Nov</td></tr>
<tr><td></td><td>Winter</td><td>Spring</td><td>Summer</td><td>Fall</td></tr>
</table>

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:

1. Period of Record used : 1/1/1917 to 12/31/1939.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 305 cfs.

Recommended Environmental Flow Regime

The recommended environmental flow regime for the Colorado River at Wharton includes monthly regimes for subsistence and two levels of base flow, and periodic pulse flows, channel maintenance flows and overbank flows. It should be noted that the pulse, channel maintenance and overbank flow recommendations are the same amongst the Bastrop, Columbus, and Wharton gages.

Colorado River at Columbus, USGS Gage 08161000, Recommended Environmental Flow Regime

Flow	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Subsistence	315	303	204	270	304	371	212	107	188	147	173	202
Base – Dry	492	597	531	561	985	984	577	314	410	360	486	470
Base - Average	838	906	1036	1011	1397	1512	906	522	617	749	764	746
Pulse flow -Base	Magnitude (2,000 to 3,000 cfs); Frequency (8-10 times annually); Duration (3-5 days)											
Pulse flow - High	Magnitude (8,000 cfs); Frequency (2 events in a 3-year period); Duration (2-3 days)											
Channel Maintenance	Magnitude (27,000 to 30,000 cfs); Frequency (1 event in 3-year period); Duration (3 days)											
Overbank	Magnitude (>30,000 cfs); Frequency and Duration (naturally driven)											

2.4 Lavaca-Navidad

2.4.1 Lavaca River near Edna — USGS Gage 08164000

Upstream, Lavaca River near Edna (left) Downstream, Lavaca River near Edna (right) (photos by Cathy Wakefield, July 9, 2010)

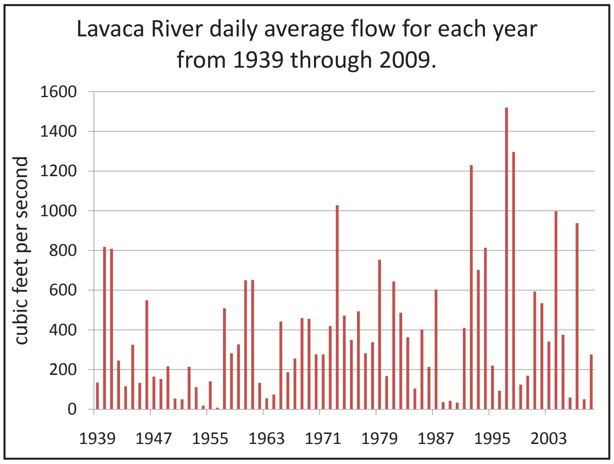
General Area Description (Omernik 1987, USGS 2010)

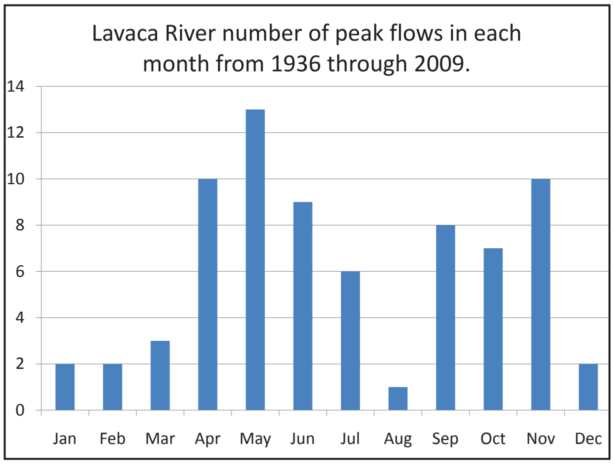
- Small diversions above station for irrigation; No flow at times; Maximum stage, since 1980, 33.8 ft, May 25, 1936, 83,400 cfs,
- Alluvial floodplain, evergreen and deciduous shrubland including mesquite and huisache, and cold deciduous forest with live oak; Pure live oak stand 2500 meters NW of gage, prairie soil
- Floodplains and Low Terraces, Western Gulf Coastal Plain

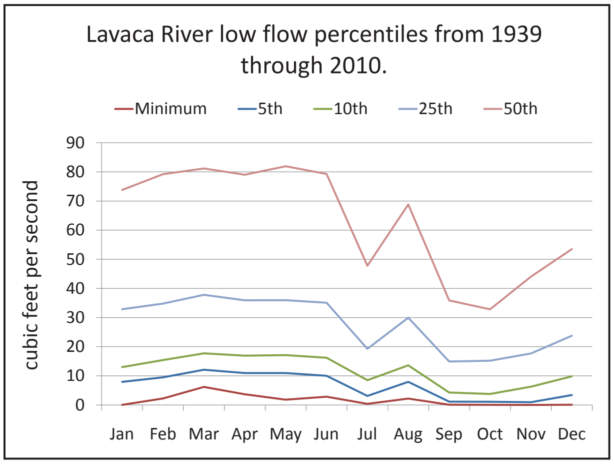
USGS Gage 08164000 Description

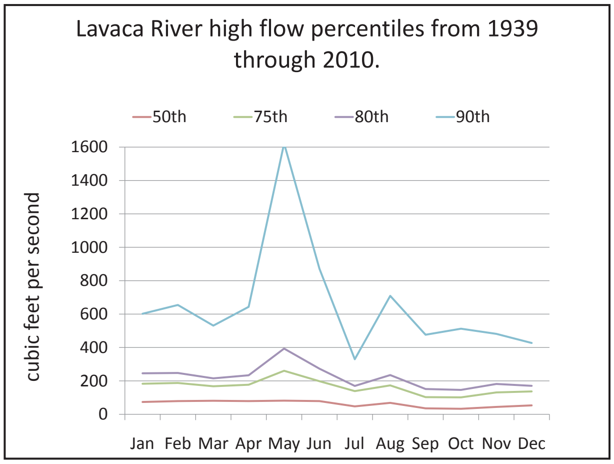
Jackson County, Texas	Hydrologic Unit Code: 12100101	Latitude: 28° 57’ 35” Longitude: 96° 41’ 10” NAD27
Drainage area (all contributing): 817 square miles	Datum of gage: 14.10 feet above sea level NGVD29	
Flood stage elevation: 6.9 ft above the USGS gage (NOAA 2010)		

Summary of Historical USGS Flow Records at Lavaca River near Edna



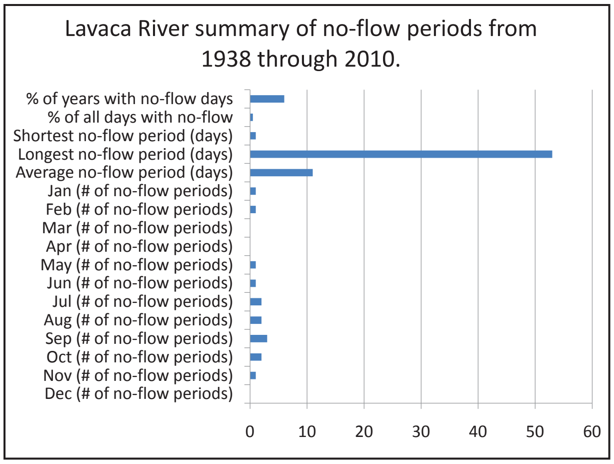


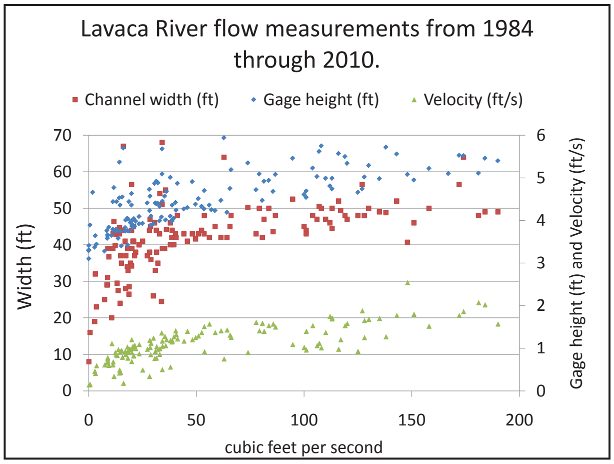




	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	5,361	6,476	5,930	7,611	11,389	9,300	9,057	8,428	10,571	13,670	12,138	6,119	8,837
Average	299	338	300	361	667	453	280	386	379	468	394	265	383
Minimum	0	2	6	4	2	3	0	2	0.1	0	0	0.1	2
5th	8	9	12	11	11	10	3	8	1	1	1	3	7
10th	13	15	18	17	17	16	8	14	4	4	6	10	12
20th	27	29	31	30	29	29	17	25	12	11	13	19	23
25th	33	35	38	36	36	35	19	30	15	15	18	24	28
50th	74	79	81	79	82	79	48	69	36	33	44	53	63
75th	183	187	168	177	261	198	139	173	103	102	131	137	163
80th	245	247	215	234	394	273	170	235	151	146	182	170	222
90th	602	655	531	643	1,621	872	330	709	477	512	482	427	655
95th	1,639	2,073	1,747	2,205	5,109	2,985	1,049	2,404	2,311	2,349	2,033	1,391	2,275

Lavaca River flow percentiles in cubic feet per second





Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases, two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5th, 25th, 50th, 75th, 80th, and 90th percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured.

Historical Hydrology

Jurgens, (1957), reported that upper and middle portions of this river were dry or intermittent during drought conditions of 1952 and 1956. Near the town of Breslau, the river bottom was mud, with pools and riffles. These characteristics change to shallow pools with a sand-silt bottom before its confluence with the Navidad River (prior to Lake Texana impoundment in 1980).

Site Description

- Review of aerial photography with Google Earth
  - A reach of ½ mile, above and below gage site was observed
  - Woody riparian vegetation obscured aerial view of physical characteristics…see cross-section comments
  - Flow on days with aerial photography
    - June 21, 1996: 17 cfs
    - October 21, 2005: 31 cfs
    - January 30, 2009: 11 cfs
- Field Observations: Cross-section work at this site included one run, one riffle and one pond
  - Run: Vegetation observed along the banks of the run: green ash, pecan, rag weed and sea oats on the slope, cedar and American elm along the ridge and sycamore, hackberry (seed), china berry, Mexican buckeye and live oak on top of the ridge: trumpet vine, day flower, grape, and box elder observed among the live oak
  - Riffle: Downstream, an island with willow centered in the observed riffle; A sand bar flanked the right bank; Willow, green ash, ragweed, sycamore and box elder common along the slopes. Inland sea oats, grape, aster, and burr or overcup oak found along the ridge
  - Pond: Vegetation appearing on the slope included box elder, sycamore, ragweed, hackberry; pecan, and American elm observed on top of the ridge

Soil Types

Soil data were obtained from the Natural Resource Conservation Service for a 5-mile stretch along the river downstream of the gage (NRCS 2010). The soil type is typical prairie, mollisol.

Soil	Setting	Slope	Wetland Potential	Flood Frequency
Chicolete clay	Floodplains	0-1%	Moderately well drained, no tendency to pond	More than 50 times per 100 years
Ganado clay	Floodplains	0-1%	Somewhat poorly drained, no tendency to pond	More than 50 times per 100 years
Laewest clay	Flats	3-8%	Moderately well drained, no tendency to pond	None
Marcado sandy clay loam	Flats	3-8%	Well drained, no tendency to pond	None

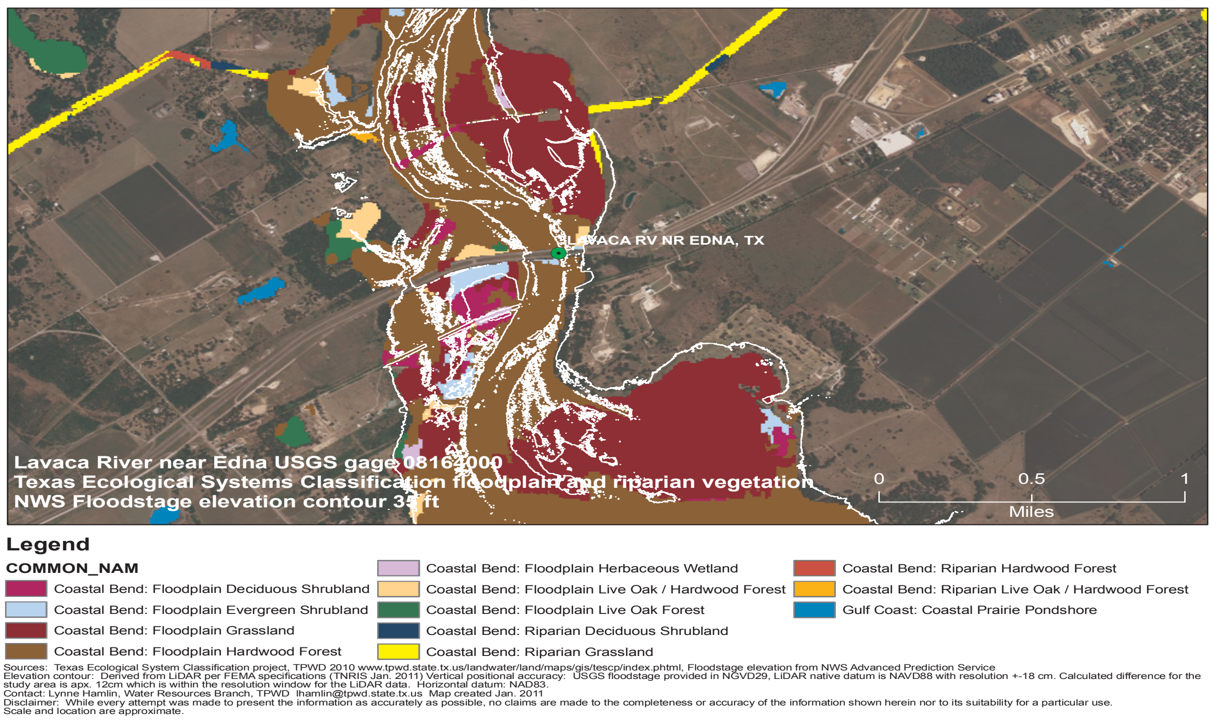
Wetlands

- Surrounding wetlands are freshwater, forested/shrubland, temporarily flooded
- Freshwater forested broad-leaved temporarily flooded (FF01A).

Riparian/Floodplain Vegetation

Texas Ecological System Classification of vegetative communities has been assessed for about 3 miles of the Lavaca River around the gage at US 59 (German et al., 2009, German et al., 2010).

- Coastal Bend Floodplain Hardwood Forest
  - Canopy dominated by deciduous hardwoods such as sugar hackberry, American sycamore, American elm, pecan; Presence of American sycamore indicates area stays saturated for 2–4 months of the year
- Coastal Bend Floodplain Grassland
  - Managed pastureland dominated by bermudagrass, King Ranch bluestem and bahiagrass
- Coastal Bend Floodplain Evergreen Shrubland
  - Dwarf palmetto, McCartney rose, colima, anacua, eastern *Baccharis*, and huisache.
- Coastal Bend Floodplain Deciduous Shrubland
  - Mesquite, huisache, common buttonbush, swamp privet, spiny aster, sugar hackberry, and cedar elm



Texas Ecological Systems Classification of Riparian and Floodplain Vegetation for the Lavaca River near Edna. The white line represents the calculated NWS flood stage elevation.

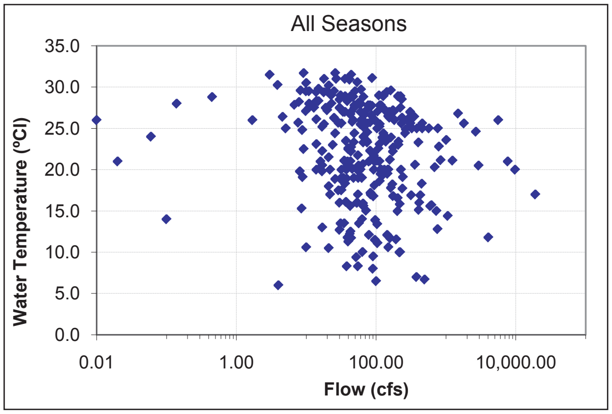
Biology

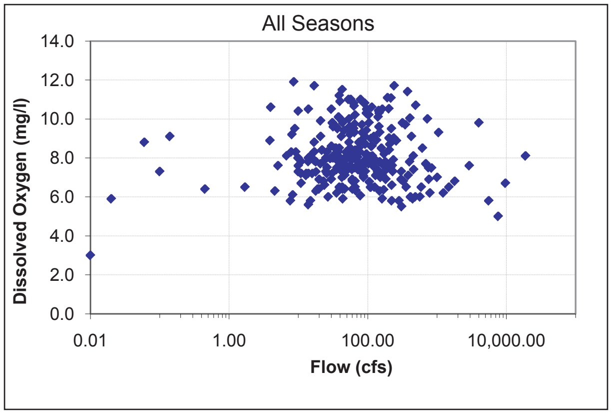
Source	Location	Biology	Observations
Jurgens 1957	Lavaca River	Redhorse shiner, golden shiner, fathead minnow, smallmouth buffalo, channel and flathead catfish, mosquitofish, largemouth bass, several sunfish species, slough darter, gizzard shad	Significant fishery
Lavaca-Navidad River Authority 2007	Lavaca River above tidal	Aquatic Life Use High	Perennial stream, classified
TPWD 2009 Fish Kill report, 1972-2006	Lavaca and Nav Rv	1978,1982,1988 1996, 1997, 1998, 1999, 2000, 2002, 2004, 2005	Drought, low DO Unknown Municipal waste Bacterial disease
TPWD 1998	Lavaca River basin, Lavaca Rv	Species of concern include the blue sucker, *Cycleptus elongatus*, (not documented in collection records, although listed for the Lavaca basin), and diamondback terrapin, *Malaclemys terrapin littoralis*	Qualifies as unique community
Hassan-Williams and Bonner 2007	Lavaca River Drainage	American. eel, ribbon shiner, channel catfish, bluegill, white crappie, slough darter, dusky darter, pugnose minnow, blue sucker, smallmouth buffalo, *Macrobrachium* (freshwater shrimp)	Variety of fish

Water Quality

- The water quality period of record for this gage is 09/24/1968 - 11/24/2009
- Relationships between flow and water quality parameters
  - Specific conductance decreases with increasing flow.
  - Chloride decreases with increasing flow.
- The 2008 Texas Water Quality Inventory Basin Assessment Data (TCEQ, 2008) indicates that water quality in the upper 29 miles of the segment does not support the designated high aquatic life use because of low dissolved oxygen. The 2010 Texas Surface Water Quality Standards (TCEQ, 2010) have subsequently removed this reach of the Lavaca River from water quality segment 1602, Lavaca River above tidal. The 29-mile reach removed from Segment 1602 is considered intermittent.

- Water quality impairments, if any, listed on the 303(d) list
  - The upper 29 miles of the segment of the river upstream of the tidal reach is impaired by depressed dissolved oxygen.
- Relationship between temperature and flow
  - No correlation was observed between water temperature and flow.
  - The highest temperature was 31.7 °C (flow: 9.2 and 26 cfs; dissolved oxygen: 7.2 mg/L).
  - The lowest temperature was 6.0 °C (flow: 4 cfs; dissolved oxygen: 10.6 mg/L).
  - The lowest flow was 0.01 cfs (temperature: 26 °C; dissolved oxygen: 3 mg/L).
  - The highest flow was 19,000 cfs (temperature: 17 °C; dissolved oxygen: 8.1 mg/L).
- Relationship between dissolved oxygen and flow
  - No correlation was observed between dissolved oxygen and flow.
  - The highest dissolved oxygen was 11.9 mg/L (flow: 8.6 cfs; temperature: 15.3 °C).
  - The lowest dissolved oxygen was 3 mg/L (flow of 0.01 cfs; temperature: 26 °C).
  - The lowest flow was 0.01 cfs (temperature: 26 °C; dissolved oxygen: 3 mg/L).
  - The highest flow was 19,000 cfs (temperature: 17 °C; dissolved oxygen: 8.1 mg/L).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - Only one chloride measurement out of 190 exceeded the TSWQS of 200 mg/L.
  - The minimum and maximum observed pH values were within the TSWQS range of 6.5-9.0.
  - The highest observed instantaneous temperature was below the TSWQS of 32. 8 °C.
  - Only one of 278 observations of dissolved oxygen measured below the TSWQS of 5.0 mg/L.





Geomorphology

Geomorphological analysis was conducted for this reach and is described in Section 3.5 of this report and summarized below.

1. The existing channel at the Lavaca River near Edna appears stable.
2. The HEFR regime flows illustrated in the HEFR table in this section, provide 14% of the historic annual flow volume of the Lavaca River near Edna.

3. The Lavaca River near Edna could maintain a stable channel if the annual average water yield was not reduced by more than 7%.
    a. For the Lavaca River near Edna, a stable channel would be maintained if the maximum diversion rate were no greater than a value as high as the 75th percentile flow (132 cfs) at this site. More extensive analysis than described in Section 3.5 may show that a stable channel may be maintained at a lower annual average water yield than examined in this study.

Flow Interpretations

No-flow periods: About 0.5% of the days over the period from 1938 through 2010 exhibited no flow. Increased frequency and duration of no-flow periods is not expected to beneficially affect the river ecosystem. Sixteen periods of no flow occurred mostly during the mid-1950s with an average duration of 9 days.

Subsistence flows: The TCEQ's critical low flow value is 16 cfs. Subsistence flow would be expected to be near that value.

Base flows: Biological monitoring indicates diverse communities of fish, which probably require different and variable levels of flow.

Pulses and overbank flows: Soils adjacent to the river indicate flooding may occur nearly every year.

HEFR/Hydrologic Flow Regime

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 22,800 cfs with Average Frequency 1 per 5 years Regressed Volume is 60,169 to 147,022 (94,054) Regressed Duration is 2 to 12 (5)			
Overbank Flows	Qp: 15,700 cfs with Average Frequency 1 per 2 years Regressed Volume is 41,004 to 100,159 (64,085) Regressed Duration is 2 to 11 (5)			
Overbank Flows	Qp: 11,400 cfs with Average Frequency 1 per year Regressed Volume is 29,509 to 72,062 (46,114) Regressed Duration is 2 to 10 (5)			
High Flow Pulses	Qp: 4,500 cfs with Average Frequency 1 per season Regressed Volume is 12,219 to 27,826 (18,439) Regressed Duration is 2 to 10 (5)	Qp: 6,770 cfs with Average Frequency 1 per season Regressed Volume is 17,341 to 40,810 (26,602) Regressed Duration is 2 to 8 (4)	Qp: 421 cfs with Average Frequency 1 per season Regressed Volume is 997 to 3,233 (1,795) Regressed Duration is 1 to 9 (4)	Qp: 4,590 cfs with Average Frequency 1 per season Regressed Volume is 11,880 to 27,407 (18,044) Regressed Duration is 2 to 9 (4)
High Flow Pulses	Qp: 2,010 cfs with Average Frequency 2 per season Regressed Volume is 5,314 to 12,087 (8,014) Regressed Duration is 2 to 8 (4)	Qp: 4,630 cfs with Average Frequency 2 per season Regressed Volume is 11,624 to 27,344 (17,828) Regressed Duration is 2 to 8 (4)	Qp: 88 cfs with Average Frequency 2 per season Regressed Volume is 204 to 665 (369) Regressed Duration is 1 to 6 (2)	Qp: 1,640 cfs with Average Frequency 2 per season Regressed Volume is 4,039 to 9,309 (6,132) Regressed Duration is 2 to 7 (3)
Base Flows (cfs) – High	90(42.6%)	97(43.0%)	48(39.8%)	58(38.4%)
Base Flows (cfs) – Medium	52(59.9%)	58(61.0%)	31(54.3%)	34(53.7%)
Base Flows (cfs) – Low	29(77.5%)	31(78.5%)	19(69.1%)	20(70.2%)
Subsistence Flows (cfs)	8.5(95.1%)	10(95.4%)	1.3(95.1%)	1.2(95.0%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:

1. Period of Record used : 1/1/1940 to 12/31/2009.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 3.9 cfs.

Recommended Environmental Flow Regime

Lavaca River near Edna, USGS Gage 08164000, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1938-2010	3 periods Max duration: 26 days	3 periods Max duration: 7 days	4 periods Max duration: 9 days	6 periods Max duration: 53 days
Subsistence	16 cfs	16 cfs	16 cfs	16 cfs
Base Low	30 cfs	30 cfs	20 cfs	20 cfs
Base Medium	55 cfs	55 cfs	33 cfs	33 cfs
Base High	94 cfs	94 cfs	48 cfs	58 cfs
2 Pulses per season	Trigger: 2,000 cfs Volume: 8,000 af Duration: 8 days	Trigger: 4,600 cfs Volume: 17,800 af Duration: 8 days	Trigger: 88 cfs Volume: 370 af Duration: 6 days	Trigger: 1,600 cfs Volume: 6,100 af Duration: 7 days
1 Pulse per season	Trigger: 4,500 cfs Volume: 18,400 af Duration: 10 days	Trigger: 6,800 cfs Volume: 26,600 af Duration: 8 days	Trigger: 420 cfs Volume: 1,800 af Duration: 9 days	Trigger: 4,500 cfs Volume: 18,000 af Duration: 9 days
1 Pulse per year (Overbank)	Trigger: 11,400 cfs Volume: 46,100 af Duration: 10 days			
1 Pulse per 2 years (Overbank)	Trigger: 15,700 cfs Volume: 64,100 af Duration: 11 days			
1 Pulse per 5 years (Overbank)	Trigger: 22,800 cfs Volume: 94,100 af Duration: 12 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second
af = acre-feet

2.4.2 Navidad River at Strane Park near Edna — USGS Gage 08164390

Downstream, Navidad River at Strane (left) Upstream, Navidad River at Strane (right) (photos by Cathy Wakefield, July 9, 2010)

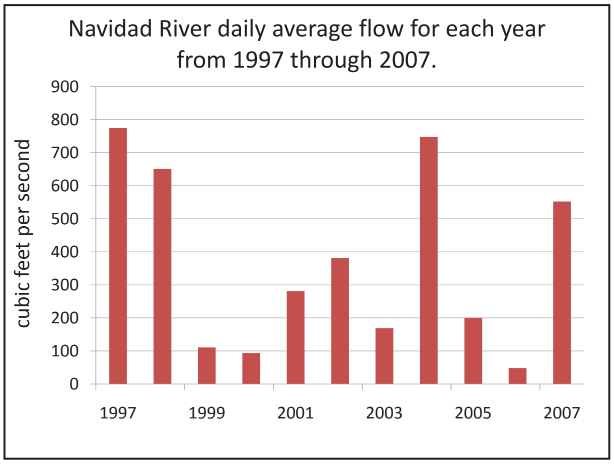
General Description of Area (Omernik 1987, USGS 2010)

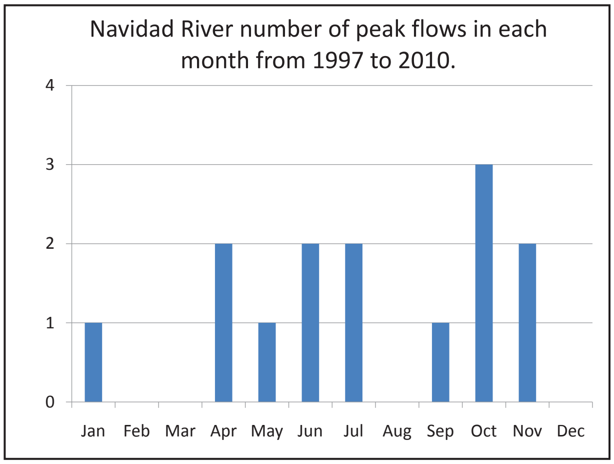
- Located in Jackson County; On the right bank at downstream side of bridge on County Road 401, and 6.3 miles north of Edna
- Much low flow during irrigation season, (April to September): drainage from rice fields irrigated by water originally diverted from the Colorado River
- Steep banks, Stream bottom sandy; One tributary appears on the east side, upstream of the gage and bridge
- Alluvial floodplain, deciduous forest, and some evergreen shrubland is disturbed
- Western Gulf Coastal Plain (EPA Level III ecoregion).
- Floodplain grassland and hardwood forest flank both banks
- River rises on the Blackland Prairie; Flows through Post Oak belt and Coastal Prairies
- Source of drainage is southern part of Fayette County
- Major tributary to the Lavaca River
- Banks are low to moderate steep-cut banks and the bottom is mostly mud with some gravel in the riffles at headwaters, changing to sand throughout the rest of its flow (Jurgens 1957).

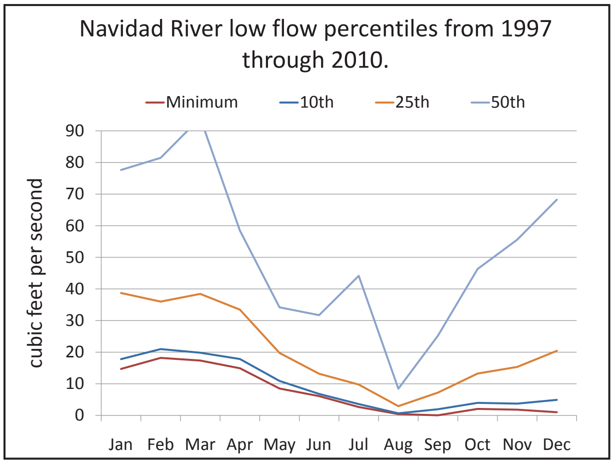
USGS Gage 08164390 Description

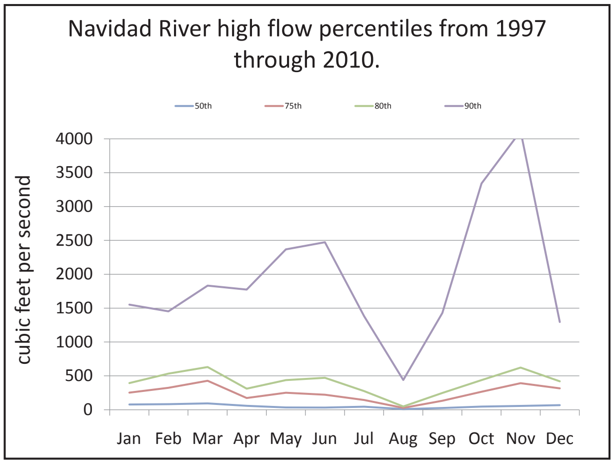
Jackson County, Texas	Hydrologic Unit Code: 12100102	Latitude: 29° 03’ 55” Longitude: 96° 40’ 26” NAD27
Drainage area: 579 square miles	Contributing drainage area: 579 square miles	
Datum of gage: 42.53 feet above sea level NGVD29		

Summary of Historical USGS Flow Records at Navidad River at Strane Park near Edna



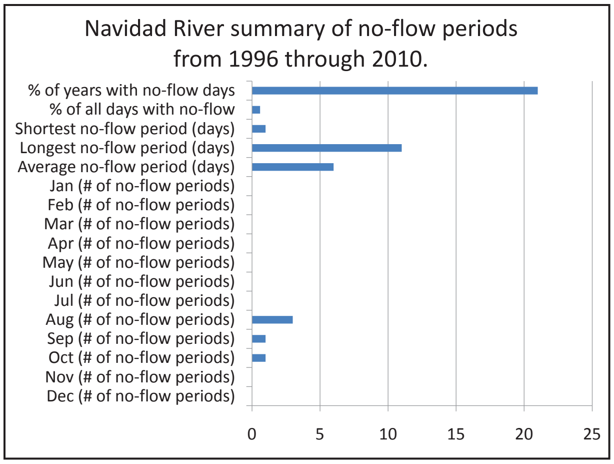


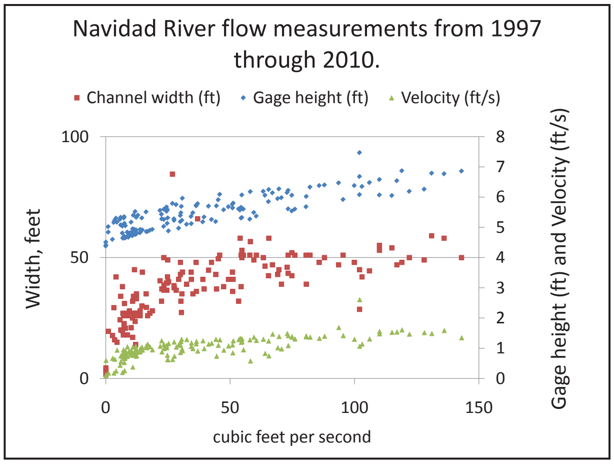




	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	2,129	1,804	2,435	2,518	3,429	3,305	1,889	660	2,077	5,016	6,261	1,742	2,772
Average	298	294	373	302	384	401	235	67	227	525	639	264	334
Minimum	15	18	17	15	8	6	3	0.4	0	2	2	1	7
10th	18	21	20	18	11	7	4	1	2	4	4	5	9
20th	30	31	30	27	17	10	7	2	6	10	11	17	16
25th	39	36	38	33	20	13	10	3	7	13	15	20	21
50th	78	81	94	58	34	32	44	8	25	46	56	68	52
75th	252	324	427	173	251	222	144	26	132	266	393	316	244
80th	394	533	630	311	438	472	275	49	248	437	621	420	402
90th	1,551	1,452	1,832	1,775	2,367	2,472	1,382	440	1,429	3,340	4,113	1,295	1,954

Navidad River flow percentiles in cubic feet per second





Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases, two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5th, 25th, 50th, 75th, 80th, and 90th percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured

Site Description

- Review of aerial photography with Google Earth
  - A reach of ½ mile, above and below gage site was observed
  - Woody riparian vegetation obscured an aerial view of physical stream characteristics.
  - Flow on dates with aerial photography:
    - October 1, 1996: 33 cfs
    - October 21, 2005: 20 cfs
    - January 1, 2009: 6.9 cfs

Soil Types

The Blackland prairie soil here is mollisols. Mollisols have a dark colored surface horizon (NRCS 2010).

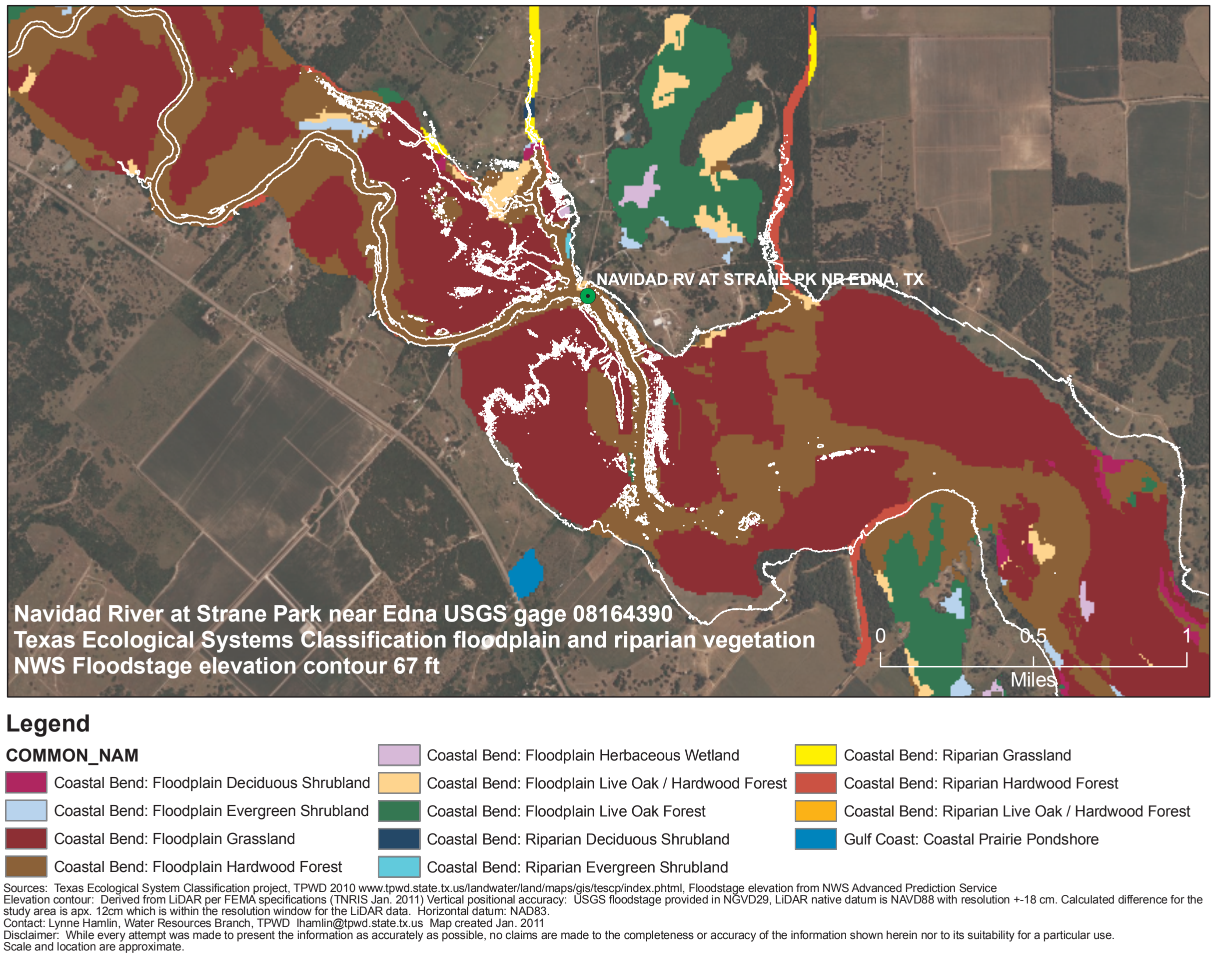
Type	Setting	Slope	Wetland Potential	Flood Frequency
Navidad fine sandy loam	Flood plains	0-1%	Well drained, no ponding	More than 50 times per 100 years
Chicolete clay	Floodplains	0-1%	Moderately drained, no ponding	More than 50 times per 100 years
Ganado clay	Flood plains	0-1%	Somewhat poorly drained, no ponding	More than 50 times per 100 years
Marcado sandy clay loam	Flats	3-8%	Well drained, no ponding	More than 50 times per 100 years

Wetlands (USFWS 2010)

- Northeast of the site is an emergent, persistent and temporarily flooded wetland, (PEM1a).
- A forested, persistent, semipermanently flooded, wetland is also nearby. (PFO1Fh).
- Southwest of the gage is a wetland with emergent, erect, rooted, herbaceous vegetation.
- A freshwater, forested and scrub (stems less than 6 m in height) wetland is also nearby. There are no wetlands adjacent to the river.

Riparian/Floodplain Vegetation (German et al. 2009, German et al. 2010)

- Coastal Bend Floodplain Hardwood Forest
  - Canopy dominated by deciduous hardwoods such as sugar hackberry, sycamore, American elm, pecan
- Coastal Bend Floodplain Grassland
  - Managed pastureland dominated by bermudagrass, King Ranch bluestem and bahiagrass
- Coastal Bend Floodplain Evergreen Shrubland
  - Dwarf palmetto, McCartney rose, colima, anacua, eastern *Baccharis*, and huisache
- Coastal Bend Floodplain Deciduous Shrubland
  - Mesquite, huisache, common buttonbush, swamp privet, spiny aster, sugar hackberry, and cedar elm



Texas Ecological Systems Classification of Riparian and Floodplain Vegetation for the Navidad River at Strane Park near Edna. The white line represents the calculated NWS flood stage elevation.

Biology

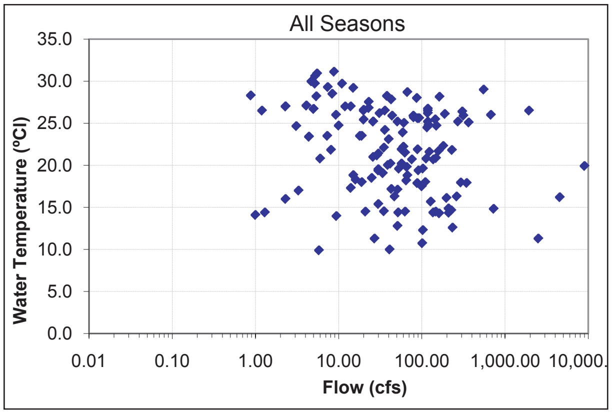
Source	Location	Biology	Observations
Jurgens 1957. Fisheries investigations, Region 6-B.	Navidad River	Channel catfish, yellow bullhead, largemouth bass, various minnows, sunfish, striped mullet, slough darter, gizzard shad	A potential fishery of varying importance
LNRA Lavaca Basin Summary Report 2002	Navidad River	Land use is farming and ranching, receives. wastewater effluent from Schulenberg	Water quality remains high due to low density of human population, wastewater treatment plant improvements, watershed protection
LNRA Lavaca Basin Summary Report 2007	Navidad River at Strane	Aquatic Life Use rating is high, (H)	Perennial stream, classified
Hassan-Williams, Bonner 2007. Fishes of Texas	Lavaca River drainage	Spotted gar, American. eel, gizzard/threadfin shad, reed shiner, blacktail shiner, smallmouth buffalo, slough darter	Same species listed for Lavaca River
TPWD 1973	Navidad River	49 species of fish and 11 species of benthic invertebrates collected	Channel catfish was the most abundant game fish in the river
TPWD 2009		21 species of fish collected	

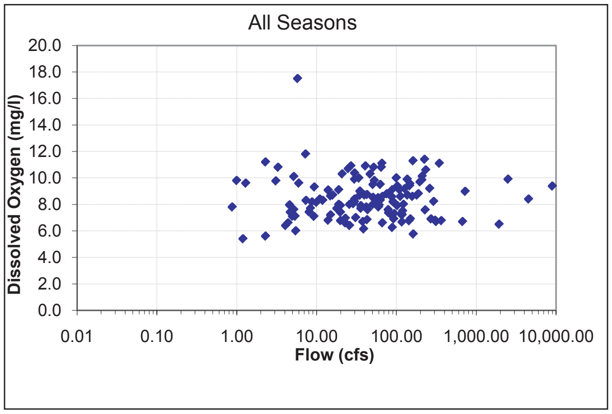
Water Quality

- The water quality period of record for this gage is 1/16/1996–11/24/2009
- Relationships between flow and water quality parameters
    - Specific conductance decreases with increasing flow.
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in Water Quality Segment 1605, Navidad River above Tidal. The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated high aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
    - The segment of river where this gage site is located is not listed on the 303(d) list.
- Relationship between temperature and flow
    - No correlation was observed between water temperature and flow.
    - The highest temperature was 31.12 °C (flow: 8.8 cfs; dissolved oxygen: 8.18 mg/L).
    - The lowest temperature was 9.9 °C (flow: 5.8 cfs; dissolved oxygen: 17.5 mg/L).
    - The lowest flow was 0 cfs (temperature: 29.2 °C; dissolved oxygen: 5.5 mg/L).
    - The highest flow was 9,000 cfs (temperature: 19.92 °C; dissolved oxygen: 9.38 mg/L).
- Relationship between dissolved oxygen and flow
    - No correlation was observed between dissolved oxygen and flow.

- The highest dissolved oxygen was 17.5 mg/L (flow: 5.8 cfs; temperature: 9.9 °C).
- The lowest dissolved oxygen was 5.4 mg/L (flow of 1.2 cfs; temperature: 26.5 °C).
- The lowest flow was 0 cfs (temperature: 29.2 °C; dissolved oxygen: 5.5 mg/L).
- The highest flow was 9,000 cfs (temperature: 19.92 °C; dissolved oxygen: 9.38 mg/L).

- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - The maximum observed chloride was below the TSWQS of 100 mg/L.
  - The minimum and maximum observed pH values were within the TSWQS range of 6.5-9.0.
  - The highest observed instantaneous temperature was below the TSWQS of 32.8 °C.
  - The minimum observed dissolved oxygen concentration was above the TSWQS of 5.0 mg/L.





Geomorphology

Geomorphic analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77 to 93 percent of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows.

HEFR/Hydrologic Regime

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 15,484 cfs with Average Frequency 1 per 5 years Regressed Volume is 47,635 to 126,482 (77,621) Regressed Duration is 3 to 12 (6)			
Overbank Flows	Qp: 10,181 cfs with Average Frequency 1 per 2 years Regressed Volume is 30,675 to 81,412 (49,973) Regressed Duration is 3 to 11 (6)			
Overbank Flows	Qp: 7,142 cfs with Average Frequency 1 per year Regressed Volume is 21,141 to 56,090 (34,435) Regressed Duration is 3 to 10 (5)			
High Flow Pulses	Qp: 3,751 cfs with Average Frequency 1 per season Regressed Volume is 11,261 to 25,605 (16,980) Regressed Duration is 2 to 9 (5)	Qp: 4,870 cfs with Average Frequency 1 per season Regressed Volume is 14,494 to 33,774 (22,126) Regressed Duration is 2 to 8 (4)	Qp: 612 cfs with Average Frequency 1 per season Regressed Volume is 1,727 to 6,793 (3,425) Regressed Duration is 2 to 9 (4)	Qp: 3,806 cfs with Average Frequency 1 per season Regressed Volume is 11,698 to 30,247 (18,811) Regressed Duration is 2 to 10 (5)
High Flow Pulses	Qp: 2,070 cfs with Average Frequency 2 per season Regressed Volume is 5,999 to 13,629 (9,042) Regressed Duration is 2 to 8 (4)	Qp: 3,882 cfs with Average Frequency 2 per season Regressed Volume is 11,325 to 26,382 (17,285) Regressed Duration is 2 to 8 (4)	Qp: 198 cfs with Average Frequency 2 per season Regressed Volume is 515 to 2,031 (1,023) Regressed Duration is 1 to 7 (3)	Qp: 1,867 cfs with Average Frequency 2 per season Regressed Volume is 5,435 to 14,038 (8,734) Regressed Duration is 2 to 8 (4)
Base Flows (cfs)	69 (40.7%)	68 (42.0%)	84 (41.0%)	75 (41.8%)
Base Flows (cfs)	32 (56.4%)	37 (58.7%)	47 (57.0%)	37 (57.9%)
Base Flows (cfs)	14 (72.4%)	18 (75.5%)	24 (73.2%)	17 (74.3%)
Subsistence Flows (cfs)	0.85 (95.0%)	2.8 (95.0%)	1.2 (95.0%)	2.2 (95.1%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:

1. Period of Record used : 1/1/1940 to 12/31/2009.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 1.8 cfs.

Recommended Environmental Flow Regime

Navidad River at Strane Park near Edna, USGS Gage 08164390, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1996-2010	0 periods Max duration: 0 days	0 periods Max duration: 0 days	3 periods Max duration: 11 days	2 periods Max duration: 3 days
Subsistence	4 cfs	4 cfs	4 cfs	4 cfs
Base Low	14 cfs	18 cfs	24 cfs	17 cfs
Base Medium	35 cfs	35 cfs	47 cfs	35 cfs
Base High	71 cfs	71 cfs	84 cfs	71 cfs
2 Pulses per season	Trigger: 2,000 cfs Volume: 9,000 af Duration: 8 days	Trigger: 3,900 cfs Volume: 17,300 af Duration: 8 days	Trigger: 200 cfs Volume: 1,000 af Duration: 7 days	Trigger: 2,000 cfs Volume: 8,700 af Duration: 8 days
1 Pulse per season	Trigger: 3,800 cfs Volume: 17,000 af Duration: 9 days	Trigger: 4,900 cfs Volume: 22,100 af Duration: 8 days	Trigger: 610 cfs Volume: 3,400 af Duration: 9 days	Trigger: 3,800 cfs Volume: 18,800 af Duration: 10 days
1 Pulse per year (Overbank)	Trigger: 7,100 cfs Volume: 34,400 af Duration: 10 days			
1 Pulse per 2 years (Overbank)	Trigger: 10,200 cfs Volume: 50,000 af Duration: 11 days			
1 Pulse per 5 years (Overbank)	Trigger: 15,500 cfs Volume: 77,600 af Duration: 12 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second
af = acre-feet

2.4.3 Sandy Creek near Ganado — USGS Gage 08164450

Upstream, Sandy Creek near Ganado (left), Upstream, Sandy Creek near Ganado (right) (photos by Cathy Wakefield, July 9, 2010)

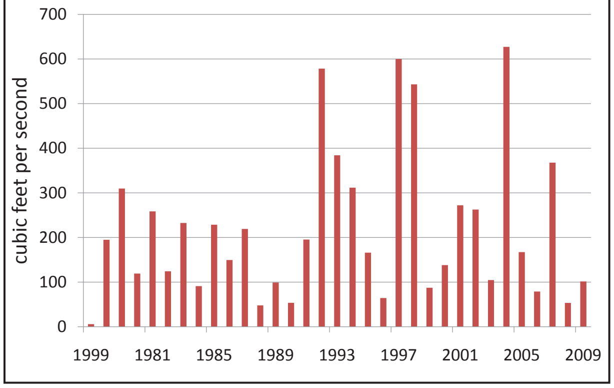
General Area Description (USGS 2009)

- Located in Jackson County; On the left bank at downstream end of bridge on Farm Road 710, 0.9 miles upstream from Goldenrod Creek, and 8.0 miles north of Ganado
- Sandy bottom, shallow area, with towering hardwoods
- Small islands abound; Cold deciduous forest including species such as live oak, cedar elm, and sugar hackberry; Stand of live oak appears northwest of the site, (personal communication, Duane German TPWD).
- Northern Humid Gulf Coastal Prairies, Western Gulf Coastal Plain
- Much low flow during irrigation season (April to September), is drainage from rice fields irrigated by water originally diverted from the Colorado River; No known regulation or diversions; No flow at times
- Wooded area, live oak and hardwood forest

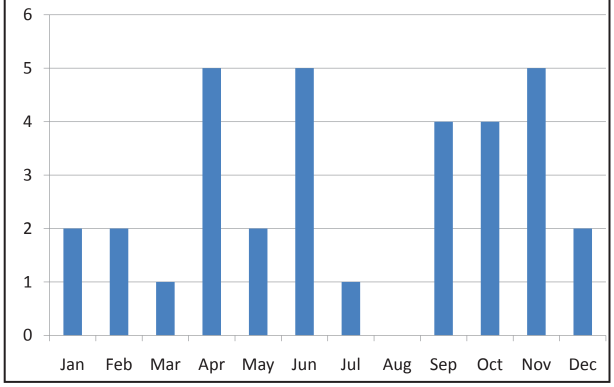
USGS Gage 08164450 Description

Jackson County, Texas	Hydrologic Unit Code: 12100102	Latitude: +29° 06’ 36” Longitude: -96° 32’ 46” NADV 27
Drainage area: 289 square miles	Contributing drainage area: 289 square miles	
Datum of gage: 59.72 ft above sea level NGVD29	Flood stage occurs at gage heights greater than 18 ft above USGS gage datum (NOAA 2010).	

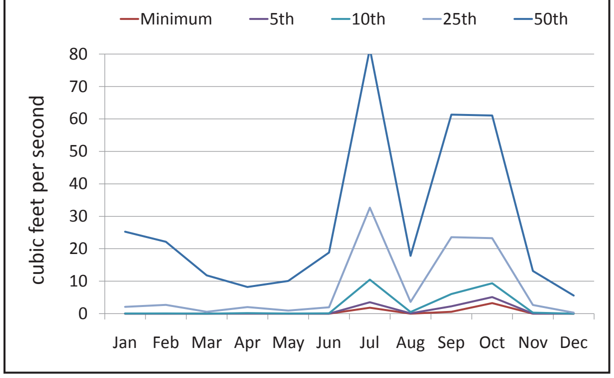
Summary of Historical USGS Flow Records at Sandy Creek



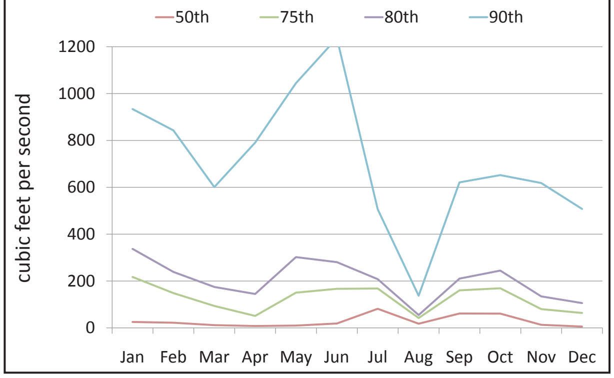
Sandy Creek daily average flow for each year from 1999 through 2009.



Sandy Creek number of peak flows in each month from 1978 through 2010.



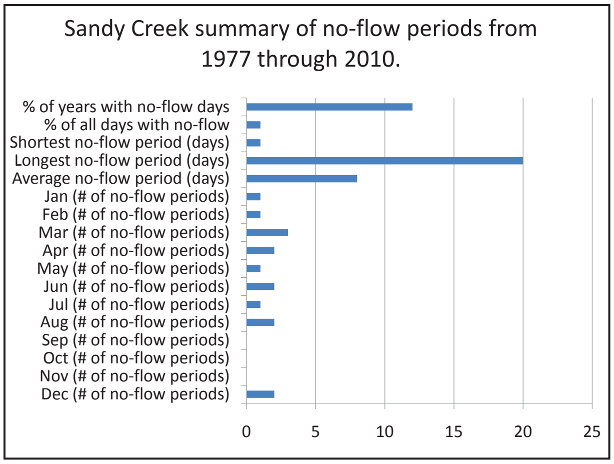
Sandy Creek low flow percentiles from 1978 through 2010.

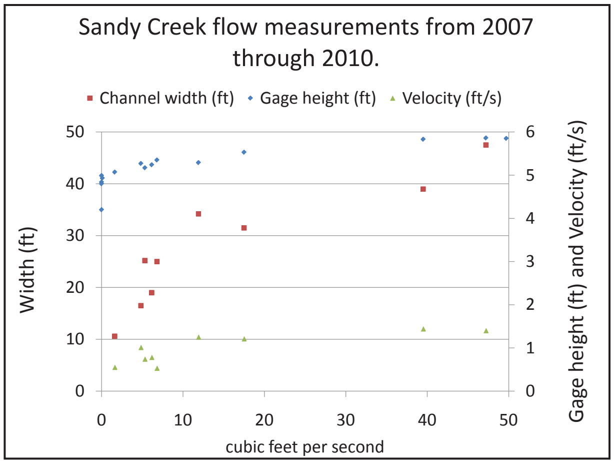


Sandy Creek high flow percentiles from 1978 to 2010.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	2,430	3,091	2,364	2,590	3,510	3,694	1,923	552	3,170	4,531	5,744	1,758	2,946.4
Average	245	240	175	195	285	313	192	50	243	323	285	139	223.8
Minimum	0.0	0.0	0.0	0.0	0.0	0.0	2	0.0	1	3	0.0	0.0	0.5
5th	0.0	0.0	0.0	0.0	0.0	0.0	4	0.1	2	5	0.0	0.0	0.9
10th	0.0	0.1	0.0	0.2	0.0	0.1	10	1	6	9	0.3	0.0	2.3
20th	1	1	0.2	1	0	1	26	2	17	18	1	0.1	5.9
25th	2	3	1	2	1	2	33	4	24	23	3	0.3	8.0
50th	25	22	12	8	10	19	82	18	61	61	13	6	28.1
75th	218	148	94	51	151	167	168	42	160	169	80	64	126.0
80th	337	239	175	145	302	281	208	55	210	245	134	106	203.1
90th	934	843	601	791	1,045	1,237	506	137	621	652	618	508	707.8
95th	1,760	2,019	1,459	1,734	2,374	2,724	1,260	345	1,959	3,103	2,715	1,270	1,893.3

Sandy Creek flow percentiles in cubic feet per second





Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases, two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5th, 25th, 50th, 75th, 80th, and 90th percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured.

Historical Hydrology

Sandy Creek is about 55 miles long with a slope of 5.97 ft/mile. The 2-year, 24-hour rainfall from 1980-1995 was 4.60 inches and the annual average rainfall was 41.0 inches (Asquith, 1998). LNRA (2002) characterized Sandy Creek as an intermittent creek draining large portion of the Navidad basin.

Site Description

- Review of aerial photography with Google Earth
  - A reach of ½ mile, above and below gage site was viewed
  - Woody riparian vegetation obscured aerial observations of physical stream characteristics
  - Flow dates
    - January 26, 1996: 1.2 cfs
    - October 21, 2005: 65 cfs
    - October 30, 2008: 6.9 cfs
    - January 30, 2009: 0 cfs
- Field Observations
  - Banks appear to be sandy; creek is shallow
  - Shallow runs and sandy riffles numerous with numerous islands

Soil Types

Soil type is alfisols, 35% saturation.

Soil	Setting	Slope	Wetland Potential	Flood Frequency
Navidad fine sandy loam	Flood plains	0-1%	Frequent	More than 50 time per 100 years
Milby sand	Terraces	0-2%	Moderately well drained	-
Kuy sand	Terraces	1-5%	Moderately well drained	-
Marcado sandy clay loam	Flats	3-8%	Well drained	-

Wetlands (USFWS 2010)

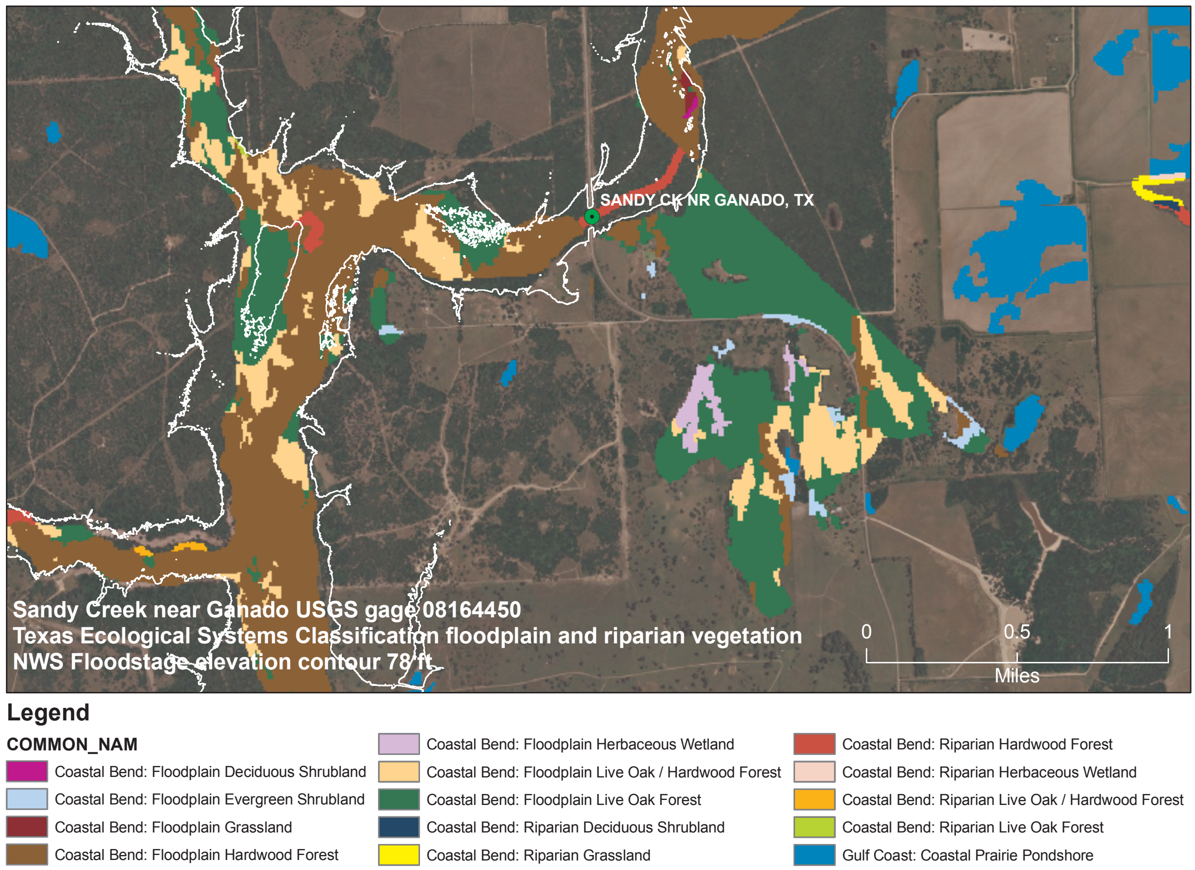
- Northeast and west sides of the site are classified as forested broad-leaved deciduous, temporarily flooded, wetlands.
- South of the site is a forested broad-leaved, seasonally flooded, wetland.

Riparian/Floodplain Vegetation

- Coastal Bend Riparian Hardwood Forest
  - Canopy dominated by sugar hackberry, cedar elm, pecan, black willow, honey mesquite, and plateau live oak; Presence of black willow, a tree that requires nearly continuous wet conditions, indicates that the area stays moist most of the year
- Coastal Bend Floodplain Grassland
  - Managed pastureland dominated by bermudagrass, King Ranch bluestem and bahiagrass
- Coastal Bend Floodplain Live Oak /Hardwood Forest
  - Community dominated by broadleaf evergreen species, plateau live oak, and anacua; also pecan, coastal live oak, some red cedar, pecan, green ash, sugar hackberry, American sycamore, vines such as Virginia creeper, and herbaceous species such as Cherokee sedge, eastern gamagrass, ragweed, switchgrass, bermudagrass and Johnsongrass. Presence of

American sycamore indicates area stays saturated for 2-4 months of the year

- Coastal Bend Floodplain Live Oak Forest
  - Dominated by plateau live oak; This area occupies terraces and margins of large creeks and rivers in central Texas, and is less saturated and slightly elevated.
- Gulf Coast Coastal Prairie Pond Shore



Sources: Texas Ecological System Classification project, TPWD 2010 www.tpwd.state.tx.us/landwater/land/maps/gis/tescp/index.phtml, Floodstage elevation from NWS Advanced Prediction Service
Elevation contour: Derived from LiDAR per FEMA specifications (TNRIS Jan. 2011) Vertical positional accuracy: USGS floodstage provided in NGVD29, LiDAR native datum is NAVD88 with resolution +-18 cm. Calculated difference for the study area is apx. 12cm which is within the resolution window for the LiDAR data. Horizontal datum: NAD83.
Contact: Lynne Hamlin, Water Resources Branch, TPWD lhamlin@tpwd.state.tx.us Map created Jan. 2011
Disclaimer: While every attempt was made to present the information as accurately as possible, no claims are made to the completeness or accuracy of the information shown herein nor to its suitability for a particular use.
Scale and location are approximate.

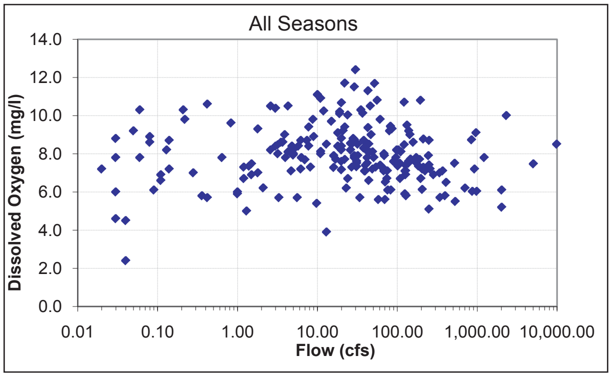
Texas Ecological Systems Classification of Riparian and Floodplain Vegetation for Sandy Creek near Ganado. The white line represents the calculated NWS flood stage elevation.

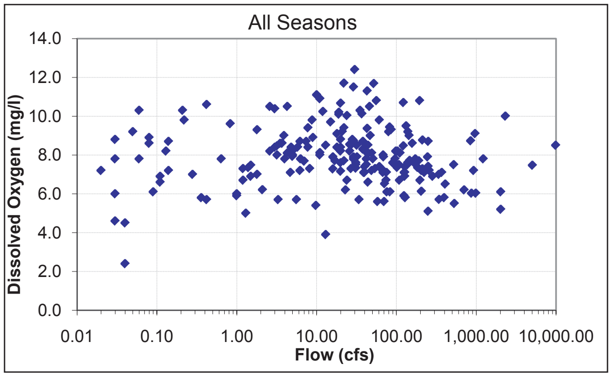
Biology

Source	Location	Biology	Observations
LNRA Lavaca Basin Summary Report 2007	Sandy Creek	Aquatic Life Use rating is high, (H)	Perennial stream, unclassified
TPWD 2009. (1972-2006) Fish Kills in the Lavaca – Navidad River Basin	Sandy Creek, Hardy Sandy Creek	1974 1984	Oil waste disposal, inorganics, drilling mud
TPWD 1973	Sandy Creek	20 species of fish collected and 11 species of benthic invertebrates	

Water Quality

- The water quality period of record for this gage is 11/18/1981 - 10/20/2009
- Relationships between flow and water quality parameters
  - Specific conductance decreases with increasing flow.
  - pH increases with increasing flow.
- According to the Texas Water Quality Inventory, this gaging station is located in the Water Quality Segment 1604C, Sandy Creek (unclassified water body). The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
  - The segment of river where this gage site is located is not listed on the 303(d) list.
- Relationship between temperature and flow
  - No correlation was observed between water temperature and flow.
  - The highest temperature was 34 °C (flow: 1.3 cfs; dissolved oxygen: 5 mg/L).
  - The lowest temperature was 6.5 °C (flow: 22 cfs; dissolved oxygen: 11.7 mg/L).
  - The lowest flow was 0 cfs (temperature: 14.1-30.5 °C; dissolved oxygen: 6.8-11.7 mg/L).
  - The highest flow was 9,840 cfs (temperature: 16 °C; dissolved oxygen: 8.5 mg/L).
- Relationship between dissolved oxygen and flow
  - No correlation was observed between dissolved oxygen and flow.
  - The highest dissolved oxygen was 12.4 mg/L (flow: 30 cfs; temperature: 9 °C).
  - The lowest dissolved oxygen was 2.4 mg/L (flow of 0.04 cfs; temperature: N/A).
  - The lowest flow was 0 cfs (temperature: 14.1-0.5 °C; dissolved oxygen: 6.8-11.7 mg/L).
  - The highest flow was 9,840 cfs (temperature: 16 °C; dissolved oxygen: 8.5 mg/L).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - There are no site-specific numeric criteria for this segment.
  - The maximum chloride measurement was 180 mg/L, although there was one apparent outlier of 2,230 mg/L measured.
  - The minimum and maximum observed pH values measured were 6.15 and 8.90.
  - The highest observed instantaneous temperature was 34 °C.
  - The minimum observed dissolved oxygen concentration was 2.4 mg/L. Only four out of 216 measurements were below 5 mg/L.





Geomorphology

Geomorphic analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77 to 93 percent of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows.

HEFR/Hydrological Analysis

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 8,310 cfs with Average Frequency 1 per 5 years Regressed Volume is 33,572 to 83,270 (52,873) Regressed Duration is 5 to 17 (9)			
High Flow Pulses	Qp: 5,760 cfs with Average Frequency 1 per 2 years Regressed Volume is 22,482 to 55,739 (35,400) Regressed Duration is 5 to 15 (8)			
	Qp: 4,450 cfs with Average Frequency 1 per year Regressed Volume is 16,952 to 42,019 (26,689) Regressed Duration is 4 to 14 (8)			
	Qp: 1,760 cfs with Average Frequency 1 per season Regressed Volume is 7,155 to 14,010 (10,012) Regressed Duration is 4 to 10 (7)	Qp: 3,129 cfs with Average Frequency 1 per season Regressed Volume is 11,946 to 26,529 (17,802) Regressed Duration is 4 to 11 (6)	Qp: 259 cfs with Average Frequency 1 per season Regressed Volume is 886 to 2,929 (1,611) Regressed Duration is 2 to 9 (5)	Qp: 1,742 cfs with Average Frequency 1 per season Regressed Volume is 5,773 to 14,570 (9,171) Regressed Duration is 3 to 10 (5)
	Qp: 800 cfs with Average Frequency 2 per season Regressed Volume is 2,827 to 5,530 (3,954) Regressed Duration is 3 to 7 (5)	Qp: 1,420 cfs with Average Frequency 2 per season Regressed Volume is 4,898 to 10,867 (7,296) Regressed Duration is 3 to 9 (5)	Qp: 91 cfs with Average Frequency 2 per season Regressed Volume is 276 to 915 (502) Regressed Duration is 2 to 6 (3)	Qp: 628 cfs with Average Frequency 2 per season Regressed Volume is 1,929 to 4,863 (3,063) Regressed Duration is 2 to 8 (4)
Base Flows (cfs)	31(40.3%)	29(40.9%)	36(42.2%)	41(42.7%)
	14(55.6%)	14(56.7%)	21(59.4%)	20(59.8%)
	4.9(71.0%)	5.4(72.6%)	9.5(76.4%)	7.9(76.9%)
Subsistence Flows (cfs)	0(100.0%)	0.01(95.4%)	0.2(95.0%)	0.27(95.1%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:
1. Period of Record used : 1/1/1940 to 12/31/2009.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 0.03 cfs.

Recommended Environmental Flow Regime

Sandy Creek near Ganado, USGS Gage 08164450, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1977-2010	4 periods Max duration: 9 days	8 periods Max duration: 20 days	3 periods Max duration: 11 days	0 periods Max duration: 0 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	5 cfs	5 cfs	9 cfs	9 cfs
Base Medium	14 cfs	14 cfs	21 cfs	21 cfs
Base High	30 cfs	30 cfs	39 cfs	39 cfs
2 Pulses per season	Trigger: 800 cfs Volume: 4,000 af Duration: 7 days	Trigger: 1,400 cfs Volume: 7,300 af Duration: 9 days	Trigger: 91 cfs Volume: 500 af Duration: 6 days	Trigger: 630 cfs Volume: 3,100 af Duration: 8 days
1 Pulse per season	Trigger: 1,800 cfs Volume: 10,000 af Duration: 10 days	Trigger: 3,100 cfs Volume: 17,800 af Duration: 11 days	Trigger: 260 cfs Volume: 1,600 af Duration: 9 days	Trigger: 1,800 cfs Volume: 9,200 af Duration: 10 days
1 Pulse per year	Trigger: 4,500 cfs Volume: 26,700 af Duration: 14 days			
1 Pulse per 2 years	Trigger: 5,800 cfs Volume: 35,400 af Duration: 15 days			
1 Pulse per 5 years (Overbank)	Trigger: 8,300 cfs Volume: 52,900 af Duration: 17 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second
af = acre-feet

2.4.4 East Mustang Creek near Louise USGS gage 08164504


Upstream, East Mustang Creek near Louise (left), Downstream, East Mustang Creek near Louise (right) (photos by Cathy Wakefield, July 9, 2010)

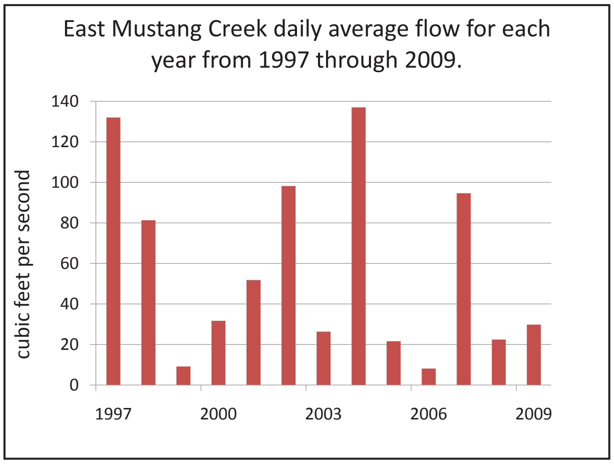
General Area Description (USGS 2009)

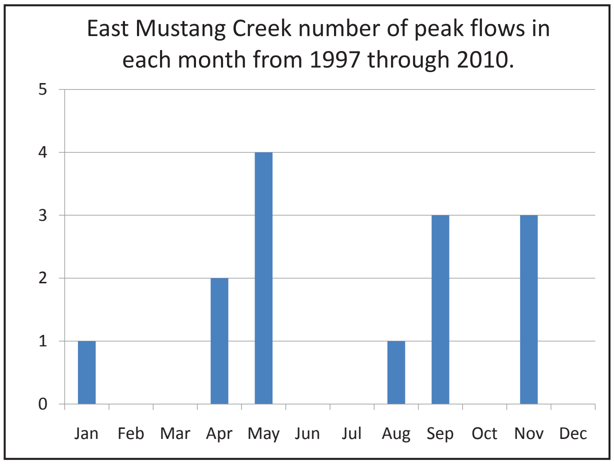
- Located in Wharton County; On the right bank, 50 feet downstream from right end of bridge on Farm Road 647, and 2.7 miles south of Louise
- Much low flow during irrigation season, (April – September); drainage from rice fields irrigated by water originally diverted from the Colorado River
- Surrounding area is not floodplain; native invasive community to the north, farmland surrounding creek; deciduous forest and savannah, some live oak, bahiagrass, evergreen shrub, invasive prairie
- Northern Humid Gulf Coastal Plain, Western Gulf Coastal Plain, (EPA Level III ecoregion).
- Wastewater from Louise flows into East Mustang

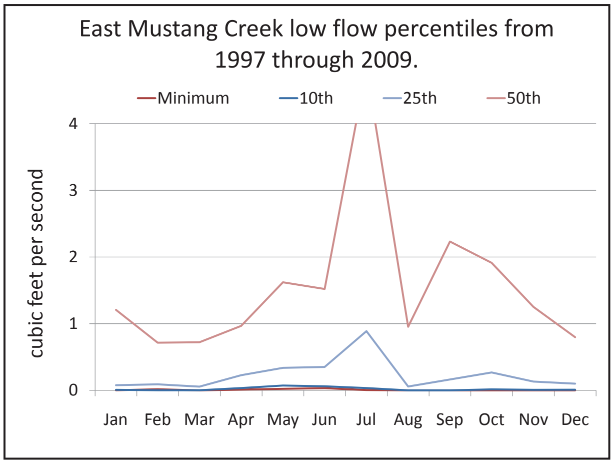
USGS Gage 08164504 Description

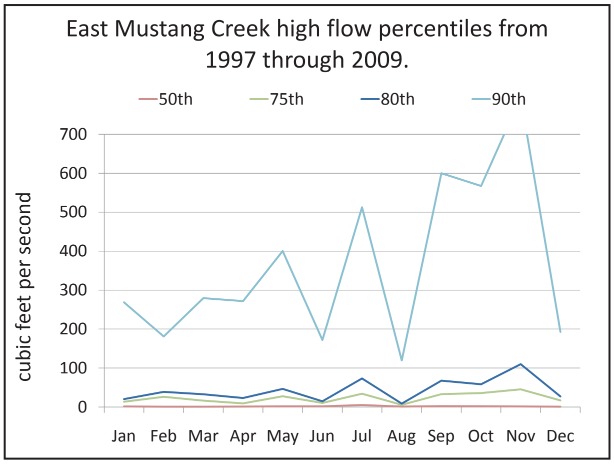
Wharton County, Texas	Hydrologic Unit Code: 12100102	Latitude: 29° 04’ 14” Longitude: 96° 25’ 01” NAD27
Drainage Area: 53.9 square miles	Contributing drainage area: 53.9 square miles	
Datum of gage: 43 feet above sea level NGVD29	Flood stage occurs at gage heights greater than 19 ft above the USGS gage datum	

Summary of Historical USGS Flow Records at East Mustang Creek



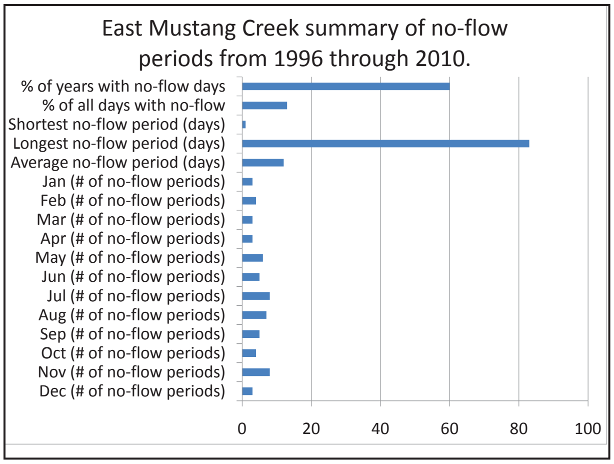


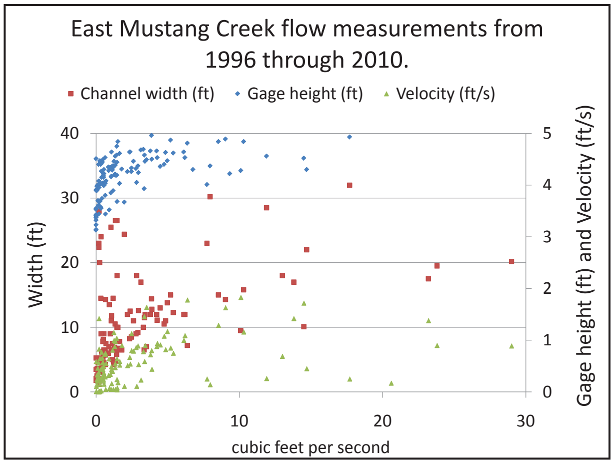




	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	477	256	490	476	619	305	741	206	951	892	1,378	304	591
Average	41	30	44	41	63	27	82	18	94	89	124	31	57
Minimum	0	0	0	0	0	0	0	0	0	0	0	0	0
5th	No data												
10th	0	0	0	0	0.1	0.1	0	0	0	0	0	0	0
20th	0.1	0	0	0.1	0.2	0.2	0.2	0	0	0.1	0.1	0.1	0
25th	0.1	0.1	0.1	0.2	0.3	0.4	0.9	0.1	0.2	0.3	0.1	0.1	0.2
50th	1	1	1	1	2	2	5	1	2	2	1	1	2
75th	14	26	16	9	27	10	34	6	33	36	45	17	23
80th	20	39	33	23	46	14	73	9	68	58	110	27	43
90th	269	181	279	272	400	172	512	119	600	567	795	193	363

East Mustang Creek Streamflow percentiles in cubic feet per second





Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases, two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5th, 25th, 50th, 75th, 80th, and 90th percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured

Historical Hydrology

Dominant habitat type is glide with some riffles and pools. The substrate is primarily clay with sand (LNRA 1998). The stream is considered intermittent with perennial pools (LNRA 2007).

Site Description

- Review of aerial photography with Google Earth
  - A reach of ½ mile, above and below gage site
  - Riparian vegetation obscured a view of physical characteristics
  - Flow on aerial photography dates
    - October 1, 1996: 2.8 cfs
    - October 30, 2008: 0.39 cfs
    - January 1, 2009: 0.07 cfs
- Field Observations:
  - Herbaceous vegetation flanked both banks upstream and downstream
  - Several islands present upstream, within ½ mile of gage
  - Channel appears to have been channelized with riparian vegetation cleared for much of the creek. The downstream-most 2 miles of the creek are in a dense riparian forest that obscures the creek.

Soil Types

The main soil type is alfisols, although southeast of the gage occur finger like projections of mollisols. Alfisols have a base saturation of 35% and a fine texture. Mollisols have a dark colored surface and a rich base. Many have an argillic, natric, or calcic horizon. Both of these soil types are clay over loam.

Soil	Setting	Slope	Wetland Potential	Flooding Frequency
Edna fine sandy loam	Flats	0-1%	Somewhat poorly drained, no ponding	None
Marcado sandy clay loam	Flats	3-8%	Well drained, no ponding	None

Wetlands (USFWS 2010)

There are no significant wetlands adjacent to the creek which interact with the creek's flow regime.

Riparian/Floodplain Vegetation (German, et al. 2010)

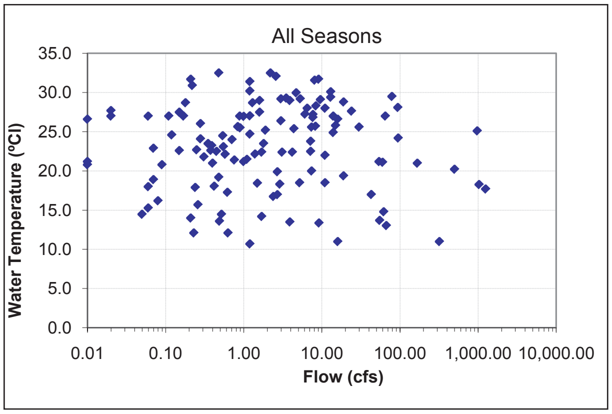
- Not considered to be in a floodplain, (personal comm., Duane German, TPWD).
- Coastal Bend Riparian Hardwood Forest
  - Canopy dominates the area, including sugar hackberry, cedar elm, pecan, black willow, honey mesquite, and huisache; Plateau live oak also present. Black willow is classified as a facultative wetland species that requires abundant and continuously moist soil during the growing season and can survive more than 30 days of inundation. It does not tolerate drought conditions.

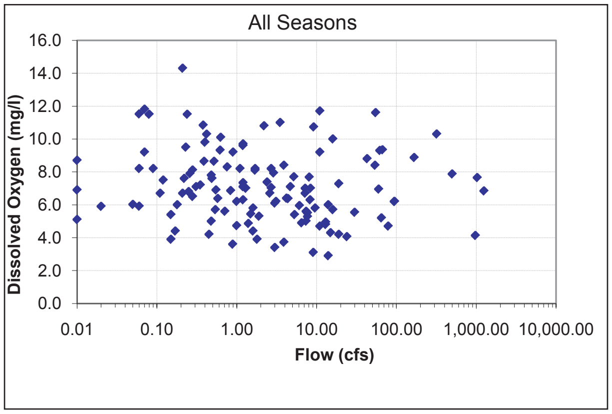
Biology

Source	Location	Biology	Observations
LNRA Basin Report 2007	East Mustang Creek	Intermediate aquatic life use	Flow is intermittent with pools
LNRA Receiving Water Assessment Report 1998	East Mustang Creek, near Louise	Mosquitofish, red shiner, bullhead minnow, longear sunfish most abundant in samples	Fish community composition supported an intermediate value for its Index of Biotic Integrity
TPWD Fish Kills 2009 (1995-2006)	East Mustang Creek	Over 16,000 fish, frogs, and aquatic invertebrates killed	Kill caused by an ammonia spill

Water Quality

- The water quality period of record for this gage is 01/06/1998 - 11/23/2009
- Relationships between flow and water quality parameters
  - Specific conductance decreases with increasing flow.
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in the Water Quality Segment 1604A, East Mustang Creek (unclassified water body, intermittent stream with perennial pools). The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated intermediate aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
  - The segment of river where this gage site is located is not listed on the 303(d) list.
- Relationship between temperature and flow
  - No correlation was observed between water temperature and flow.
  - The highest temperature was 32.5 °C (flow: 0.48 cfs; dissolved oxygen: 5.0 mg/L).
  - The lowest temperature was 10.7 °C (flow: 1.2 cfs; dissolved oxygen: 9.7 mg/L).
  - The lowest flow was 0 cfs (temperature: 12.0-30.1 °C; dissolved oxygen: 3.6-16.3 mg/L).
  - The highest flow was 1,250 cfs (temperature: 17.7 °C; dissolved oxygen: 6.84 mg/L).
- Relationship between dissolved oxygen and flow
  - No correlation was observed between dissolved oxygen and flow.
  - The highest dissolved oxygen was 16.3 mg/L (flow: 0 cfs; temperature: 12 °C).
  - The lowest dissolved oxygen was 2.9 mg/L (flow of 14 cfs; temperature: 27 °C).
  - The lowest flow was 0 cfs (temperature: 12.0-30.1 °C; dissolved oxygen: 3.6-16.3 mg/L).
  - The highest flow was 1,250 cfs (temperature: 17.7 °C; dissolved oxygen: 6.84 mg/L).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - Six instantaneous chloride measurements exceeded the TSWQS criterion of 100 mg/L.
  - The minimum and maximum observed pH values were within the TSWQS range of 6.5-9.0.
  - Temperatures were below the TSWQS of 35 °C.
  - Seven out of 140 instantaneous dissolved oxygen measurements were below the TSWQS criterion of 4.0 mg/L.





Geomorphology

Geomorphic analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77 to 93 percent of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows.

Flow Interpretations

No-flow periods: Periods of no flow have occurred. Change in the frequency and duration of no-flow periods from historical patterns is expected to affect the aquatic ecosystem. Increased frequency and duration of no-flow periods is not expected to beneficially affect ecosystem health.

Subsistence flows: Subsistence flows are expected to be low and to protect water quality for at least a limited period of time.

Base flows: The presence of some fish collected during a receiving water assessment and an intermediate aquatic life use designation suggest that perennial pools exist in the system and that base flows are generally relatively low.

Pulses and overbank flows: The lack of broad riparian and floodplain vegetation communities and soil types adjacent to the creek indicate flooding does not commonly occur at this site.

HEFR/Hydrological Analysis

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 2,150 cfs with Average Frequency 1 per 5 years Regressed Volume is 7,685 to 20,204 (12,461) Regressed Duration is 5 to 17 (9)			
Overbank Flows	Qp: 1,520 cfs with Average Frequency 1 per 2 years Regressed Volume is 5,294 to 13,912 (8,582) Regressed Duration is 4 to 16 (8)			
High Flow Pulses	Qp: 1,150 cfs with Average Frequency 1 per year Regressed Volume is 3,922 to 10,305 (6,357) Regressed Duration is 4 to 14 (8)			
High Flow Pulses	Qp: 340 cfs with Average Frequency 1 per season Regressed Volume is 1,176 to 2,448 (1,696) Regressed Duration is 4 to 10 (6)	Qp: 553 cfs with Average Frequency 1 per season Regressed Volume is 2,001 to 4,568 (3,023) Regressed Duration is 4 to 11 (7)	Qp: 60 cfs with Average Frequency 1 per season Regressed Volume is 153 to 623 (308) Regressed Duration is 2 to 9 (4)	Qp: 427 cfs with Average Frequency 1 per season Regressed Volume is 1,298 to 3,398 (2,100) Regressed Duration is 3 to 10 (5)
High Flow Pulses	Qp: 150 cfs with Average Frequency 2 per season Regressed Volume is 475 to 988 (685) Regressed Duration is 3 to 7 (4)	Qp: 281 cfs with Average Frequency 2 per season Regressed Volume is 931 to 2,122 (1,405) Regressed Duration is 3 to 9 (5)	Qp: 20 cfs with Average Frequency 2 per season Regressed Volume is 50 to 203 (100) Regressed Duration is 1 to 7 (3)	Qp: 139 cfs with Average Frequency 2 per season Regressed Volume is 405 to 1,059 (655) Regressed Duration is 2 to 8 (4)
Base Flows (cfs) – High	4.8(40.4%)	5.8(41.8%)	8.1(41.8%)	6.7(42.3%)
Base Flows (cfs) – Medium	2.1(55.9%)	2.9(58.5%)	4.6(58.5%)	3(58.6%)
Base Flows (cfs) – Low	0.81(71.4%)	1.2(75.1%)	2.4(75.1%)	1.3(74.6%)
Subsistence Flows (cfs)	0.02(95.2%)	0.11(95.0%)	0.08(95.1%)	0.03(95.1%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:

1. Period of Record used : 1/1/1940 to 12/31/2008.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 0.05 cfs.

Recommended Environmental Flow Regime

East Mustang Creek near Louise, USGS Gage 08164504, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1996-2010	10 periods Max duration: 83 days	17 periods Max duration: 20 days	14 periods Max duration: 53 days	17 periods Max duration: 42 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	1 cfs	1 cfs	2 cfs	1 cfs
Base Medium	2 cfs	3 cfs	5 cfs	3 cfs
Base High	6 cfs	6 cfs	8 cfs	8 cfs
2 Pulses per season	Trigger: 150 cfs Volume: 680 af Duration: 7 days	Trigger: 280 cfs Volume: 1,400 af Duration: 9 days	Trigger: 20 cfs Volume: 100 af Duration: 7 days	Trigger: 150 cfs Volume: 650 af Duration: 8 days
1 Pulse per season	Trigger: 340 cfs Volume: 1,700 af Duration: 10 days	Trigger: 550 cfs Volume: 3,000 af Duration: 11 days	Trigger: 60 cfs Volume: 310 af Duration: 9 days	Trigger: 430 cfs Volume: 2,100 af Duration: 10 days
1 Pulse per year	Trigger: 1,200 cfs Volume: 6,400 af Duration: 14 days			
1 Pulse per 2 years (Overbank)	Trigger: 1,500 cfs Volume: 8,600 af Duration: 16 days			
1 Pulse per 5 years (Overbank)	Trigger: 2,200 cfs Volume: 12,500 af Duration: 17 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology and sound ecological environment. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second
af = acre-feet

2.4.5 West Mustang Creek near Ganado

USGS Gage 08164503

Upstream, West Mustang Creek near Ganado (left), Downstream, West Mustang Creek near Ganado (right) (photos by Cathy Wakefield, July 9, 2010)

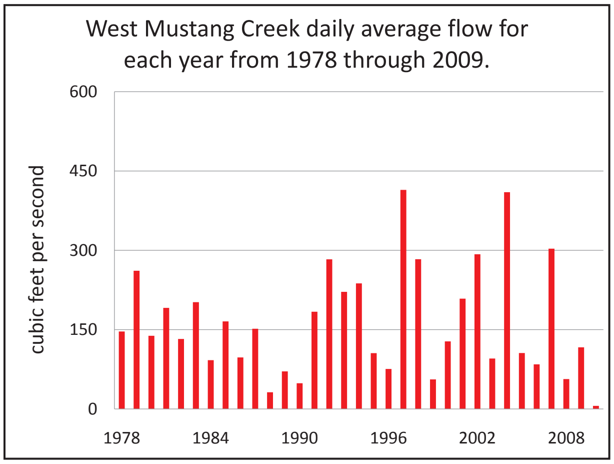
General Area Description

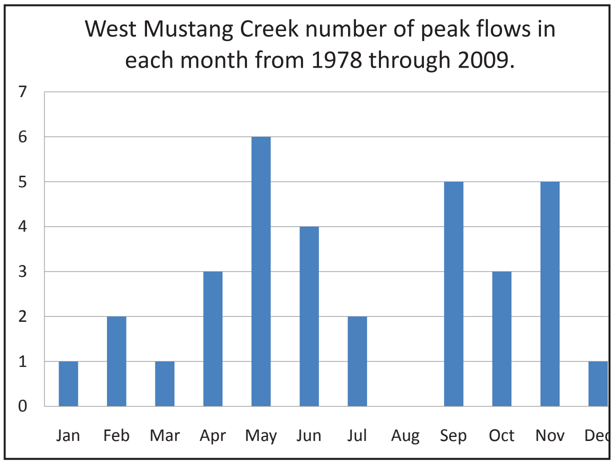
- Located in Jackson County on the right bank at upstream end of southbound U.S. Highway 59 bridge, 2 miles upstream from Middle Mustang Creek, and 3.6 miles east of Ganado
- Much low flow during the irrigation season, (April to September), is drainage from rice fields irrigated by water originally diverted from the Colorado River; No known regulation or diversions; No flow at times
- Northern Humid Gulf Coastal Plain, Western Gulf Coastal Plain, (EPA Level III ecoregion).
- Deciduous woodland species include pecan, cedar elm, sugar hackberry, American elm, green ash, and non-native grass, bermudagrass and Johnsongrass; Some floodplain hardwood forest, (see above species), and Riparian Live Oak Forest exist; Species in live oak forest may include plateau or coastal live oak, and some eastern red cedar.

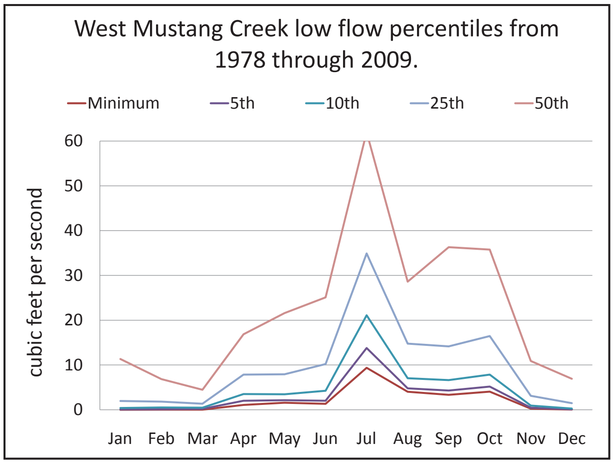
USGS Gage 08164503 Description

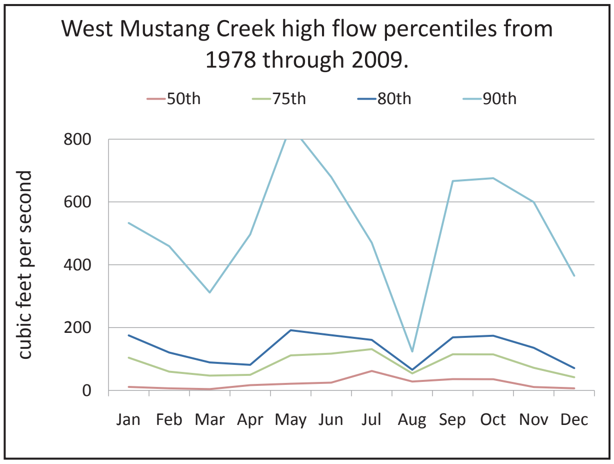
Jackson County, Texas	Hydrologic Unit Code: 12100102	Latitude: 29° 04’ 17” Longitude: 96° 28’ 01” NAD27
Drainage area: 178 square miles	Contributing drainage area: 178 square miles	
Flood stage elevation is 20 ft above the USGS gage datum (NOAA 2010)		

Summary of Historical USGS Flow Records at West Mustang Creek



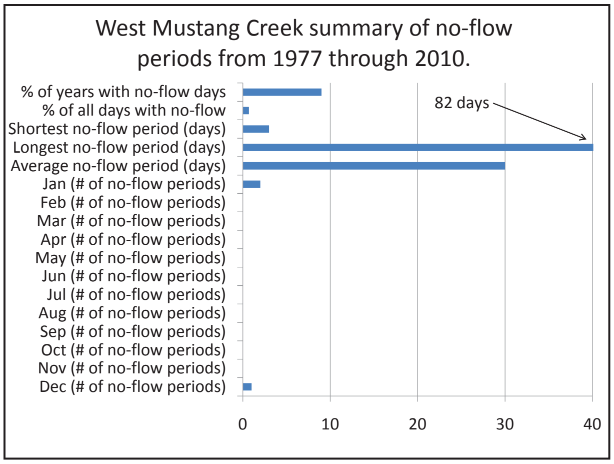


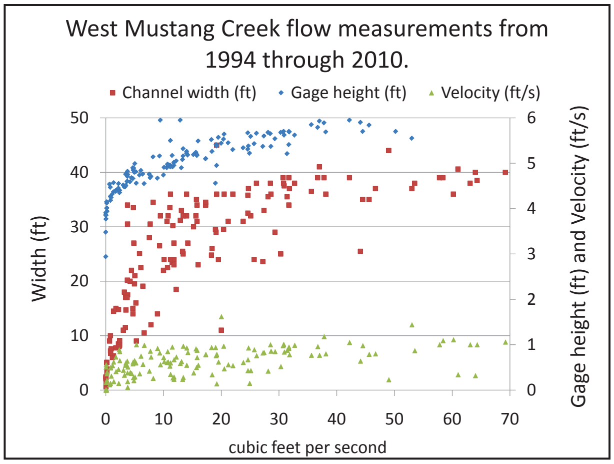




	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	2,250	1,927	1,686	2,108	2,274	1,879	2,271	518	3,441	3,725	4,221	1,489	2,316
Average	167	135	106	148	210	176	187	56	235	252	232	107	168
Minimum	0	0	0	1	2	1	9	4	3	4	0.2	0	2
5th	0.1	0.1	0.2	2	2	2	14	5	4	5	0.5	0.1	3
10th	0.4	1	0.5	4	3	4	21	7	7	8	1	0.3	5
20th	1	1	1	6	6	8	31	12	11	14	2	1	8
25th	2	2	1	8	8	10	35	15	14	16	3	1	10
50th	11	7	4	17	22	25	62	29	36	36	11	7	22
75th	104	60	47	50	112	117	132	54	115	115	72	42	85
80th	175	121	89	82	192	176	161	66	169	174	136	71	134
90th	533	459	312	497	843	679	470	124	667	676	599	365	519
95th	1,397	1,200	924	1,348	1,715	1,373	1,370	323	2,032	2,308	2,161	983	1,428

West Mustang Creek flow percentiles in cubic feet per second





Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases, two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5th, 25th, 50th, 75th, 80th, and 90th percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured

Historical Hydrology

Creek has a sandy bottom with long pools with occasional riffles, runs, and pools (TPWD, 2002). Instream habitat consists of woody debris, undercut banks, and root mats at a flow 0.2 cfs.

Site Description

- A review of aerial photography with Google Earth
  - A view of the reach of one mile, above and below gage site indicated that riparian vegetation, especially woody, obscured any observation of physical characteristics of the stream
  - Flow dates
    - January 23, 1996: 1.4 cfs
    - October 21, 2005: 36 cfs
    - April 11, 2007: 13 cfs
    - October 30, 2008: 2.5 cfs
    - January 30, 2009: 0 cfs

Soil Types

The major soil type described for this area is alfisols, however, beyond the flooded area is a wide margin of mollisols.

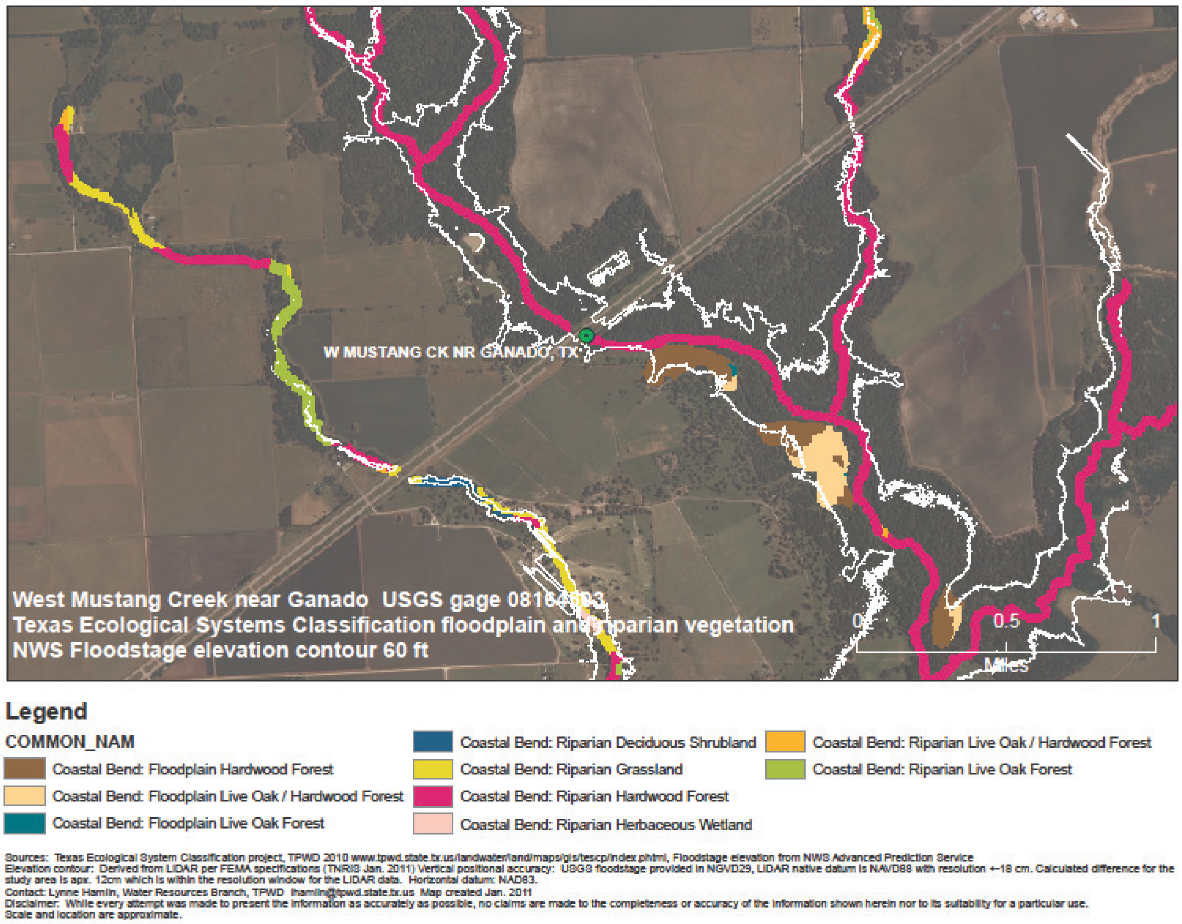
Soil	Setting	Slope	Wetland Potential	Flooding Frequency
Edna fine sandy loam	Flats	0-1%	Somewhat poorly drained, no ponding	None
Marcado sandy clay loam	Flats	3-8%	Well drained, no ponding	None

Wetlands

- To the NW of the gage, a forested semi-permanent flooded wetland exists. There is some FW emergent forested/shrubland.
- SW of the gage is a freshwater forested semi-permanently flooded cottonwood dominant forest

Riparian/Floodplain Vegetation (German, et al. 2009)

- Coastal Bend Floodplain Hardwood Forest
  - (Coastal Bend Native invasive deciduous woodland). Species include pecan, cedar elm, sugar hackberry, American elm, green ash, and non-native grass, Bermuda grass, Johnson grass.
- Coastal Bend Riparian Live Oak Forest
  - Plateau live oak, some eastern cedar, American sycamore; found along both banks of the river; facultative wet species in this community is American sycamore, which indicates area stays saturated for 2–4 months of the year



Texas Ecological Systems Classification of Riparian and Floodplain Vegetation for West Mustang Creek near Ganado. The white line represents the calculated NWS flood stage elevation.

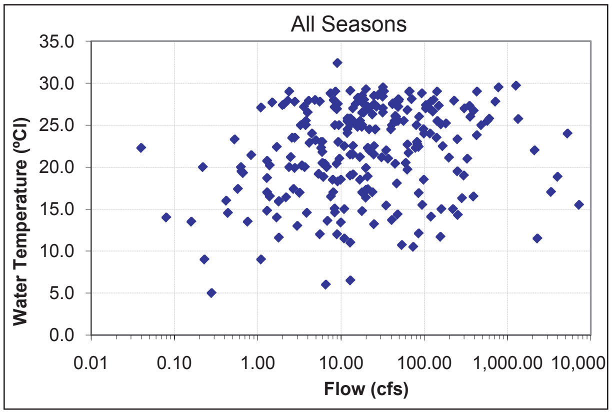
Biology

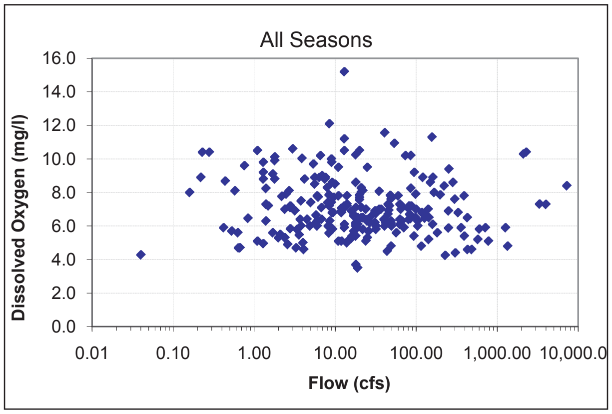
Source	Location	Biology	Observations
Higgins, C.L. 2005	Lavaca River basin, West Mustang Creek	Functional groupings of fish studied.	Egg-eaters, surface feeding fish were most abundant, followed by browsers and water-column particulate feeders
TPWD 2002	Western Gulf Coastal Plain, West Mustang	Western mosquitofish, red shiner, blacktail shiner, and bullhead minnow most abundant in samples 12 species of fish were collected.	Scoring criteria were developed to assess stream assemblages.
LNRA Lavaca Basin Summary Report 2007	West Mustang Creek	Aquatic life use was high	Flow is perennial
TPWD, fish kill report, 1978	Mustang creek near Louise	Fish kill	Industrial cause
TPWD 1997	Eval. of natural resources, Region P West Mustang Creek	Benthic macroinvertebrates	Ecologically unique stream segment, exceptional ALU

Water Quality

- The water quality period of record for this gage is 11/18/1981 - 11/23/2009
- Relationships between flow and water quality parameters
  - Specific conductance decreases with increasing flow.
  - Chloride decreases with increasing flow.
- According to the Texas Water Quality Inventory, this gaging station is located in the Water Quality Segment 1604B, West Mustang Creek (unclassified water body). The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports aquatic life use.
- Water quality impairments, if any, listed on the 303(d) list
  - The segment of river where this gage site is located is not listed on the 303(d) list.
- Relationship between temperature and flow:
  - No correlation was observed between water temperature and flow.
  - The highest temperature was 32.4 °C (flow: 9.1 cfs; dissolved oxygen: 9.8 mg/L).
  - The lowest temperature was 5 °C (flow: 0.28 cfs; dissolved oxygen: 10.4 mg/L).
  - The lowest flow was 0 cfs (temperature: 11.9-21.3 °C; dissolved oxygen: 6.4-14.6 mg/L).
  - The highest flow was 7,250 cfs (temperature: 15.5 °C; dissolved oxygen: 8.4 mg/L).
- Relationship between dissolved oxygen and flow
  - No correlation was observed between dissolved oxygen and flow.
  - The highest dissolved oxygen was 15.2 mg/L (flow: 13 cfs; temperature: 19 °C).
  - The lowest dissolved oxygen was 3.5 mg/L (flow of 19 cfs; temperature: 28 °C).

  - The lowest flow was 0 cfs (temperature: 11.9 °C - 21.3 °C; dissolved oxygen: 6.4 - 14.6 mg/L).
  - The highest flow was 7,250 cfs (temperature: 15.5 °C; dissolved oxygen: 8.4 mg/L).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - There are no site-specific numeric criteria for this segment.
  - The maximum observed chloride concentration was 200 mg/L.
  - The minimum and maximum observed pH values measured were 6.10 and 9.12.
  - The highest observed instantaneous temperature was 32.4 °C.
  - The minimum observed dissolved oxygen concentration was 3.5 mg/L. Seventeen of 246 dissolved oxygen measurements were less than 5 mg/L.





Geomorphology

Geomorphological analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77-93% of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows.

HEFR/Hydrological Analysis

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct, Nov)
High Flow Pulses	Qp: 6,650 cfs with Average Frequency 1 per 5 years Regressed Volume is 30,719 to 71,694 (46,930) Regressed Duration is 7 to 21 (12)			
High Flow Pulses	Qp: 4,720 cfs with Average Frequency 1 per 2 years Regressed Volume is 20,908 to 48,777 (31,935) Regressed Duration is 6 to 18 (11)			
High Flow Pulses	Qp: 2,800 cfs with Average Frequency 1 per year Regressed Volume is 11,635 to 27,129 (17,766) Regressed Duration is 5 to 15 (9)			
High Flow Pulses	Qp: 1,040 cfs with Average Frequency 1 per season Regressed Volume is 4,046 to 7,761 (5,604) Regressed Duration is 4 to 10 (6)	Qp: 1,529 cfs with Average Frequency 1 per season Regressed Volume is 6,802 to 13,072 (9,429) Regressed Duration is 5 to 11 (7)	Qp: 192 cfs with Average Frequency 1 per season Regressed Volume is 636 to 2,084 (1,151) Regressed Duration is 2 to 9 (4)	Qp: 1,300 cfs with Average Frequency 1 per season Regressed Volume is 4,595 to 11,102 (7,142) Regressed Duration is 3 to 11 (6)
High Flow Pulses	Qp: 493 cfs with Average Frequency 2 per season Regressed Volume is 1,705 to 3,268 (2,361) Regressed Duration is 3 to 7 (5)	Qp: 812 cfs with Average Frequency 2 per season Regressed Volume is 3,200 to 6,147 (4,435) Regressed Duration is 4 to 8 (6)	Qp: 75 cfs with Average Frequency 2 per season Regressed Volume is 229 to 753 (415) Regressed Duration is 2 to 6 (3)	Qp: 439 cfs with Average Frequency 2 per season Regressed Volume is 1,405 to 3,390 (2,182) Regressed Duration is 2 to 8 (4)
Base Flows (cfs) – High	19(39.8%)	21(42.0%)	32(42.4%)	26(42.5%)
Base Flows (cfs) – Medium	8.6(54.6%)	11(58.3%)	18(59.9%)	14(58.8%)
Base Flows (cfs) – Low	3.9(69.5%)	5.4(74.8%)	9.9(77.2%)	6.2(75.1%)
Subsistence Flows (cfs)	0.1(95.3%)	0.72(95.0%)	1.1(95.0%)	0.8(95.0%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:

1. Period of Record used : 1/1/1940 to 12/31/2009.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 0.53 cfs.

Recommended Environmental Flow Regime

West Mustang Creek near Ganado, USGS Gage 08164503, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1977-2010	3 periods Max duration: 82 days	0 periods Max duration: 0 days	0 periods Max duration: 0 days	0 periods Max duration: 0 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	4 cfs	5 cfs	10 cfs	6 cfs
Base Medium	9 cfs	11 cfs	18 cfs	14 cfs
Base High	20 cfs	20 cfs	32 cfs	26 cfs
2 Pulses per season	Trigger: 470 cfs Volume: 2,400 af Duration: 7 days	Trigger: 810 cfs Volume: 4,400 af Duration: 8 days	Trigger: 75 cfs Volume: 420 af Duration: 6 days	Trigger: 470 cfs Volume: 2,200 af Duration: 8 days
1 Pulse per season	Trigger: 1,000 cfs Volume: 5,600 af Duration: 10 days	Trigger: 1,500 cfs Volume: 9,400 af Duration: 11 days	Trigger: 190 cfs Volume: 1,200 af Duration: 9 days	Trigger: 1,300 cfs Volume: 7,100 af Duration: 11 days
1 Pulse per year	Trigger: 2,800 cfs Volume: 17,800 af Duration: 15 days			
1 Pulse per 2 years	Trigger: 4,700 cfs Volume: 31,900 af Duration: 18 days			
1 Pulse per 5 years	Trigger: 6,700 cfs Volume: 46,900 af Duration: 21 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second
af = acre-feet

2.5 Coastal Streams

2.5.1 Garcitas Creek near Inez — USGS Gage 08164600

Upstream Garcitas Creek near Inez (left), Downstream, Garcitas Creek near Inez (right) (photos by Cathy Wakefield, July 9, 2010)

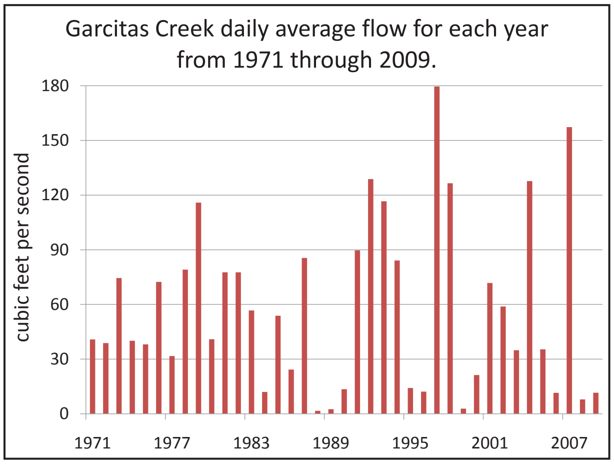
General Description of Area (USGS Water Data Report 2010)

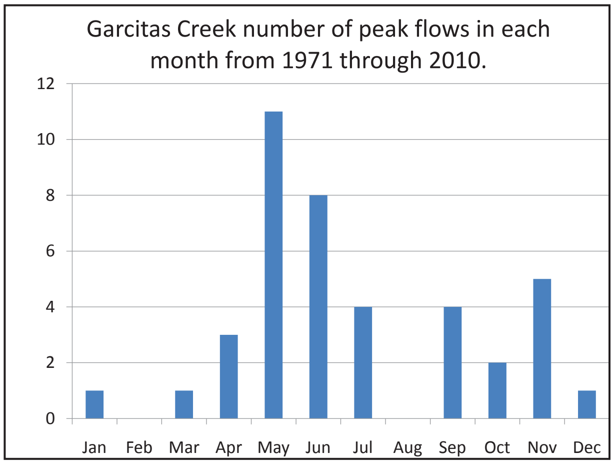
- Near Inez, located in Victoria County, Texas; Gage on the right, downstream end of bridge on Hwy 59 access road, 0.3 miles upstream from Southern Pacific Railroad bridge, 2.0 miles southwest of Inez, and 3.6 miles upstream from Casa Blanca Creek
- No known regulation or diversions; An undetermined amount of return water from irrigation enters the stream above the station
- No flow at times
- Geologic description: Northern Humid Coastal Prairies, Western Gulf Coastal Plain

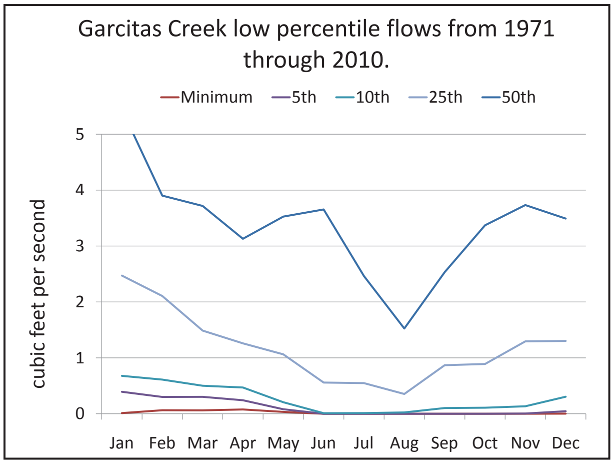
USGS Gage 08164600 Description

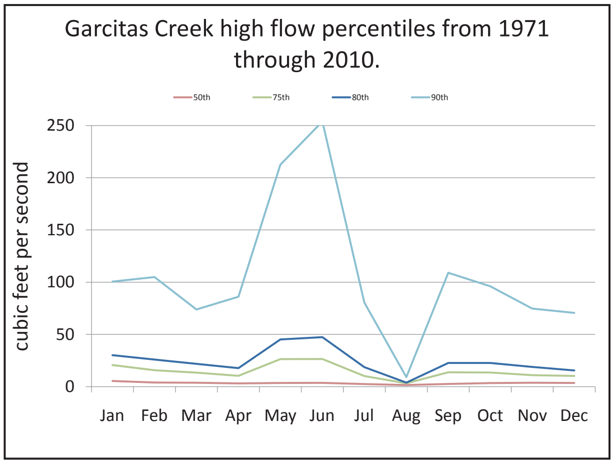
Victoria County, Texas	Hydrologic Unit: 12100402	Latitude: 28° 53’ 28” Longitude: 96° 49’ 08” NAD27
Drainage area: 91.7 square miles	Contributing drainage area: 91.7 square miles	
Flood stage elevation is 18 ft above the USGS gage datum		

Summary of Historical USGS Flow Records at Garcitas Creek



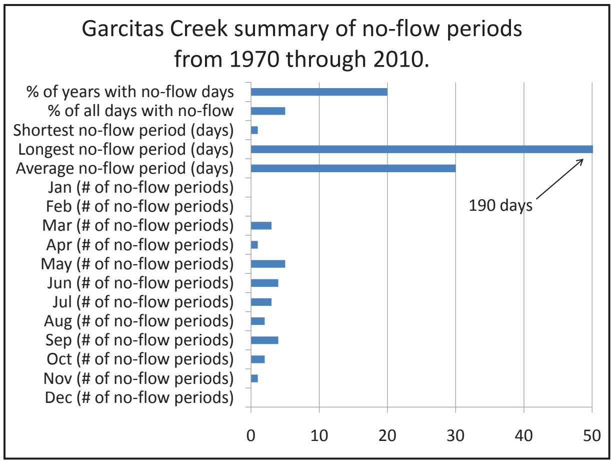


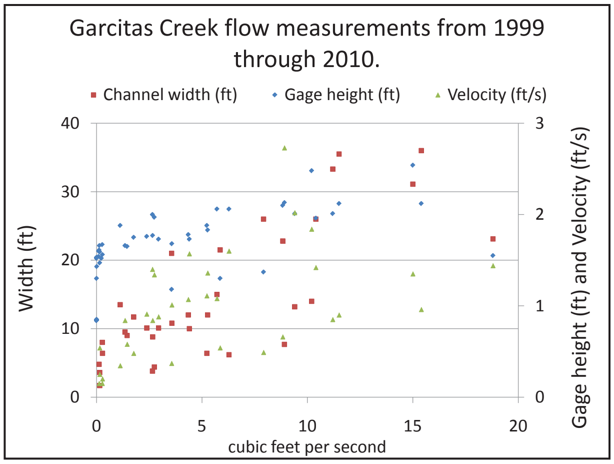




	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	762	856	898	1,687	2,109	1,759	1,533	227	1,889	1,410	1,629	754	1,293
Average	43	48	43	69	102	96	59	9	75	62	59	37	58
Minimum	0	0.1	0.1	0.1	0	0	0	0	0	0	0	0	0
5th	0.4	0.3	0.3	0.2	0.1	0	0	0	0	0	0	0	0
10th	1	1	1	0.5	0.2	0	0	0	0.1	0.1	0.1	0.3	0
20th	2	2	1	1	1	0.3	0.3	0.2	1	1	1	1	1
25th	2	2	1	1	1	1	1	0	1	1	1	1	1
50th	5	4	4	3	4	4	2	2	3	3	4	3	3
75th	21	16	13	10	26	26	10	3	14	14	11	10	15
80th	30	26	22	18	45	47	19	4	23	23	19	16	24
90th	101	105	74	86	213	254	80	9	109	96	75	71	106
95th	294	393	299	517	748	851	370	32	500	517	274	284	423

Garcitas Creek flow percentiles in cubic feet per second





Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases, two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5th, 25th, 50th, 75th, 80th, and 90th percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured.

Historical Hydrology

Garcitas Creek is about 25 miles long with a slope of 6.83 ft/mile (Asquith 1998). The 24-hour precipitation rate that occurs at a frequency of once every 2 years is 4.51 inches and the average annual rainfall from 1951-1980 was 37 inches.

Site Description

- Review of aerial photography with Google Earth
  - A reach of ½ mile, above and below gage site was observed
  - Woody riparian vegetation obscured an aerial observation of physical stream characteristics….see Field Observation cross-section descriptions for characteristics
  - Photography dates: March 17, 1995; October 21, 2005; January 30, 2009
  - Flow dates
    - June 21, 1996: 0.00 cfs
    - October 21, 2005: 3.3 cfs
    - January 30, 2009: 0.68 cfs
- Field Observations
  - One run, riffle and pool observed during cross-section studies
  - Run: Looking downstream, vegetation on the steep banks included green ash, cedar elm, Chinese tallow, sycamore, pecan, mulberry, American elm, grape and orange
  - Riffle: A riffle surrounds a sandbar midstream; Sycamore, holly, pecan on the slopes (RB)
  - Twidwell and Davis (1989) describe the creek watershed as nearly level or gently sloping; Rangeland with a little cropland; Bordered by narrow wooded belts, stream banks are low and heavily wooded; Bottom substrates: uniform, consisting of fine sands

Soil types

Soil	Setting	Slope	Wetland Potential	Flooding Frequency
Zalco fine sand	Flood plains	0-1%	Somewhat excessively drained, no ponding	Floods more than 50 times in 100 years
Inez fine sandy loam	Stream terraces	0-2%	Moderately well drained, no ponding	None
Rupley fine sand	Terraces	1-5%	Somewhat excessively drained, no ponding	None

Wetlands

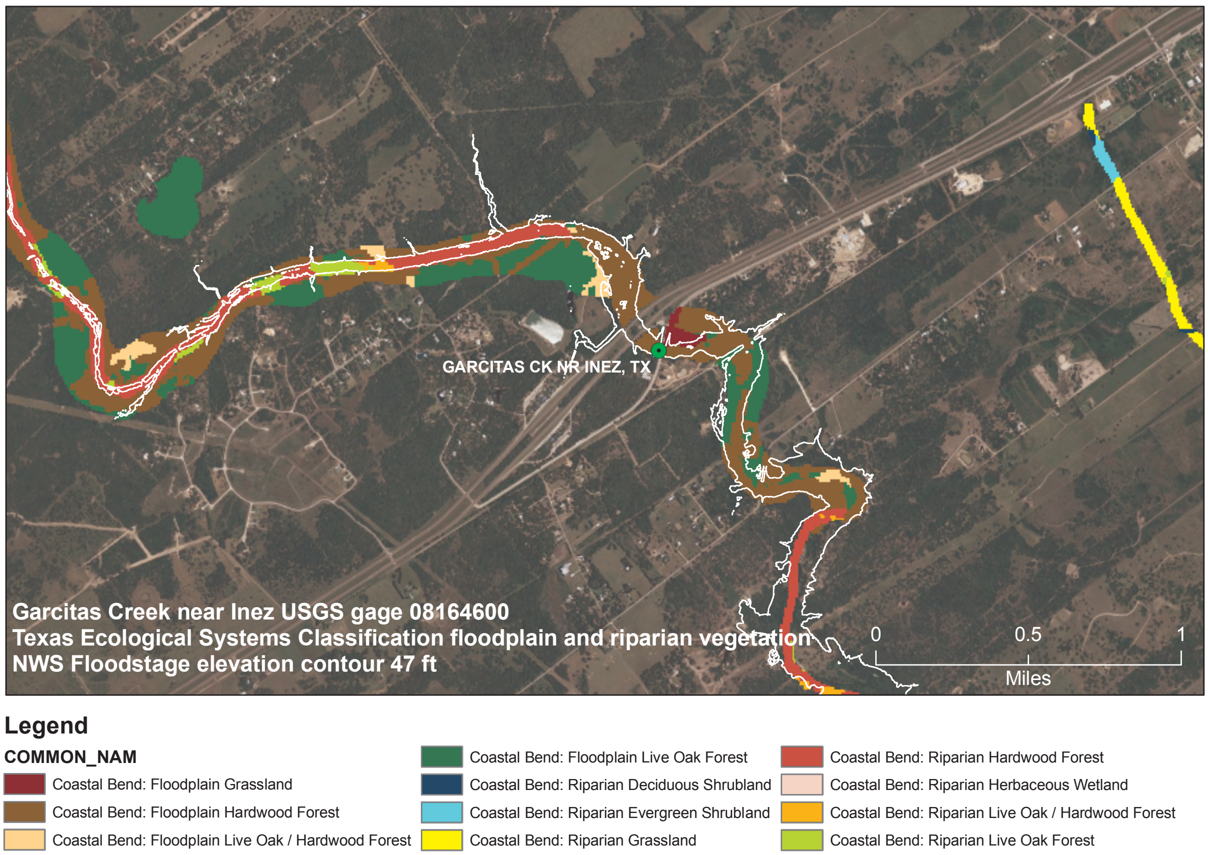
Freshwater emergent wetlands can be found northwest of the creek.

Riparian/Floodplain Vegetation

- Coastal Bend Floodplain Hardwood Forest
  - Includes sugar hackberry, American elm, live oak, American sycamore, and green ash; Shrubs: yaupon, vines such as trumpet creeper, and non-native grasses such as bermudagrass, and Johnsongrass; Presence of American sycamore indicates area may stay saturated for 2–4 months per year
- Coastal Bend Floodplain Live Oak Forest
  - Dominated by plateau live oak and includes boxelder, honey locust, eastern cottonwood and American sycamore; Found on terraces and margins of the creek; Eastern cottonwood and American sycamore are considered a facultative to facultative wetland species

and can grow in areas where the soil is saturated 2–4 months of the year

- Floodplain grassland
  - Bermudagrass and Johnsongrass.
- Coastal Bend Floodplain Live Oak/Hardwood Forest
  - Deciduous and broadleaf evergreen species including plateau live oak and anacua, located on terraces and margins of the creek.
- Coastal Bend Riparian Hardwood Forest
  - Deciduous canopy species such as sugar hackberry, cedar elm, pecan, black willow, and honey mesquite; Presence of black willow, a facultative wetland to obligate wetland species indicates that this area stays very moist most of the year; Species can tolerate inundation of more than 30 days



Sources: Texas Ecological System Classification project, TPWD 2010 www.tpwd.state.tx.us/landwater/land/maps/gis/tescp/index.phtml, Floodstage elevation from NWS Advanced Prediction Service
Elevation contour: Derived from LiDAR per FEMA specifications (TNRIS Jan. 2011) Vertical positional accuracy: USGS floodstage provided in NGVD29, LiDAR native datum is NAVD88 with resolution +-18 cm. Calculated difference for the study area is apx. 12cm which is within the resolution window for the LiDAR data. Horizontal datum: NAD83.
Contact: Lynne Hamlin, Water Resources Branch, TPWD lhamlin@tpwd.state.tx.us Map created Jan. 2011
Disclaimer: While every attempt was made to present the information as accurately as possible, no claims are made to the completeness or accuracy of the information shown herein nor to its suitability for a particular use.
Scale and location are approximate.

Texas Ecological Systems Classification of Riparian and Floodplain Vegetation for Garcitas Creek near Inez. The white line represents the calculated NWS flood stage elevation.

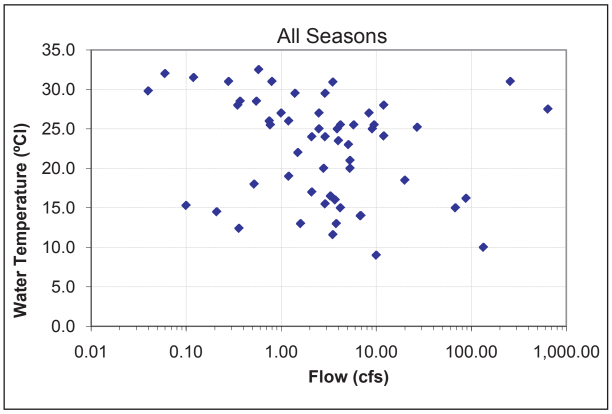
Biology

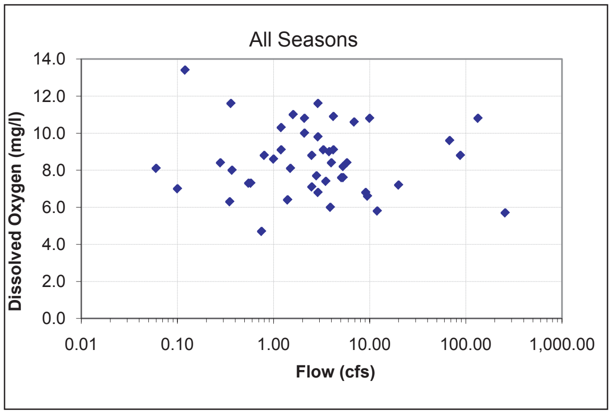
Source	Location	Biology	Observations
Twidwell and Davis 1989	Garcitas Creek	Fish and benthic invertebrates samples. Collected 24 species of fish.	Fish had an intermediate to high Index of Biotic Integrity value and benthic invertebrates had an exceptional Index of Biotic Integrity value. Stream with small pools and riffles.
Contreras 2002	Garcitas Creek	Classified as impaired in 2002, due to three low DO values	Now is unclassified, has a high aquatic life use
Bowman 1991.	Garcitas Creek, above tidal	Species identified included bluntnose darter, golden topminnow, mosquito fish, dollar sunfish, largemouth bass, spottail shiner, freshwater shrimp	In this study, species richness, diversity and standing crop were low, may be due to sampling technique
TPWD 1999.	Garcitas Creek	Diamond back terrapin, good dissolved oxygen values and benthic macroinvertebrates	Ecologically unique stream/river segment
TPWD 2007.	Garcitas Creek, tidal	Changes in nekton assemblage were driven by salinity gradient, water quality, riparian veg. were examined	Biological data indicates a healthy aquatic community

Water Quality

- The water quality period of record for this gage is 11/17/1981–06/26/2001
- Relationships between flow and water quality parameters
  - Water temperature decreases with increasing flow.
  - Specific conductance decreases with increasing flow.
  - Dissolved oxygen decreases with increasing flow.
  - Chloride decreases with increasing flow.
- This gaging station was not assessed in the 2008 Texas Water Quality Inventory [i.e., 305(b)] report.
- Water quality impairments, if any, listed on the 303(d) list
  - This gaging station is located in segment 2453A, Garcitas Creek Tidal. The 303(d) list indicates that from the confluence of Lavaca Bay in Jackson County to a point 8.5 miles upstream of FM 616 in Jackson County (15.2 miles) is impaired by depressed dissolved oxygen. This unclassified water body was first listed in 1999.
- Relationships between temperature and flow
  - An inverse correlation was observed between water temperature and flow.
  - The highest temperature was 32.5 °C (flow: 0.58 cfs; dissolved oxygen: 7.3 mg/L).

  - The lowest temperature was 9.0 °C (flow: 10 cfs; dissolved oxygen: 10.8 mg/L).
  - The lowest flow was 0 cfs (temperature: 17.1 °C; dissolved oxygen: 9.8 mg/L).
  - The highest flow was 257 cfs (temperature: 31 °C; dissolved oxygen: 5.7 mg/L).
- Relationships between dissolved oxygen and flow
  - An inverse correlation was observed between dissolved oxygen and flow.
  - The highest dissolved oxygen was 13.4 mg/L (flow: 0.12 cfs; temperature: 31.5 °C).
  - The lowest dissolved oxygen was 4.7 mg/L (flow of 0.75 cfs; temperature: 27 °C).
  - The lowest flow was 0 cfs (temperature: 17.1 °C; dissolved oxygen: 9.8 mg/L).
  - The highest flow was 257 cfs (temperature: 31 °C; dissolved oxygen: 5.7 mg/L).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - There are no site-specific numeric criteria for this segment.
  - The maximum value chloride was 110 mg/L.
  - The minimum and maximum observed pH values measured were 7.00 and 8.70.
  - The highest observed instantaneous temperature was 32.5 °C.
  - The minimum observed dissolved oxygen was 4.7 mg/L.





Geomorphology

Geomorphic analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77 to 93 percent of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows

HEFR/Hydrological Analysis

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct, Nov)
High Flow Pulses	Qp: 5,440 cfs with Average Frequency 1 per 5 years Regressed Volume is 16,177 to 36,182 (24,193) Regressed Duration is 5 to 22 (11)			
High Flow Pulses	Qp: 3,100 cfs with Average Frequency 1 per 2 years Regressed Volume is 9,098 to 20,339 (13,603) Regressed Duration is 5 to 19 (9)			
High Flow Pulses	Qp: 2,040 cfs with Average Frequency 1 per year Regressed Volume is 5,928 to 13,249 (8,863) Regressed Duration is 4 to 17 (9)			
High Flow Pulses	Qp: 407 cfs with Average Frequency 1 per season Regressed Volume is 1,275 to 2,601 (1,821) Regressed Duration is 4 to 12 (7)	Qp: 1,077 cfs with Average Frequency 1 per season Regressed Volume is 3,027 to 6,467 (4,425) Regressed Duration is 3 to 13 (6)	Qp: 36 cfs with Average Frequency 1 per season Regressed Volume is 88 to 253 (150) Regressed Duration is 2 to 8 (4)	Qp: 513 cfs with Average Frequency 1 per season Regressed Volume is 1,400 to 2,970 (2,040) Regressed Duration is 3 to 11 (6)
High Flow Pulses	Qp: 123 cfs with Average Frequency 2 per season Regressed Volume is 363 to 739 (518) Regressed Duration is 3 to 8 (4)	Qp: 381 cfs with Average Frequency 2 per season Regressed Volume is 1,054 to 2,249 (1,540) Regressed Duration is 2 to 10 (5)	Qp: 8 cfs with Average Frequency 2 per season Regressed Volume is 17 to 48 (28) Regressed Duration is 1 to 4 (2)	Qp: 106 cfs with Average Frequency 2 per season Regressed Volume is 286 to 606 (416) Regressed Duration is 2 to 8 (4)
Base Flows (cfs) – High	6.6(42.7%)	7.1(42.0%)	3.2(39.7%)	4.6(39.6%)
Base Flows (cfs) – Medium	3.5(60.2%)	3.7(58.9%)	2.1(54.1%)	2.5(55.8%)
Base Flows (cfs) – Low	1.9(77.5%)	1.8(75.9%)	1.1(68.6%)	1.3(72.3%)
Subsistence Flows (cfs)	0.32(95.1%)	0.18(95.0%)	0(100.0%)	0.01(95.3%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:
1. Period of Record used : 1/1/1940 to 12/31/2009.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 0.06 cfs.

Recommended Environmental Flow Regime

Garcitas Creek near Inez, USGS Gage 08164600, Recommended Environmental Flow Regime

	Winter	Spring	Summer	Fall
No-flow periods 1970-2010	0 periods Max duration: 0 days	13 periods Max duration: 59 days	5 periods Max duration: 190 days	7 periods Max duration: 34 days
Subsistence	1 cfs	1 cfs	1 cfs	1 cfs
Base Low	2 cfs	2 cfs	1 cfs	1 cfs
Base Medium	4 cfs	4 cfs	2 cfs	2 cfs
Base High	7 cfs	7 cfs	3 cfs	5 cfs
2 Pulses per season	Trigger: 110 cfs Volume: 520 af Duration: 8 days	Trigger: 380 cfs Volume: 1,500 af Duration: 10 days	Trigger: 8 cfs Volume: 28 af Duration: 4 days	Trigger: 110 cfs Volume: 420 af Duration: 8 days
1 Pulse per season	Trigger: 410 cfs Volume: 1,800 af Duration: 12 days	Trigger: 1,100 cfs Volume: 4,400 af Duration: 13 days	Trigger: 36 cfs Volume: 150 af Duration: 8 days	Trigger: 510 cfs Volume: 2,000 af Duration: 11 days
1 Pulse per year	Trigger: 2,000 cfs Volume: 8,900 af Duration: 17 days			
1 Pulse per 2 years	Trigger: 3,100 cfs Volume: 13,600 af Duration: 19 days			
1 Pulse per 5 years (Overbank)	Trigger: 5,400 cfs Volume: 24,200 af Duration: 22 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

af = acre-feet
cfs = cubic feet per second

2.5.2 Tres Palacios Creek

USGS Gage 08162600

Upstream, Tres Palacios Creek (left), Downstream, Tres Palacios Creek (right) (photos by Cathy Wakefield, July 9, 2010)

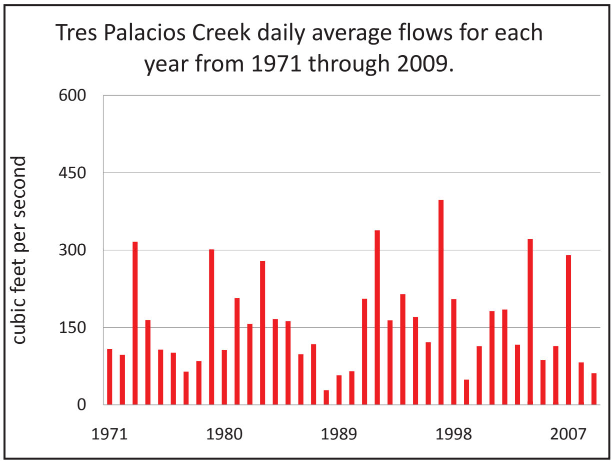
General Area Description

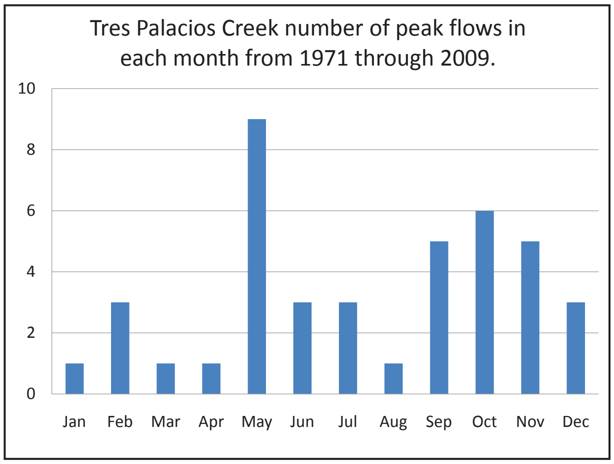
- Located on Farm Road 456, 1.0 mile downstream from Juanita Creek, 2.4 miles southeast of Midfield
- Northern Humid Gulf Coast Prairie, Western Gulf Coastal Prairie, (EPA Level III ecoregion)
- Surrounding land agricultural, grazing, crop land
- Ten diversions above station
- Undetermined amount of water from irrigated rice fields enters river at various points upstream
- Extensive channel cleaning upstream and downstream from gage, 1983-1985 water years.
- Vegetation in flood plain has increased in density in recent years; Mixed deciduous and live oak; also, cedar elm, sugar hackberry.
- Northern Humid Gulf Coast Prairie, Western Gulf Coastal Prairie

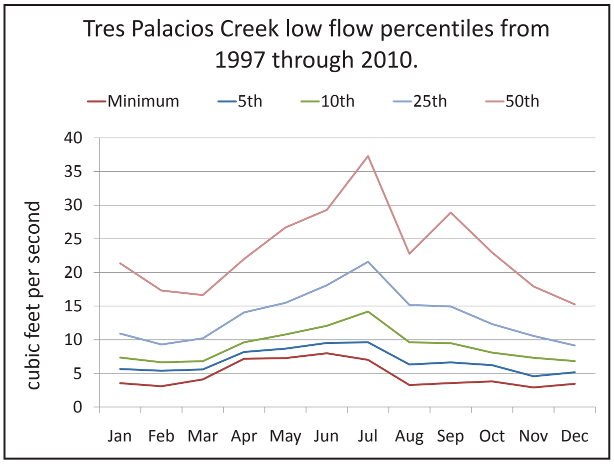
USGS Gage 08162600 Description

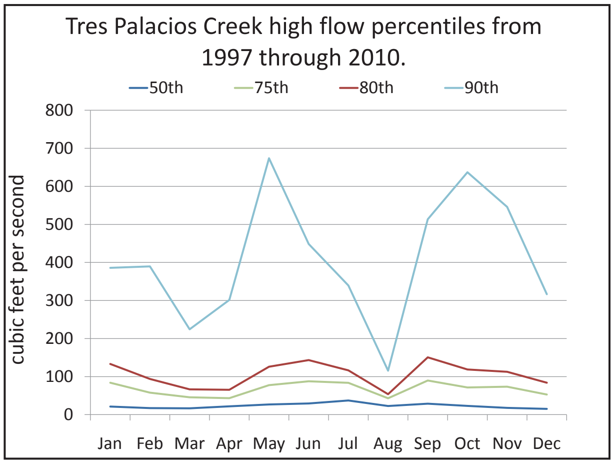
Matagorda County, Texas	Hydrologic Unit Code: 12100401	Latitude: 28° 55' 40" Longitude: 96° 10' 15" NAD27
Drainage area: 145 square miles	Contributing drainage area: 145 square miles	
Datum of gage: 5.38 feet above sea level NGVD29		

Summary of Historical USGS Flow Records at Tres Palacios Creek



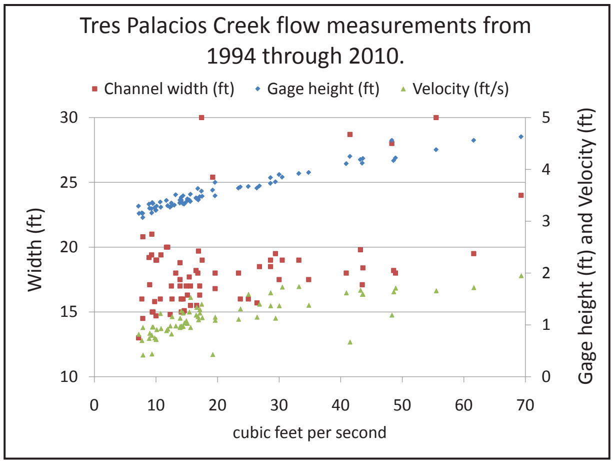






	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Maximum	2,008	2,329	2,110	2,129	3,792	2,383	2,415	509	3,821	3,836	2,607	1,980	2,493
Average	146	139	112	127	233	167	169	53	237	235	175	124	160
Minimum	4	3	4	7	7	8	7	3	4	4	3	3	5
5th	6	5	6	8	9	10	10	6	7	6	5	5	7
10th	7	7	7	10	11	12	14	10	9	8	7	7	9
20th	10	8	9	13	14	16	19	14	13	11	10	8	12
25th	11	9	10	14	15	18	22	15	15	12	11	9	13
50th	21	17	17	22	27	29	37	23	29	23	18	15	23
75th	84	58	46	43	78	88	84	43	90	72	73	53	68
80th	133	94	67	65	126	144	116	54	151	119	113	84	105
90th	386	390	224	301	674	449	339	115	514	637	546	317	408
95th	1,068	991	737	983	1,750	1,178	1,375	332	2,073	1,994	1,242	873	1,216

Tres Palacios Creek flow percentiles in cubic feet per second



Graph Explanations

Daily average flow for each year: USGS calculates the daily average flow for this site. Each column on the graph represents the average of all daily average flows measured during a calendar year.

Number of peaks by month: USGS identifies the highest instantaneous flow that has occurred during each year. In some cases, two high flow events are identified in a year. Each column on the graph is the number of times the highest instantaneous flows occurred in each month over the period of record.

Flow percentiles: USGS calculates an average daily flow for each calendar day of the year over the period of record. For example, if the period of record is 40 years long, USGS calculates a daily average flow for January 1 by averaging the daily average flows for 40, January 1's. The flow percentile graphs and the following table show the monthly average values calculated by averaging all the daily values over the period of record for each calendar date's maximum, minimum, average, 5th, 25th, 50th, 75th, 80th, and 90th percentile daily average flow for each month.

No-flow periods: A no-flow period described in this table consists of the number of consecutive days with daily average flows of 0.0 cfs. The number of no-flow periods in a month is the number of no-flow periods that started in that month over the period of record. Some months in the same year may have had more than 1 no-flow period.

Flow measurements: USGS personnel regularly measure flow, which includes measurements of water depth, velocity, and width at several points across the stream channel. The values in this graph represent the width of the stream, the average depth, and the average velocity when the flow was measured

Historical Hydrology

Tres Palacios Creek is about 55 miles long with a slope of 3.33 ft/mile (Asquith 1998). The 24-hour precipitation rate that occurs at a frequency of once every 2 years is 4.79 inches and the average annual rainfall from 1971-1995 was 42 inches.

Site Description

- Review of aerial photography with Google Earth
  - A reach of ½ mile, above and below gage site were observed
  - Woody vegetation obscured aerial observation of physical stream characteristics. See Field observation cross-section descriptions
  - Flow dates
    - June 17, 1970: 41 cfs
    - February 1995: 19 cfs
    - January 30, 2009: 7.7 cfs
- Field Observations
  - Cross-section performed Oct 20, 2010
  - Downstream run: horsetail on slope, sumpweed, dewberry, green ash, box elder, American elm, morning glory, live oak on ridge
  - Downstream riffle: alligator weed, smartweed, aster, greenbriar proceeding up slope, dewberry, ragweed, cedar elm; Blue-eyed grass, trumpet vine, Johnson grass
  - Downstream pool: willow, aster, cedar elm smartweed on slope, *Baccharis*, horsetail, Johnsongrass, morning glory, green ash on ridge.
  - All willows observed downstream were dead as a possible result of a herbicide application

Soil Types

Soil data obtained from Natural Resource Conservation Service (NRCS 2010).

Type	Setting	Slope	Wetland Potential	Flood Frequency
Laewest clay(A)	Flats	0-1%	Moderately well drained, no ponding	None
Fulshear fine sandy loam	Terraces	2-5%	Well drained, no ponding	None
Laewest clay(B)	Flats	1-3%	Moderately well drained, no ponding	None

Wetlands (USFWS 2010)

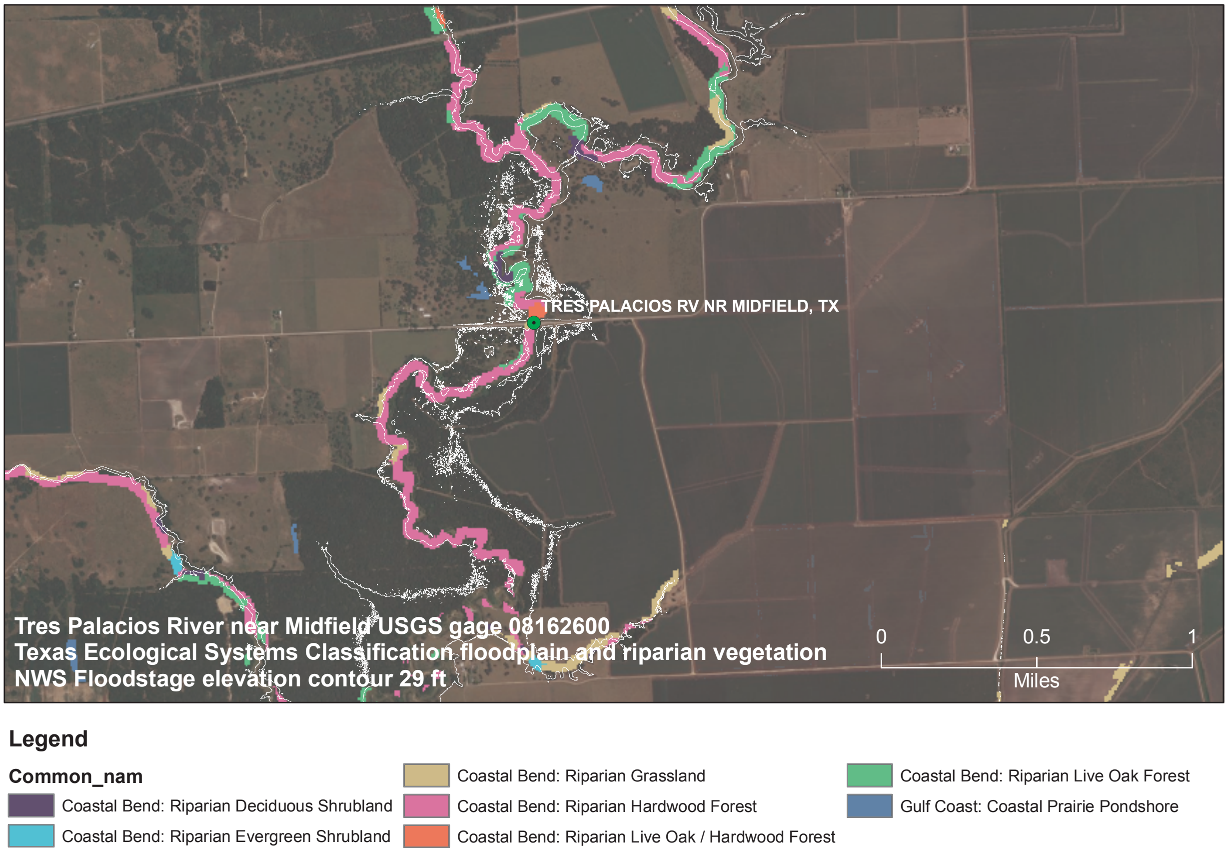
No wetlands along river. Freshwater pond to the north of site.

Riparian/Floodplain Vegetation

This area is not described as bottomland. Floodplain and riparian vegetative communities are confined to the immediate vicinity of the channel (German et al. 2009, German et al. 2010).

- Coastal Bend Riparian Live Oak/Hardwood forest.
  - Canopy dominance is shared by broadleaf evergreen species such as plateau live oak, and deciduous species such as hackberry and cedar elm.

- Coastal Bend Riparian Hardwood Forest
  - Dominates the community downstream; Sugar hackberry, cedar elm, pecan, black willow and honey mesquite common here; presence of black willow, a facultative wetland to obligate wetland species indicates this area stays very moist most of the year; black willow can tolerate inundation of more than 30 days
- Coastal Bend Riparian Live Oak
  - Dominated by plateau live oak, with honey mesquite, Virginia wild-rye and spiny aster; Wild-rye is facultative species, tolerating wet soils and seasonal flooding



Sources: Texas Ecological System Classification project, TPWD 2010 www.tpwd.state.tx.us/landwater/land/maps/gis/tescp/index.phtml, Floodstage elevation from NWS Advanced Prediction Service
Vertical Datums: USGS floodstage provided in NGVD29, LiDAR native datum is NAVD88 with resolution +-18.5cm (LCRA). Calculated difference for the study area is apx. 12cm. Horizontal datum: NAD83.
Contact: Lynne Hamlin, Water Resources Branch, TPWD lhamlin@tpwd.state.tx.us Map created Dec. 2010
Disclaimer: While every attempt was made to present the information as accurately as possible, no claims are made to the completeness or accuracy of the information shown herein nor to its suitability for a particular use.
Scale and location are approximate.

Texas Ecological Systems Classification of Riparian and Floodplain Vegetation for Tres Palacios Creek. The white line represents the calculated NWS flood stage elevation.

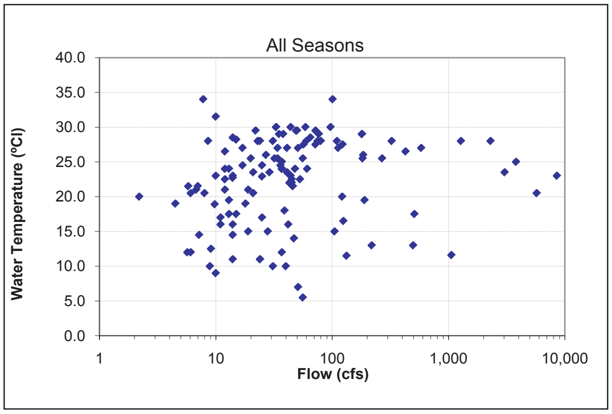
Biology

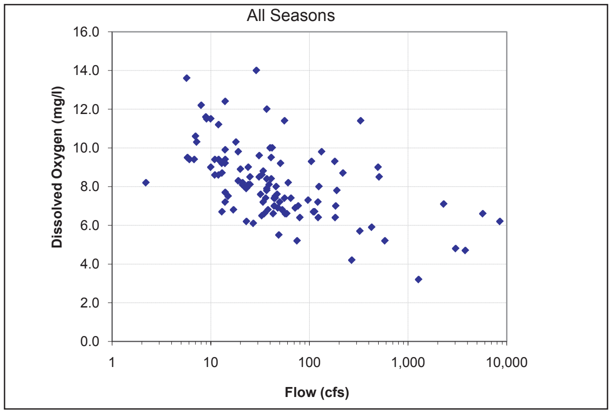
Source	Location	Biology	Observations
Day 1959	Tres Palacios Creek and mouth	Surveyed movement of white shrimp from river to river mouth and bay	The major cause of movement for vertebrate and invertebrate populations is the rise and fall of water temperature.
TDWR 1980	Tres Palacios Creek	Salinity-inflow relationships, nutrients and fisheries were studied in the bay system and all three major sources of freshwater inflow: Colorado and Lavaca River and Tres Palacios Creek.	Tres Palacios Creek is one of three major sources of nutrients for the bay system
LCRA 1999	Wilson Creek, a tributary of Tres Palacios Creek	Fish, macroinvertebrates and water quality were surveyed.	A high aquatic life rating was issued
TPWD 2007	Tres Palacios Creek	Water quality, instream and riparian habitat and biological sampling was done to determine ecosystem health.	Tidal streams are highly productive areas between freshwater and saltwater systems. The aquatic life use rating for Tres Palacios was found to be exceptional
Tremblay and Calnan 2007	Overview of wetlands of the Matagorda Bay area, including Tres Palacios Creek	Saltmarshes are common at bayheads where sediment has formed narrow deltas. Saltmarshes integrate with fresh marshes as salinity decreases.	Higher productivity occurs with higher freshwater inflow.

Water Quality

- The water quality period of record for this gage is 02/06/1968–06/26/2001
- Relationships between flow and water quality parameters
  - Specific conductance decreases with increasing flow.
  - pH increases with increasing flow.
  - Chloride decreases with increasing flow.
- According to the 2008 Texas Water Quality Inventory, this gaging station is located in Water Quality Segment 1502, Tres Palacios Creek above Tidal. The 2008 Texas Water Quality Inventory Basin Assessment Data indicates that water quality in this segment fully supports the designated high aquatic life use.

- Water quality impairments, if any, listed on the 303(d) list
  - The 303(d) list indicates that the middle 23 miles of the segment is impaired by bacteria. The unclassified water body was first listed in 1996.
- Relationship between temperature and flow
  - No correlation was observed between water temperature and flow.
  - The highest temperature was 34 °C (flow: 101 cfs; dissolved oxygen: not sampled).
  - The lowest temperature was 5.5 °C (flow: 56 cfs; dissolved oxygen: 11.4 mg/L).
  - The lowest flow was 2.2 cfs (temperature: 20 °C; dissolved oxygen: 8.2 mg/L).
  - The highest flow was 8,540 cfs (temperature: 23 °C; dissolved oxygen: 6.2 mg/L).
- Relationship between dissolved oxygen and flow
  - No correlation was observed between dissolved oxygen and flow.
  - The highest dissolved oxygen was 14 mg/L (flow: 29 cfs; temperature: 23.5 °C).
  - The lowest dissolved oxygen was 3.2 mg/L (flow of 1,280 cfs; temperature: 28 °C).
  - The lowest flow was 2.2 cfs (temperature: 20 °C; dissolved oxygen: 8.2 mg/L).
  - The highest flow was 8,540 cfs (temperature: 23 °C; dissolved oxygen: 6.2 mg/L).
- Observations compared to the Texas Surface Water Quality Standards (TSWQS) criteria
  - Nine instantaneous chloride measurements exceeded the TSWQS criterion of 250 mg/L.
  - The minimum and maximum observed pH values were within the TSWQS range of 6.5-9.0.
  - Two of 127 temperature measurements exceeded the TSWQS criterion of 32.2 °C.
  - Four out of 111 instantaneous dissolved oxygen measurements were below the TSWQS criterion of 5.0 mg/L.





Geomorphology

Geomorphic analysis was not conducted for this specific site, but analysis of representative sites in this study found that 77 to 93 percent of average annual flow volume may maintain channel shape (see Section 3.10 for more details). This is a larger volume of water than is provided by the proposed subsistence, base, pulse and overbank flows

HEFR/Hydrological Analysis

	Winter (Dec, Jan, Feb)	Spring (Mar, Apr, May, Jun)	Summer (Jul, Aug)	Fall (Sep, Oct, Nov)
Overbank Flows	Qp: 6,650 cfs with Average Frequency 1 per 5 years Regressed Volume is 16,603 to 41,083 (26,117) Regressed Duration is 3 to 11 (5)			
Overbank Flows	Qp: 4,630 cfs with Average Frequency 1 per 2 years Regressed Volume is 11,582 to 28,651 (18,216) Regressed Duration is 2 to 11 (5)			
Overbank Flows	Qp: 3,490 cfs with Average Frequency 1 per year Regressed Volume is 8,743 to 21,624 (13,750) Regressed Duration is 2 to 10 (5)			
High Flow Pulses	Qp: 1,250 cfs with Average Frequency 1 per season Regressed Volume is 3,415 to 7,041 (4,903) Regressed Duration is 2 to 9 (4)	Qp: 1,890 cfs with Average Frequency 1 per season Regressed Volume is 4,570 to 10,930 (7,067) Regressed Duration is 2 to 8 (4)	Qp: 279 cfs with Average Frequency 1 per season Regressed Volume is 719 to 2,424 (1,320) Regressed Duration is 2 to 9 (4)	Qp: 1,880 cfs with Average Frequency 1 per season Regressed Volume is 4,935 to 11,864 (7,652) Regressed Duration is 2 to 10 (5)
High Flow Pulses	Qp: 648 cfs with Average Frequency 2 per season Regressed Volume is 1,758 to 3,622 (2,523) Regressed Duration is 2 to 8 (4)	Qp: 1,171 cfs with Average Frequency 2 per season Regressed Volume is 2,859 to 6,835 (4,421) Regressed Duration is 2 to 8 (4)	Qp: 75 cfs with Average Frequency 2 per season Regressed Volume is 194 to 656 (357) Regressed Duration is 1 to 7 (3)	Qp: 799 cfs with Average Frequency 2 per season Regressed Volume is 2,047 to 4,917 (3,173) Regressed Duration is 2 to 8 (4)
Base Flows (cfs)	17 (41.8%)	22 (42.7%)	22 (40.5%)	19 (41.4%)
Base Flows (cfs)	12 (58.5%)	14 (60.8%)	14 (57.1%)	12 (56.7%)
Base Flows (cfs)	7.6 (75.0%)	9 (77.2%)	7 (71.1%)	6.9 (71.2%)
Subsistence Flows (cfs)	2 (95.4%)	2.5 (95.5%)	0.75 (95.1%)	0.78 (95.0%)

Flow Levels	
	High (75th %ile)
	Medium (50th %ile)
	Low (25th %ile)
	Subsistence

Notes:
1. Period of Record used : 1/1/1940 to 12/31/2009.
2. Q95 calculation used for subsistence flows. Annual Q95 value is 1.5 cfs.

Recommended Environmental Flow Regime

Tres Palacios Creek near Midfield, USGS Gage 08162600, Recommended Environmental Flow Regime

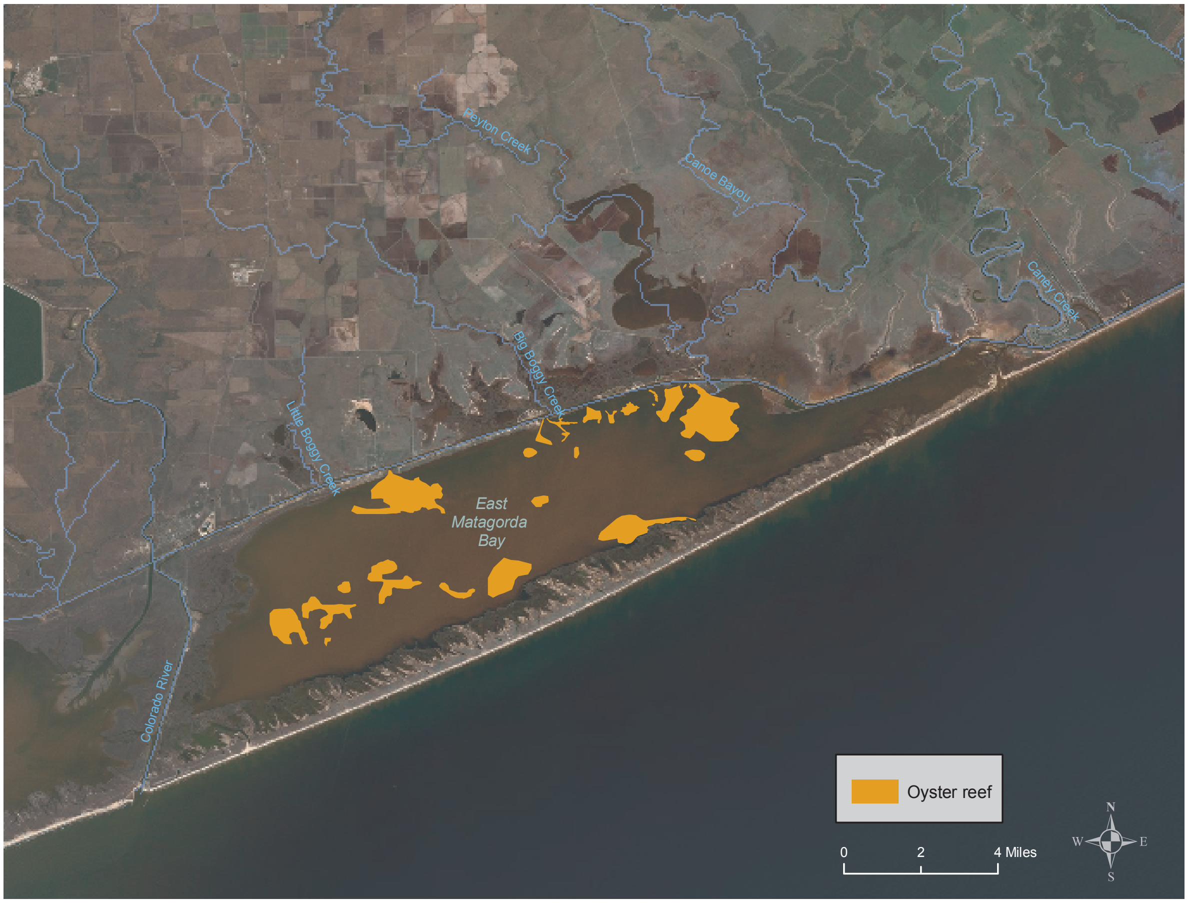
	Winter	Spring	Summer	Fall
No-flow periods 1970-2010	No periods of no flow			
Subsistence	7 cfs	7 cfs	7 cfs	7 cfs
Base Low	9 cfs	9 cfs	7 cfs	7 cfs
Base Medium	13 cfs	13 cfs	13 cfs	13 cfs
Base High	18 cfs	22 cfs	22 cfs	18 cfs
2 Pulses per season	Trigger: 650 cfs Volume: 2,500 af Duration: 8 days	Trigger: 1,200 cfs Volume: 4,400 af Duration: 8 days	Trigger: 75 cfs Volume: 360 af Duration: 7 days	Trigger: 800 cfs Volume: 3,200 af Duration: 8 days
1 Pulse per season	Trigger: 1,300 cfs Volume: 4,900 af Duration: 9 days	Trigger: 1,900 cfs Volume: 7,100 af Duration: 8 days	Trigger: 280 cfs Volume: 1,300 af Duration: 9 days	Trigger: 1,900 cfs Volume: 7,700 af Duration: 10 days
1 Pulse per year (Overbank)	Trigger: 3,500 cfs Volume: 13,800 af Duration: 10 days			
1 Pulse per 2 years (Overbank)	Trigger: 4,600 cfs Volume: 18,200 af Duration: 11 days			
1 Pulse per 5 years (Overbank)	Trigger: 6,700 cfs Volume: 26,100 af Duration: 11 days			
Channel Maintenance Flow	A quantity of flow in addition to flows provided by subsistence, base, pulse and overbank flows proposed here would be needed to maintain channel morphology. Analysis by the BBEST at 3 sites across the basins (upper Colorado, lower Colorado, and Lavaca) and within the bounds of the analysis in this report indicates a range of average annual flows on the order of 77-93% of the average annual flow from 1940-1998 with the variability characteristic of the period of record maintains existing channel morphology. The specific flow needed to maintain the channel and its ecological functions will need to be determined on a project and site-specific basis.			
Long-term Engagement Frequencies	Base-high 25%, Base-medium 50%, Base-low 25%, Subsistence 100%, and Pulses 100%. The goal of the engagement frequencies is to produce an instream flow regime that mimics natural patterns by providing the target base flows at frequencies which closely approximate historical occurrences.			

cfs = cubic feet per second
af = acre-feet

2.6 East Matagorda Bay

General Description

- Part of the Matagorda Bay system, enclosed by the Matagorda Peninsula and the delta around the former mouth of the Colorado River downstream of the Gulf Intracoastal Waterway (GIWW) to the Gulf of Mexico
- Average width of 3.7 miles and length of about 23 miles
- Depths typically range from 2 to 4 ft
- Caney Creek (flow not gaged) discharges into the bay at the northeastern border
- Delta around the former Colorado River channel forms the western boundary
- Cut off from Matagorda Bay by a rapidly prograding delta that formed in the 1930s
- Only true opening to the Gulf of Mexico is through Brown Cedar Cut, near the north end of the peninsula
- Extensive marshes occur north of the GIWW, with fringing marshes around the bay
- Scattered oyster reef and many species of shellfish and finfish occur within the bay
- Compared to other Texas bays, little development has occurred around its periphery
- Primary freshwater inflow sources are localized rainfall and runoff



Sources: Oyster reefs - TPWD, Culbertson 2010. NHDPlus 2008 Projection : UTMzone15N

East Matagorda Bay

Inflow to East Matagorda Bay

Once connected to Matagorda Bay, East Matagorda Bay was cut off from the main bay by a rapidly prograding delta of the Colorado River in the 1930s. It is now considered a minor bay of the Matagorda Bay system. East Matagorda Bay is approximately rectangular and relatively shallow.

Freshwater inflow into minor bays is generally dominated by non-point source runoff or an indirect source via circulation from adjacent systems. Localized rainfall and runoff are primary sources of freshwater to East Matagorda Bay. The extent to which East Matagorda Bay relies on the Colorado River (partly through the GIWW) versus local runoff for freshwater input is not known. Flows from the Colorado River are distributed to Matagorda Bay, East Matagorda Bay, and the Gulf of Mexico at several locations. The distribution changes with the amount of flow in the main stem of the river and has changed substantially over time. The biggest single change in recent history was the river diversion project implemented from 1989 to 1992, which redirected flow from the Colorado River through a diversion channel into the Eastern Arm of Matagorda Bay. The distribution of mainstem flow is also dramatically affected by the operation of navigation locks in the GIWW on both sides of the Colorado River. A flow split analysis to assess the amount of Colorado River flow that is distributed to Matagorda Bay and East Matagorda Bay was undertaken in fall 2006, but there is still uncertainty in how much freshwater inflow goes into East Matagorda Bay. Additionally, rice field irrigation return flows likely contribute freshwater inflow to East Matagorda Bay at times.

Daily inflow data for East Matagorda Bay was calculated by the Texas Water Development Board (TWDB) using the Texas Rainfall-Runoff Model (TxRR) (TWDB 2011a). This model is able to estimate runoff from ungaged watersheds and streamflows. Data from the watersheds north and east of East Matagorda Bay were used in the calculation (Figure 2.6.1). During the period from 1977 to 2009, there was no gaged inflow to East Matagorda Bay (TWDB 2011a). Daily inflow volumes were summed to monthly values for the period from 1977-2009 and are presented as monthly modeled inflow in Figure 2.6.2. During the 1977 through 2009 period, the freshwater inflow balance varied from a minimum of 4,059 acre-feet in 1988 to a maximum of 1.3 million acre-feet in 1979, and averaged 524,008 acre-feet per year (TWDB 2011a).

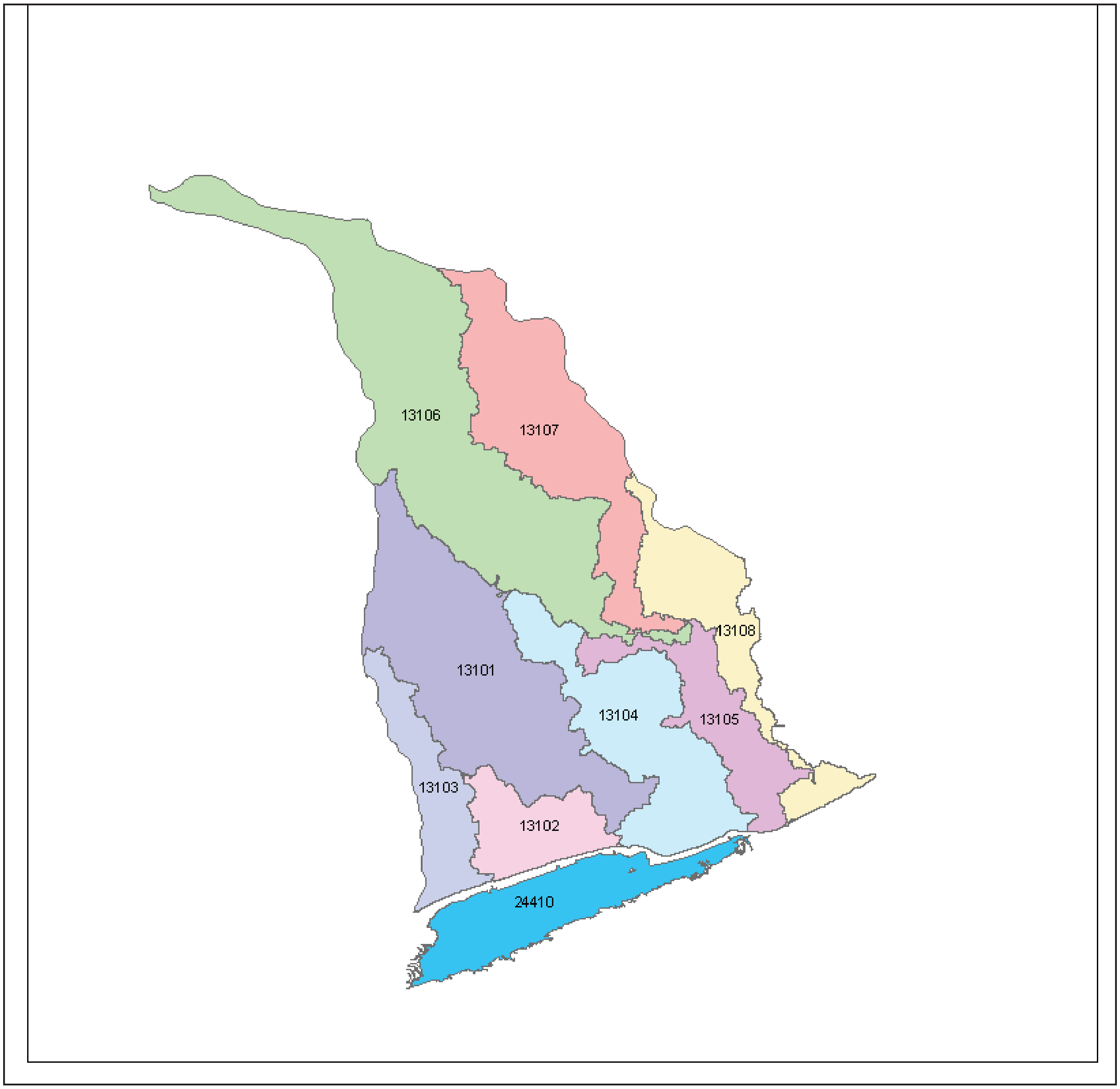


Figure 2.6.1 Ungaged watershed delineation used in TxRR model to determine ungaged inflows to the East Matagorda Bay system. The location of the LCRA tripod is denoted with a star (*).

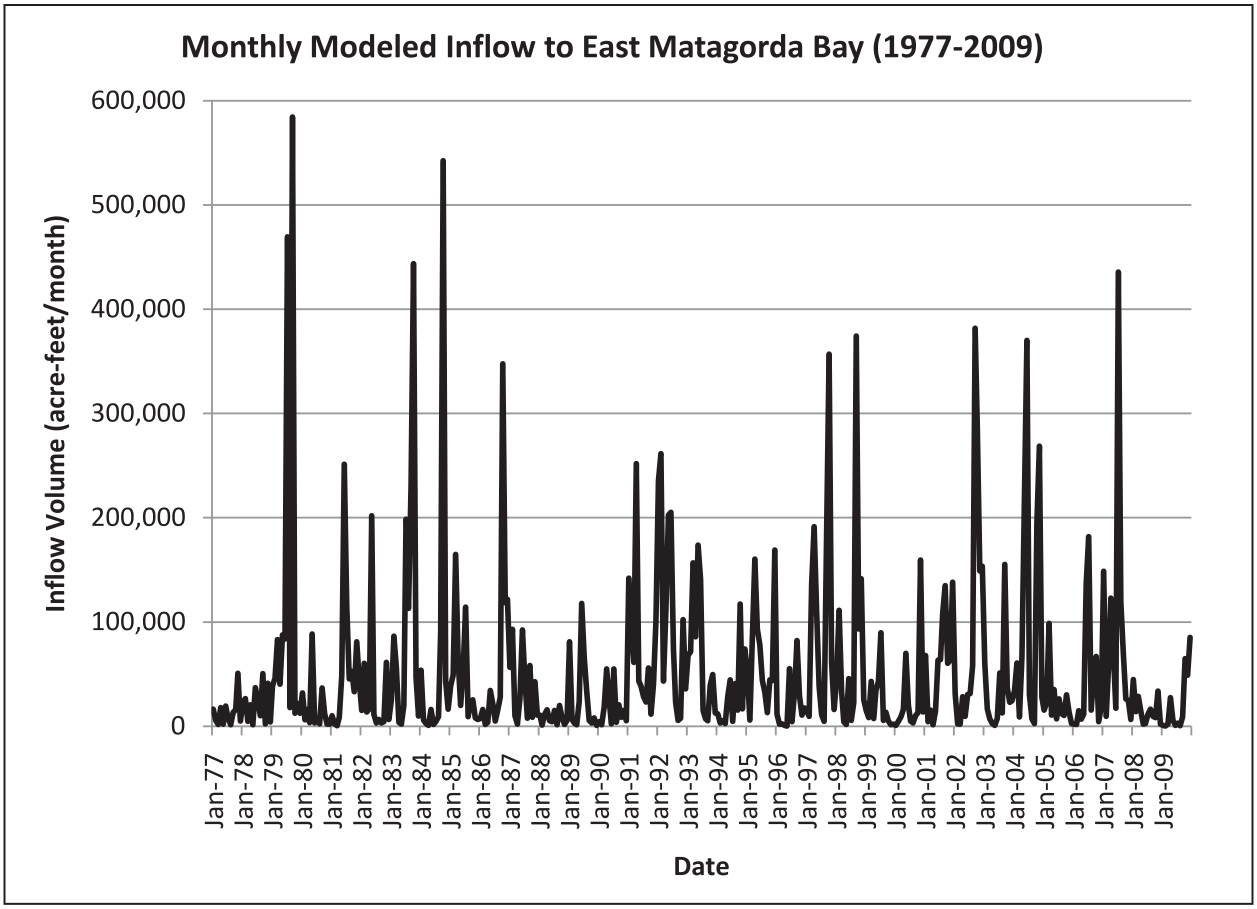


Figure 2.6.2 Total monthly modeled inflow volume to East Matagorda Bay based on TxRR modeling for the period 1977-2009 (courtesy of TWDB).

Salinity patterns identified in previous studies in East Matagorda Bay indicate that the main freshwater source is at the northeastern corner of the bay, and salinity generally increases to the southwest (Montagna 2001, MBHE 2007). An almost continuous salinity data record at the LCRA East Bay Tripod in the west end of East Matagorda Bay from 1998-2010 was provided by LCRA (Figure 2.6.3). During this period, salinities ranged from 0 ppt to 42.5 ppt, with a daily average of 25.4 ppt. The noticeable drop in salinity to almost 0 ppt in fall 2008 corresponds with the onset of rains during Hurricane Ike, which made landfall in Galveston, Texas, on September 13, 2008, and brought heavy rains to the Texas coast.

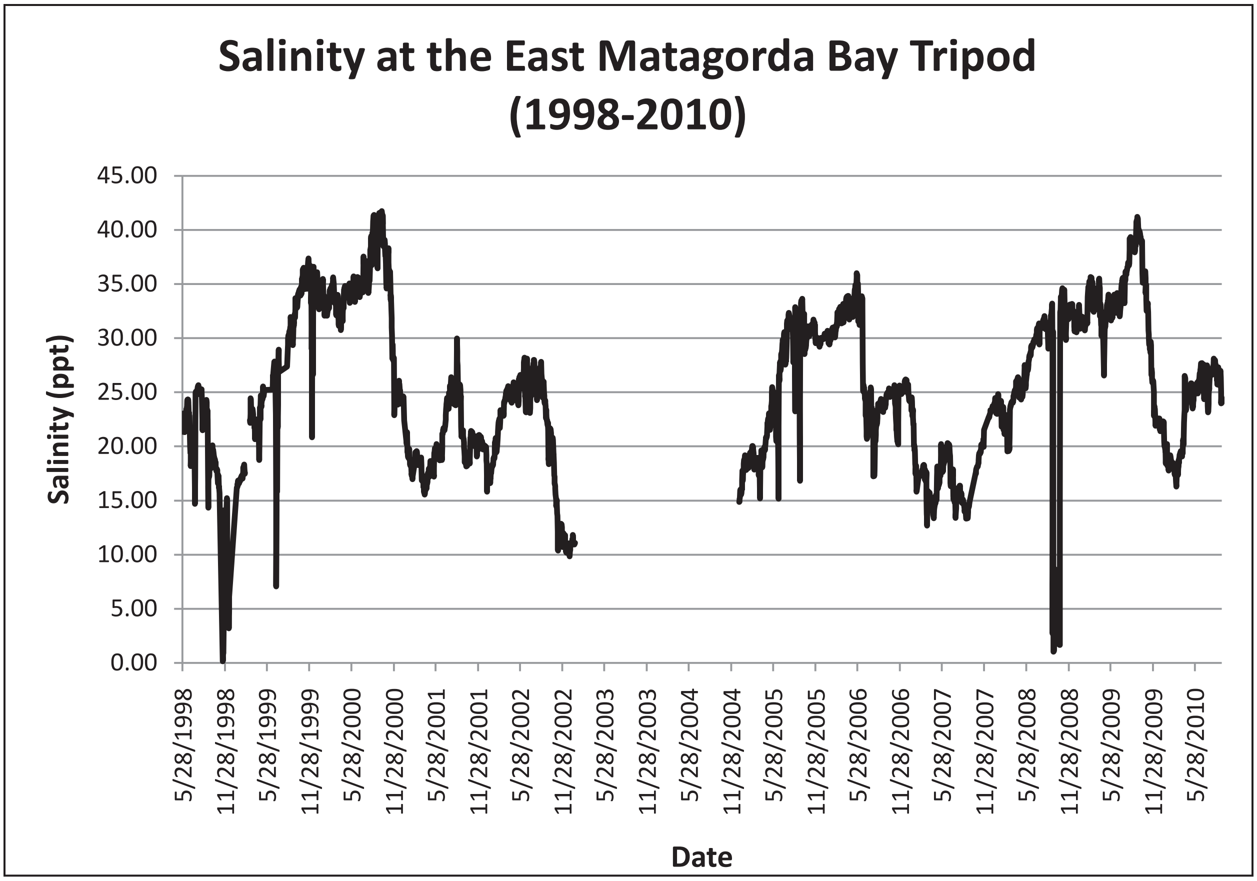


Figure 2.6.3 Daily average salinity measured at the LCRA tripod in East Matagorda Bay (courtesy of LCRA).

Biology

Recent studies indicate that while phytoplankton biomass is not particularly high (Cifuentes and Kaldy 2006), the bay does support a diversity of aquatic species including oysters, shellfish, finfish, and turtles (MBHE 2007, TPWD 2010). Popular sportfish in the bay include trout and redfish (TPWD 2011). In addition to freshwater marsh on the northeast side of the bay, the western and southern borders of the bay support brackish and saltmarsh communities. The shallow open bay habitat includes pockets of oyster reef that range from the southwestern corner to the northeastern corner of the bay (MBHE 2005, MBHE 2007).

Seagrasses including *Halodule* sp. and *Halophila* sp. are present in the bay, with widgeon grass (*Ruppia maritima*) present in Lake Austin. Extensive freshwater and brackish marshes are present north of the GIWW, especially near the Big Boggy National Wildlife Refuge. Fringing salt marshes occur around much of the perimeter of the bay.

The BBEST gathered scientists, local experts and researchers familiar with East Matagorda Bay in 2010 to elicit opinions of the importance of freshwater inflow to East Matagorda Bay and the current environmental state of the bay. Specific comments regarding important species, habitats, and relationships between inflow and the bay are provided in the bay expert meeting summary table (Table 2.6.1). General observations regarding the East Matagorda Bay system were that the system is stabilizing since being cut off from Matagorda Bay in the 1930s, is a relatively shallow and sometimes turbid system, supports a diversity of aquatic species and habitats, and is relatively undeveloped with a natural shoreline. While opinions on a variety of metrics related to the health of the bay may vary, the general conclusion from the bay expert meeting is that East Matagorda Bay is overall a sound environment even though it may have changed community composition since it was cut off from the main bay. For example, since the diversion of the Colorado River into the Eastern Arm of Matagorda Bay in 1992, the white shrimp population in East Matagorda Bay no longer supports a regular commercial shrimp fishery there.

Since there are no gaged inflows to East Matagorda Bay at this time, no gaged stream flow recommendation is being offered for this bay. Additionally, the primary sources of freshwater to East Matagorda Bay are localized rainfall and runoff and the BBEST is providing a recommendation for a Colorado River inflow to Matagorda Bay. Therefore, the BBEST considers the future inflows to East Matagorda Bay to be protected at this time without a specific recommendation for this portion of the Matagorda Bay system.

Table 2.6.1 East Matagorda Bay Results of Bay Expert Information provided in a meeting of bay experts on July 2010 in Palacios, Texas, in telephone conversations, and email
Key Species
• Benthic animals and plants, particularly clams and oysters are best indicators for ecosystem health (Montagna) • Oysters • Birds • *Halodule* • Ruppia along North Shore (Balboa) • *Halophila* • Small fish • Shrimp numbers good up to the late 1980s, declined after that • Fishing pressure, blue crab • Green sea turtles • Spotted and alligator gar • Seagrass, especially downwind from peninsula • Spartina • Brown shrimp along south shore
Key Habitats
• Oyster reefs at delta, NE and W shores, and middle near freshwater inflow locations (Culbertson) • Patch oysters at tributaries • Dead oyster reefs • Ringed with seagrass • Fringing marsh (Hartman) • Open bay bottom (Dumesnil) • Marsh edge
Ecological Processes
• Relatively high fish productivity - high numbers and good length/weight ratios (Balboa, Hartman) • Detrital/algae based food webs • Marsh detritus supports productivity (Hartman) • Hypersaline during drought (Hartman) • Productivity enhanced by rice field discharge (Jensen), tannic aids, decomposing seagrasses (Balboa), marsh detritus (Hartman) • Hydraulics improved because of ICWW • Shrimp nursery • Rain is a primary source of nutrients (Hartman)

Inflow Remarks
• No additional inflow recommendations • High retention time for FW (Jensen) • Nice, productive, healthy system • Most freshwater inflow is localized runoff and rice field runoff (Balboa) • Drought causes hypersalinity (Hartman) • Reductions in inflow from the small watersheds would reduce productivity (Hartman) • Groundwater inflow may be significant (Hartman) • Inflow from Colorado River is not relatively substantial because ICWW locks are closed at river flows >5,000 cfs (Cook) • Rain is primary source of freshwater inflow (Hartman, Gurthie, Balboa) • Freshwater important to north portion of bay, less important to entire bay • Prior to Colorado River diversion, flooding would push freshwater inflow into East Matagorda Bay
Sound Environment
• Yes - supports threatened and endangered species, relatively isolated from development, and relatively low inflow from Colorado (Culbertson) • Yes-supports Culbertson's rationale and believes it is a relatively young and still evolving system (Hartman) • Yes (Balboa) • Yes (Schlicht) • Yes-based on day's discussion (Ray) • Yes (Dailey, former TPWD ecosystem leader for Matagorda Bay) • Yes (Arnold, commercial fisherman)
Threats
• Bulkheading could imperil marsh and seagrasses • Dermo-unknown how much of a threat it is in estuary (Ray) • Oyster drills • Subsidence resulting from fault (Culbertson"
Information Needs
• Concentration of dermo and drills • Need plankton data

2.7 Matagorda Bay

Summary of Matagorda Bay Freshwater Inflow Relationships

- Freshwater inflows add nutrients, primarily inorganic nitrogen which feeds phytoplankton that are likely to be a very important component of the base of the estuarine food web.
- Organic matter carried on inflows is also important to the base of the food web.
- Physical habitat (e.g., marsh, oyster reef, open bay) and salinity combine to create varying conditions for juvenile life stages of important species like white shrimp, brown shrimp, blue crab, Atlantic croaker, and Gulf menhaden.
- Lower two-year average salinity conditions have been related to lower dermo (an oyster parasite) infection levels in oyster reefs.
- Increases in freshwater inflow lead to greater community and functional diversity of benthic macroinvertebrates, while reduced inflow results in reduced suspension-feeder productivity and increased deposit-feeder productivity.

Sources: Oyster reefs - Lavaca Bay (TPWD, Simons et al. 2004), Matagorda Bay (General Land Office), East Matagorda Bay (TPWD, Culbertson 2010). Projection : UTMzone15N

Map of the Matagorda Bay System

Historical Matagorda Bay Inflow

It is widely accepted that the Matagorda Bay system, like other Gulf Coast estuaries, is a highly dynamic environment, which reacts to many drivers, one of which is freshwater inflow. Other factors influencing bay conditions are Gulf salinity, meteorology, physiographic modifications, harvest pressures, and large-scale Gulf of Mexico conditions that can affect species productivity in the bay. Any one or more of these factors can be of primary importance in influencing bay conditions at any point in time. FINS (2006) estimated that the Colorado River contributes approximately 45% of the total inflow into the system on an average basis. Other inflow source estimates include the Lavaca Delta (26%), Garcitas Creek (6%), Carancahua Bay (6%), Tres Palacios (5%), Oyster Lake (3%), Powderhorn Lake (3%), Chocolate Bay (2%), Turtle Bay (2%), Keller Bay (1%), and Cox Bay (1%) (FINS 2006).

TWDB (2011b) conducted an updated TxRR modeling effort for the Matagorda Bay system, and estimates that during the period from 1941-2009, gaged inflow from the Lavaca, Colorado, and Navidad Rivers, and Garcitas, Tres Palacios, and Placedo Creeks accounted for 69% of combined inflow. Ungaged inflow accounts for 29% of combined inflow (TWDB 2011b). A summary of the estimated annual combined freshwater inflow to Matagorda Bay as calculated by TxRR model version #TWDB201004 is provided in Figure 2.7.1. Average combined surface inflow to Matagorda Bay over the study period was approximately 3.5 million acre-feet per year, and ranged from a minimum of 441,162 acre-feet in 1954 to a maximum of 14.9 million acre-feet in 1992.

Since the BBEST is providing recommendations for Matagorda Bay and Lavaca Bay (see Section 2.8), the Matagorda Bay freshwater inflow regime is related to the Colorado River flow as measured at the downstream-most gage at Bay City.

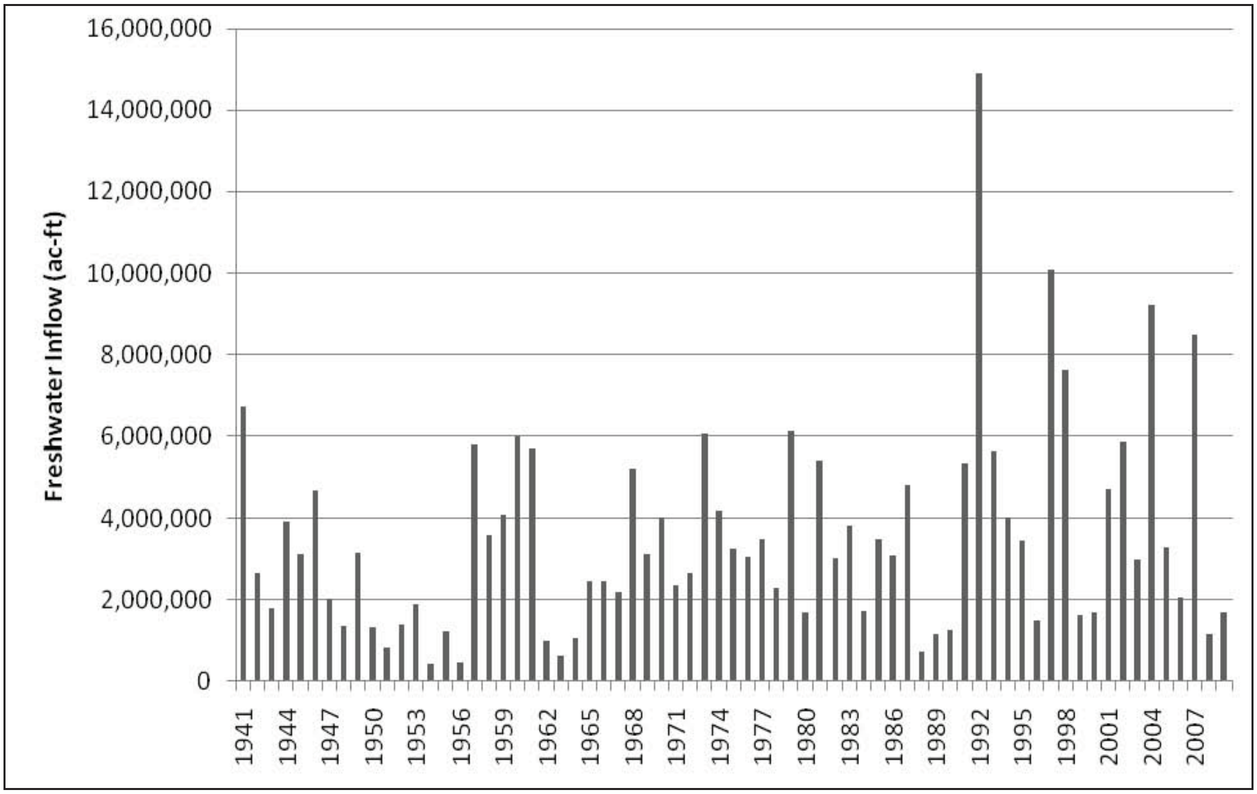


Figure 2.7.1 Summary of estimated annual combined freshwater inflow to Matagorda Bay as calculated by TxRR model version #TWDB201004 for the period 1941-2009.

Development of Matagorda Bay Freshwater Inflow Recommendation

The BBEST relied upon the best available scientific information to provide an environmental flow regime for Matagorda Bay that will protect a sound ecological environment. In developing the Matagorda Bay inflow recommendations, the BBEST reviewed the historical gage data within the Matagorda Bay watersheds, focusing on the Colorado River at Bay City gage for the recommendations, as well as salinity data collected in the Eastern Arm of Matagorda Bay, TXRR modeling by the Texas Water Development Board, and previous Matagorda Bay inflow studies including FINS (2006; LCRA 1997) and the MBHE study (MBHE 2008). The BBEST also gathered scientists, local experts and researchers familiar with the Matagorda Bay system to elicit opinions of the importance of freshwater inflow to the bay and the current environmental state of the bay. Specific comments regarding important species, habitats, and relationships between inflow and the bay are provided in Table 2.7.1.

Table. 2.7.1 Matagorda Bay Results of Bay Expert Information provided in a meeting of bay experts on July 9, 2010 in Palacios, Texas, in telephone conversations, and email

Key Species

- Benthic animals and plants, particularly clams and oysters are best indicators for ecosystem health (Montagna)
- Piping plover, sandhill cranes, wading birds, occasional whooping crane in Oyster Lake area
- Oysters, including oyster reef in east arm of bay, at least 147 acres and growing (Culbertson)
- Seagrass on south shore (Culbertson)
- Cabbageheads - because most abundant in Matagorda Bay, tolerate high salinity, also consumes oyster veligers (Culbertson)
- Lesser Blue crab, star drum, Gulf menhaden because of its dependence on plankton (Cox, fishing guide)
- Sea turtles - Greens and Kemp's Ridleys off Powderhorn Lake and Kemp's Ridleys off Palacios (Balboa)
- Diamondback terrapins in Collegeport area (Wakefield)

Key Habitats

- Marsh (upper end of Tres Palacios Bay, Oyster Lake, Crab Lake, Mad Island, Turtle Bay, and river delta)
- Seagrass on south shore - due to clearer water (sheltered from the wind and reduced turbidity because it is far from freshwater inflow)
- Oyster reefs
- Oyster Lake - sandhill cranes, geese, and a whooping crane
- Colonial water bird nesting at Sundown Island.

Ecological Processes

- Nutrient loading has increased over time because of the freshwater inflow diversion.
- Delta being formed

Inflow Remarks

- It is a flow-thru system and dermo responds quickly to flow changes (Ray)
- Oysters and marsh have increased since diversion (Culbertson)
- River diversion has had a positive impact because it has created wetlands. Bay more productive than in past (Cox, fishing guide)
- Mimic, as closely as possible, historic seasonal timing and volumes. Imperative to maintain seasonal components (Balboa)
- Two salinity zones in bay. A small freshwater zone in the eastern arm close to the mouth of the river that is very small during droughts (Montagna)

Sound Environment

- Acceptable, better than Lavaca Bay but more imperiled than East Matagorda Bay (Hartman)
- Recovers quickly from short-term changes (Wakefield)
- Resilient system. No significant change in species composition; No dams, not much diversion; Functional ecosystem - impacted by development and channel
- Holding its own for the past 20 years. Only memorable decline was in catch per unit effort for Polydactylus since 1988 (Balboa)
- No (Dailey, former TPWD ecosystem leader for Matagorda Bay)
- Yes (Arnold, commercial fisherman)
- Yes (Cox, fishing guide)
- No - Combined impacts of upstream reservoirs, loss of habitat, structural modifications, water quality concerns. Also proposed diversion of more water from the Colorado River (Boyd, TPWD ecosystem leader for San Antonio Bay)
- Yes - Huston and Oborny (Matagorda Bay Health Study)
- System is stable or returns to stability relatively quickly after disturbance (Beseres-Pollack, Palmer, and Montagna)

Threats

- Oyster drills in Powderhorn Lake (Ray)
- Dermo in oysters (Balboa)
- Development around bay (Hartman)
- Flounder and blue crab declined although flounder decline may be due to warmer winters that interfere with life cycle (Arnold, commercial fisherman)

The BBEST recommended freshwater inflow regime for Matagorda Bay adopts the MBHE inflow criteria, which are designed to cover the full range of inflow conditions into Matagorda Bay. The inflow suite for the MBHE inflow criteria includes long-term inflow conditions (presented as long-term volume and variability), an inflow regime (presented as MBHE 1–4), and extremely low and infrequent inflow events (termed Threshold).

The scientific information provided in previous freshwater inflow need studies (LCRA 1997, FINS 2006) was also considered. The 1997 FINS recommendation was based on five years of data collected after the 1991 diversion channel opening, relying on flow, salinity and biological productivity based on commercial harvest data. The 2006 FINS recommendation was based on an additional eight years of new data since the 1997 FINS, relying on flow, salinity, and TPWD coastal fisheries data. The MBHE study relied on historical flow data, salinity data, TxRR, and hydrodynamic modeling of the bay and marshes, nutrient and primary productivity modeling, habitat modeling, benthic community analysis, and biostatistical analysis (MBHE 2008).

A description of the historical inflows to Matagorda Bay, the available salinity data, and TxRR modeling is provided in the following section. While it is impractical to include a written description of all of the information and analyses that were undertaken as part of the MBHE study, it is beneficial to briefly describe the study components on which the Matagorda Bay inflow recommendations were based and include references to the background material.

The MBHE study developed substantial modeling and data analyses, which were employed to assess the relationship between causative factors and resulting bay condition. Several measures of bay condition were investigated, including salinity, habitat condition, species abundance, nutrient supply, and benthic condition. Also, it was determined that inflow criteria needed to be comprehensive and cover the full flow spectrum from very low flows (near drought-of-record conditions), in which species refuge becomes of primary importance, to higher flow events sufficient to provide adequate nutrient supply to the bay system. A summary of the MBHE study components that provided the basis of each Matagorda Bay inflow recommendation is provided in Table 2.7.2.

The portions of the bay system that were considered for the extent of influence for each inflow criteria, or "design areas" where MBHE modeling and analysis tools were applied, are presented in Table 2.7.3. These design areas were designated to depict the change in the spatial extent of the Colorado River influence in the Eastern Arm of Matagorda Bay with changes in freshwater inflow. These areas ranged from the substantial and important Delta area being formed at the mouth of the Colorado diversion channel, which was used to assess very low flow conditions, to the upper half of the Eastern Arm of Matagorda Bay (EAMB) for the inflow regime, and finally, to the entire EAMB for higher flow conditions.

Table 2.7.2 MBHE study components and analyses that provided the basis of each inflow recommendation.

Inflow Category	Inflow Criteria	Description
LONG-TERM	Long-term Average Volume and Variability	Existing primary productivity of the bay system and bay food supply
MBHE INFLOW REGIME	MBHE 4	Pulse variability, primary productivity, oyster reef health, benthic condition, low estuarine marsh, and shellfish and forage fish habitat
	MBHE 3	Pulse variability, oyster reef health, benthic condition, low estuarine marsh, and shellfish and forage fish habitat.
	MBHE 2	Inflow variability, oyster reef health, benthic condition, low estuarine marsh, and shellfish and forage fish habitat
	MBHE 1	Oyster reef health, benthic character, and habitat conditions
MINIMUM	Threshold	Refuge conditions for all species and habitats

Table 2.7.3 MBHE study design areas.

Inflow Criteria	Design Area
Long-term Average Volume and Variability	Eastern Arm of Matagorda Bay
MBHE 1, 2, 3, 4	Delta Edge to Mad Island Reef Transect
Threshold	Colorado River Delta

Physical and Salinity Modeling Component

Estuarine hydrodynamic and salinity transport are essential processes, which, in part, control the bay environment and its habitats. Movement of water and the resulting salinity patterns drive many of the higher estuarine processes; hence, a hydrodynamic and salinity transport model was essential to assess changes in habitat, nutrient balances, and productivity resulting from altered inflow regimes. After an extensive review of available models, the MBHE team selected the RMA model family (the family of finite element models supported by the U.S. Army Corps of Engineers [USACE]) to perform hydrodynamic/ salinity transport modeling. Because the coastal marsh/wetland areas are important habitats in the bay system, an RMA-based model was built to include the wetting/drying cycle in these areas, resulting in a more stable model. The final model grid is shown in Figure 2.7.2.

To provide a long-term simulation of bay hydrodynamics and salinity, the model was run for the period of July 1995 through December 2003. This time period included two extended low flow periods of 20 and 22 months, respectively, as well as a 22-month period of high flow. The results of this modeling provided the underlying hydrodynamics and salinities for the habitat and nutrient modeling.

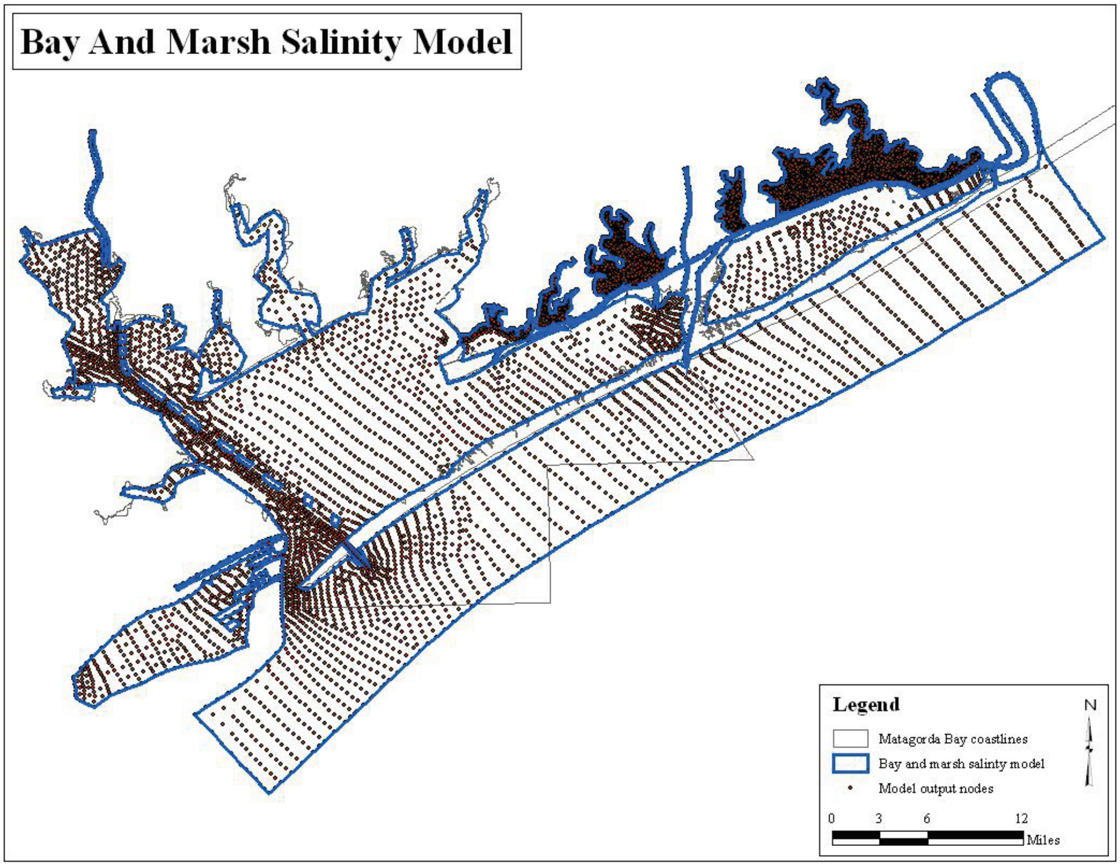


Figure 2.7.2 Map of the extent of the salinity model (blue) overlaid on an outline of Matagorda Bay (gray). Information on projected salinity and inundation was provided at the model output nodes (black dots) and interpolated between nodes.

Nutrient Component

The relation between inflows and nutrients was examined and built from a substantial amount of previous work by the TWDB, TPWD, TCEQ, LCRA, and various academic institutions (MBHE 2007c). MBHE (2007c) found that phytoplankton primary productivity is likely to be a very important component of the base of the estuarine food web in the Matagorda Bay system and the chlorophyll-a concentration measured in the bay is an acceptable measure of phytoplankton primary productivity. A conclusion from both the relevant literature and available field data indicated that inflows carrying nutrients, primarily inorganic nitrogen (N) are the dominant component regulating phytoplankton primary productivity. Phytoplankton primary productivity is also affected by release of inorganic N from the sediment, particularly during dry periods. Organic matter carried on inflows is also important to the base of the food web. Because the mechanisms involved in the transport of this organic matter are similar to those of inorganic nitrogen, they were considered in combination. Organic N contributed by inflows falls to the sediment and supplies inorganic N during dry periods. Other components of the bay food supply such as seagrass, benthic algae and tidal wetland are recognized as smaller contributors to the food web and were not explicitly quantified.

The MBHE team developed and calibrated a model that provides a simplified representation of the relation between nutrients carried by inflows and the amount of primary production, as represented by phytoplankton chlorophyll-a concentrations (Figure 2.7.3). The hydrodynamic model RMA2 developed for the MBHE provided the hydrodynamic data to drive the nutrient-primary productivity model. The WASP model provides a simplified representation of the relation between nutrients carried by inflows as well as those released from the sediment, and the amount of primary production, as represented by phytoplankton chlorophyll-a concentrations. Details of the literature, data, calibration, and accuracy checks are provided in Bay Food Supply Final Report (MBHE 2007c).

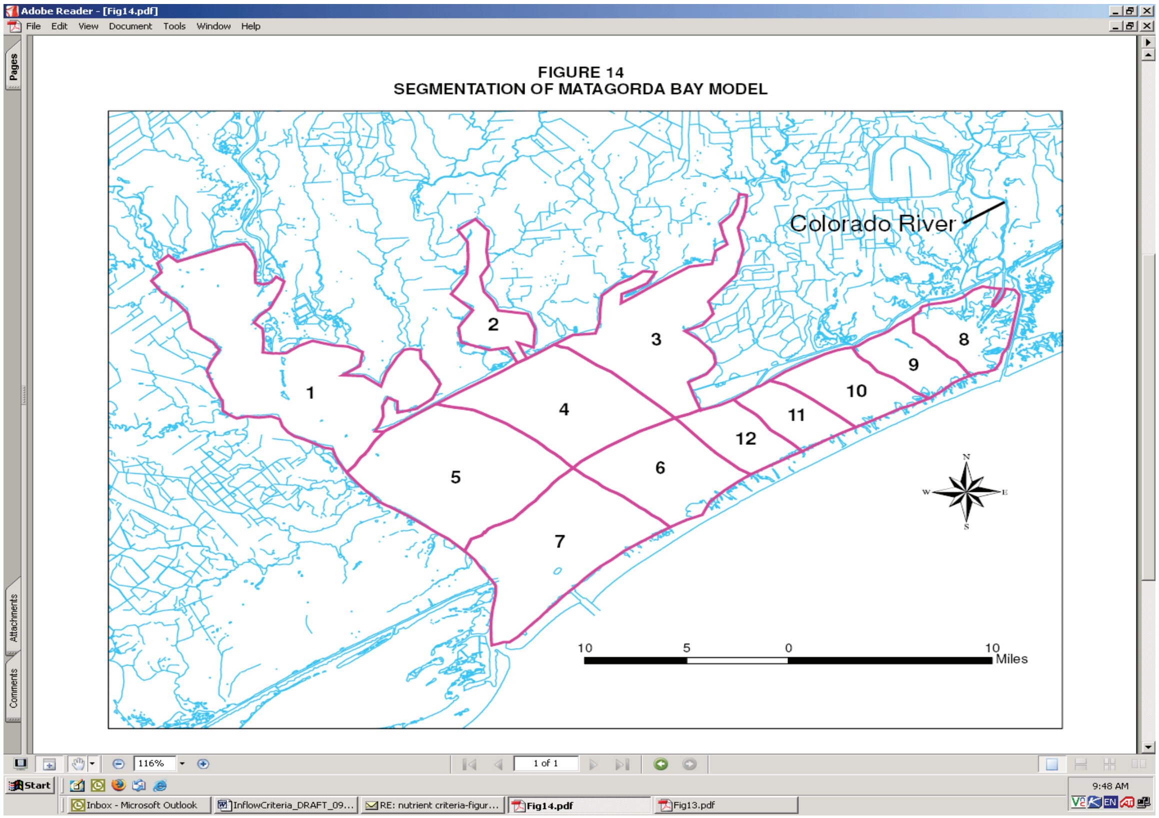


Figure 2.7.3 Segmentation of Matagorda Bay model for nutrient modeling.

Habitat Component

Key Species Habitat Condition

Habitat for five key aquatic species (brown shrimp, white shrimp, blue crab, Gulf menhaden and Atlantic croaker) and marsh within the Eastern Arm of Matagorda Bay and East Matagorda Bay were evaluated using a habitat model as part of the MBHE study. Two main analyses were performed to develop a quantitative area of suitable habitat for each of the species: habitat suitability curve development and habitat modeling to develop weighted usable area (WUA) curves (MBHE 2006a, MBHE 2007a).

In order to evaluate chemical and physical habitat within Matagorda Bay, habitat suitability curves were developed for each of the key species. Within this analysis, the chemical habitat preference is associated with an organism's affinity to certain salinities or a salinity range. Salinity ranges tolerated by each of the key species were compiled from NOAA's Estuarine Living Marine Resources (ELMR) Program information (Pattillo et al. 1997) and were refined using data from the NMFS and TPWD databases, special studies, and field and laboratory experiments. Physical habitat selection values are based on information from NMFS drop-trap samples and TPWD bag seine samples and were developed independently for each of the key species. These suitability curves are available in the MBHE final habitat assessment report (MBHE 2007a).

Using GIS, the area encompassed by the habitat model was divided into square 10-mile grid cells for both the physical habitat and chemical habitat inputs. The physical habitat map is shown in Figure 2.7.4. The Habitat Suitability Index (HSI) value corresponding with each physical habitat and chemical habitat type for a particular juvenile organism was assigned to the cells within both of the input files (MBHE 2006a). Both physical habitat HSI and chemical habitat HSI values range from 0 to 1. A selection value of 1 is the highest value assigned and indicates juvenile organisms of that species are found in the highest abundance within that habitat. Lower selection values are assigned to other habitats with proportionally lower populations of juveniles. Any habitat that is not suitable for a juvenile species receives a ranking of 0 and is consequently designated as an area that is not available for the organism. The two habitat inputs are overlaid in GIS so that every grid cell has a corresponding physical habitat attribute and chemical habitat attribute. These two habitat input files are created individually for each of five key species. The overall suitability of each grid cell is evaluated by calculating a habitat composite suitability index, combining the two suitability indices (MBHE 2008). Additionally, relative productivity (representing a proportion of maximum productivity), of low and high estuarine marsh habitats within the physical habitat input file, was evaluated based on each salinity input file. The marsh productivity relationships with salinity are presented in MBHE (2006a).

Habitat model output curves for five key species within the Colorado River delta (Delta), Mad Island Marsh Preserve (MIMP) marsh complex north of the GIWW, and the Eastern Arm of Matagorda Bay (EAMB) illustrate the WUA of habitat over a range of salinity conditions within those regions of the bay (Figures 2.7.5-2.7.10). Additional WUA curve information and results of the habitat analysis are presented in a technical report (MBHE 2007a) and the Matagorda Bay Inflow Criteria document (MBHE 2008). Several key observations were noted during habitat modeling including the importance of low estuarine marsh habitats to shellfish, a sharp decline in habitat availability for most species (brown shrimp excepted) as conditions shift from estuarine to marine, and decrease in habitat availability at the salinity extremes (MBHE 2008).

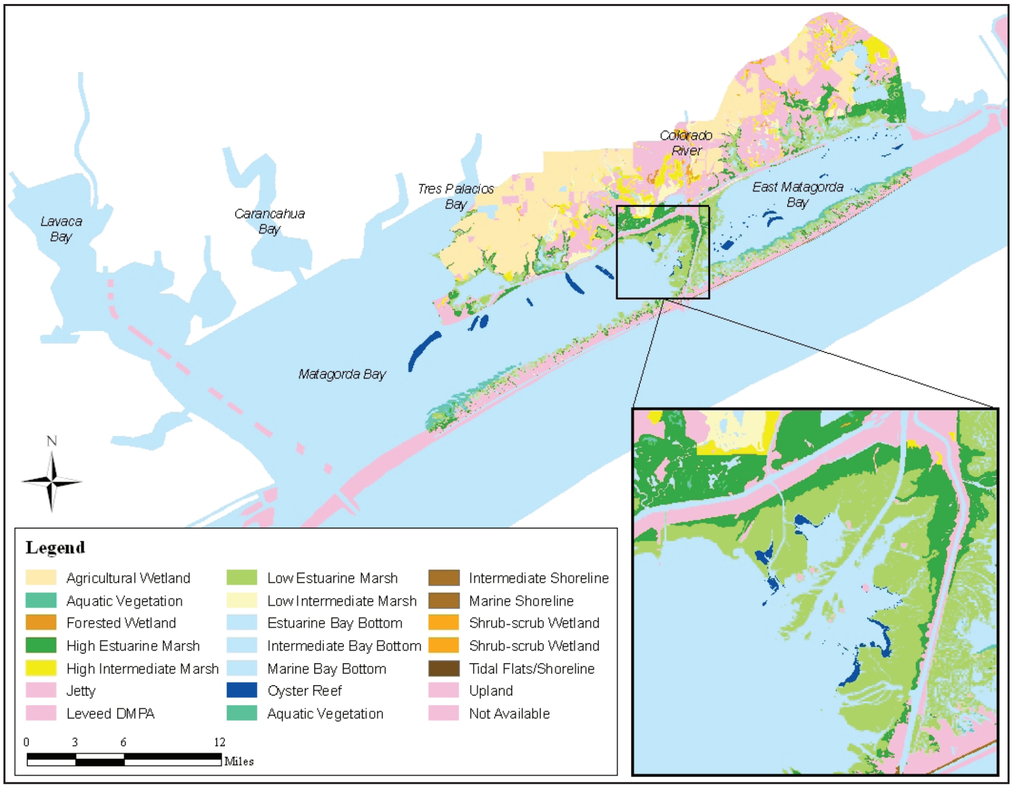


Figure 2.7.4 Map of physical habitats within the project area extending from Tres Palacios Bay to Lake Austin, including East Matagorda Bay.

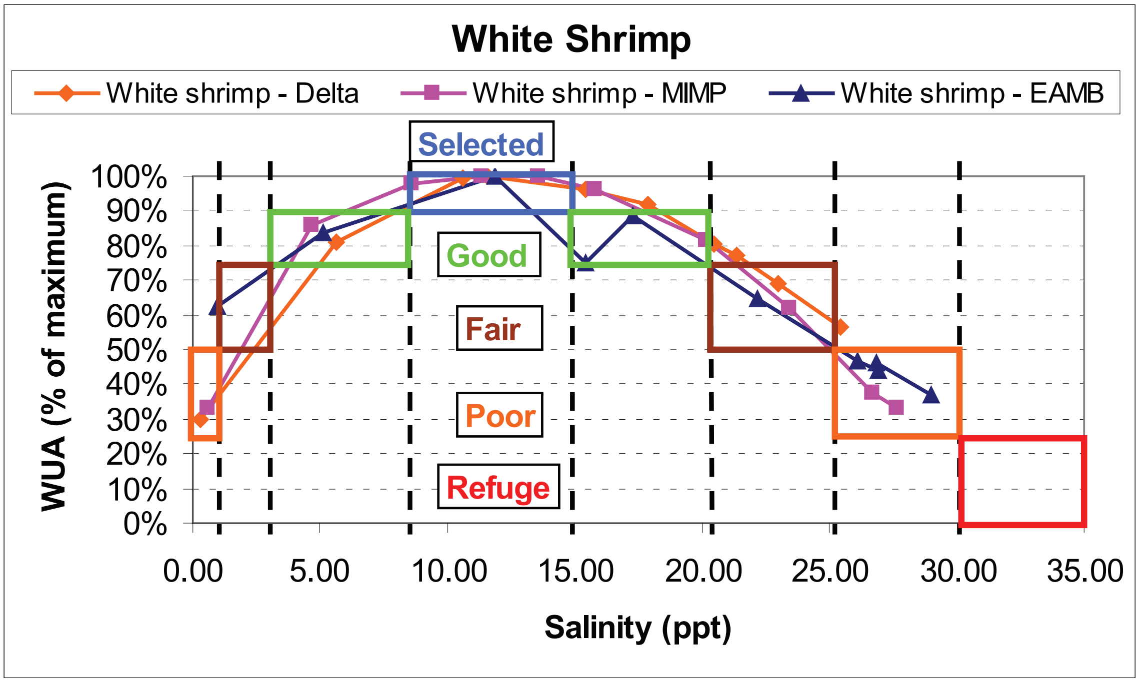


Figure 2.7.5 Habitat Model output—Percentage of Maximum WUA for white shrimp in the Delta, MIMP, and EAMB.

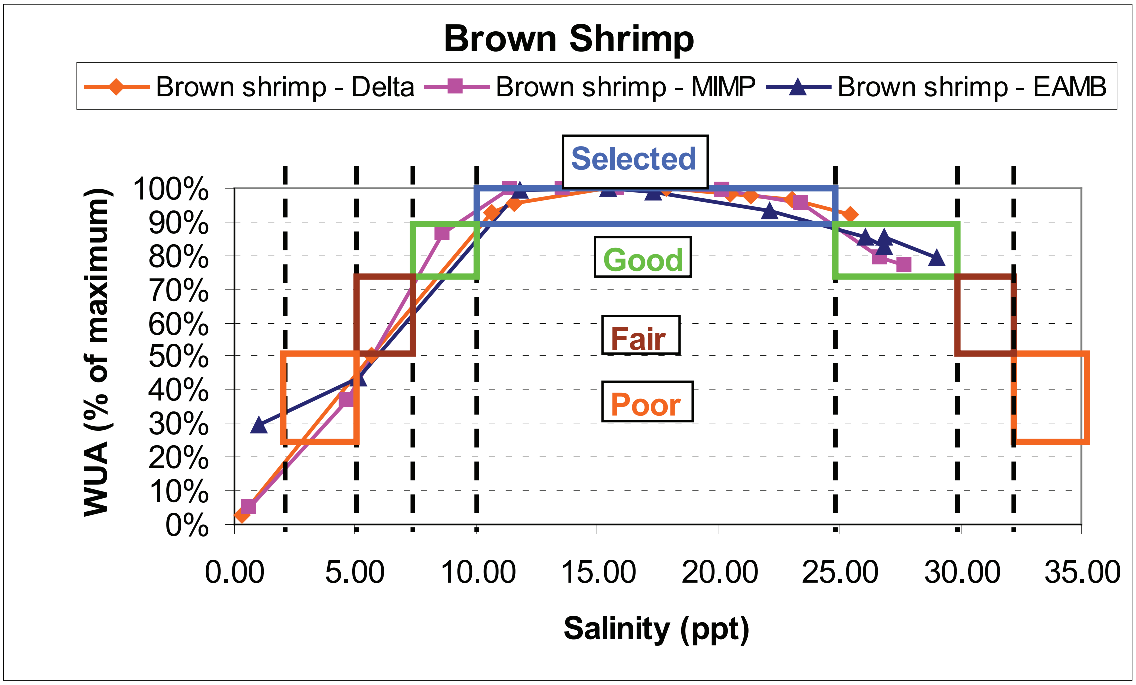


Figure 2.7.6 Habitat Model output—Percentage of Maximum WUA for brown shrimp in the Delta, MIMP, and EAMB.

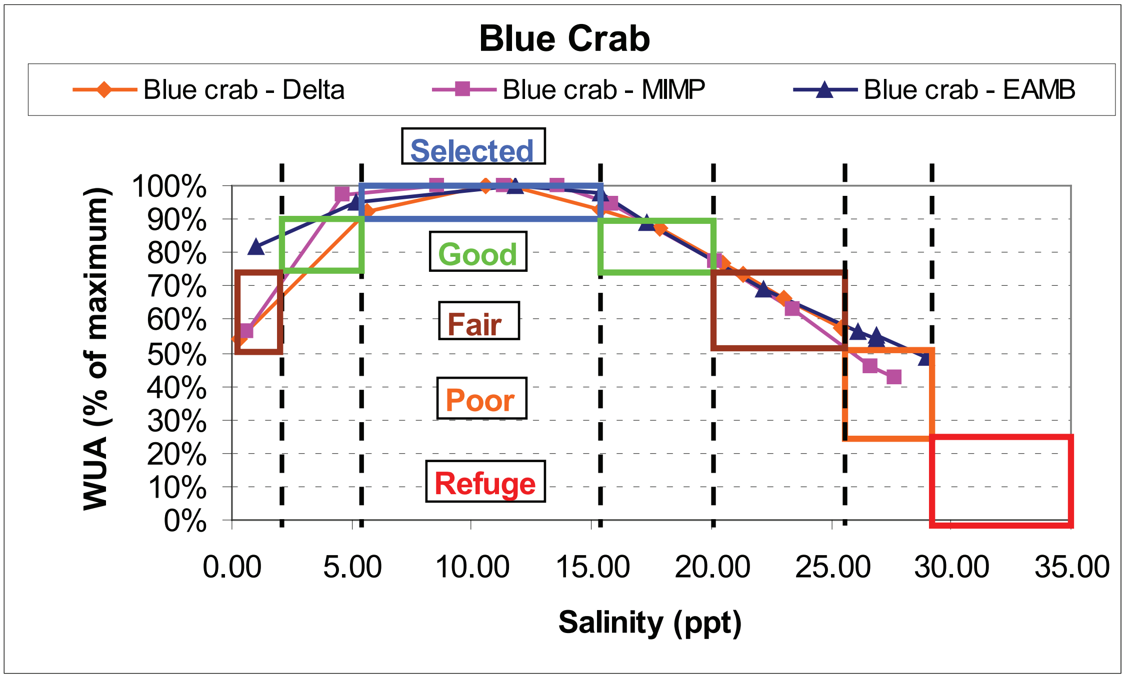


Figure 2.7.8 Habitat Model output—Percentage of Maximum WUA for blue crab in the Delta, MIMP, and EAMB.

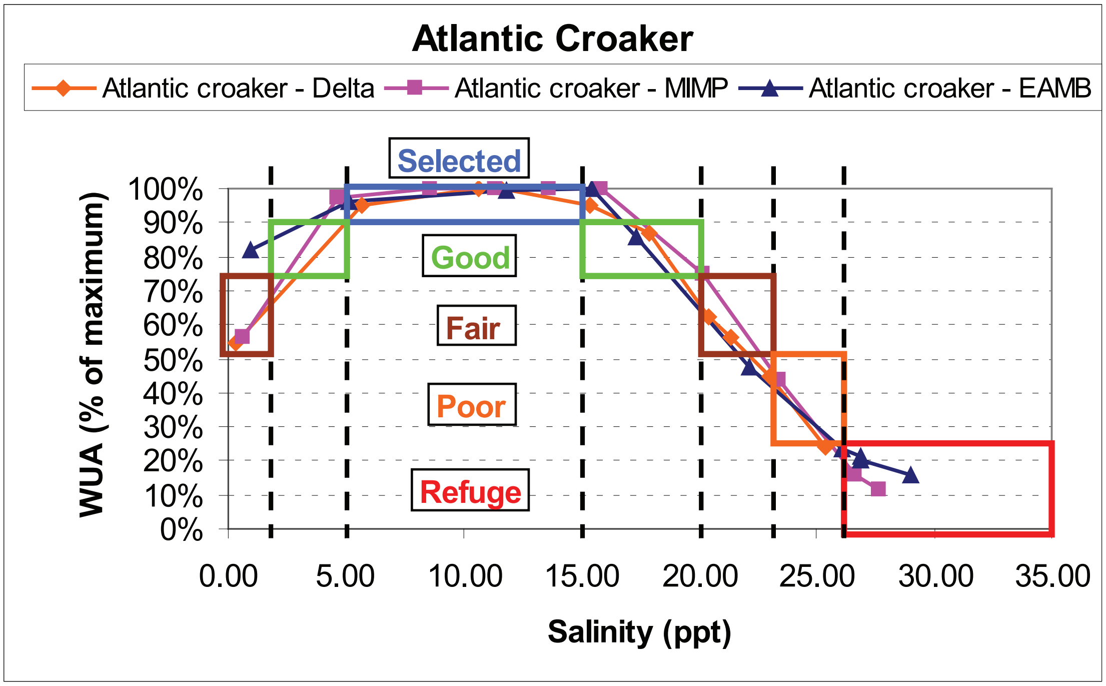


Figure 2.7.9 Habitat Model output—Percentage of Maximum WUA for Atlantic croaker in the Delta, MIMP, and EAMB.

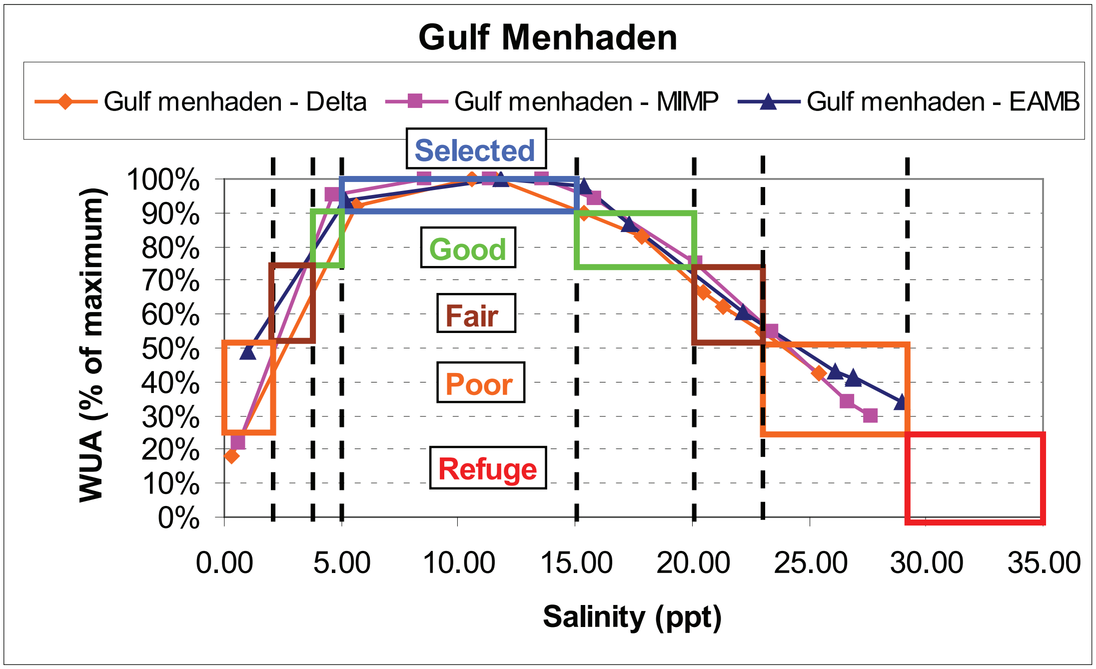


Figure 2.7.10 Habitat Model output—Percentage of Maximum WUA for Gulf Menhaden in the Delta, MIMP, and EAMB.

Oyster Condition

In the 2006 Habitat Progress report (MBHE 2006a), a number of oyster reef condition indices (CI) were developed as simple descriptors of the health of Eastern oysters, *Crassostrea virginica*, in areas potentially impacted by the LSWP. A long-term oyster database for the Matagorda Bay region was constructed by combining information from the TPWD oyster dredge database and the Dermo Watch database (also called the Oyster Sentinel database; http://www.oystersentinel.org). The combined database contains monthly averages of parameters for reef locations in Matagorda, Galveston, and San Antonio bays from 1996 through 2006 (non-Dermo Watch reefs) or 2007 (Dermo Watch reefs). Regression models were then developed to relate values of the CIs to salinity and temperature conditions in the database. These models can provide the framework for biological linkage of the health of Eastern oysters to the Matagorda Bay hydrodynamic/salinity model and for linking oyster condition to bay inflow criteria.

In 2007, two of the CIs were refined and selected for further use, while others were discontinued (MBHE 2007a). The database development, CI development and refinement, regression model development, and validation exercises were detailed in MBHE 2007a. The oyster database was further updated in early 2008. The two CIs are OCI (oyster condition index) and DCI (dermo condition index). OCI is an index of abundance of commercial-sized oysters, and DCI is an index of dermo infection level in commercial-sized oysters. Dermo is the common term for *Perkinsus marinus*, the most destructive oyster parasite in the Gulf of Mexico.

Only DCI was used for inflow criteria development, as it was preferentially chosen over OCI because of the relatively strong statistical relationship (high R2 value) of the DCI model as compared to the OCI model (MBHE 2007a). DCI model results illustrate the modeled weighted incidence of dermo infection during average and extreme salinity and temperature events (Figure 2.7.11). Lower two-year average salinity conditions have been related to lower dermo weighted incidence (lower infection levels). Additionally, high two-year spring temperature and low three-month rolling average temperatures have been related to lower dermo weighted incidence.

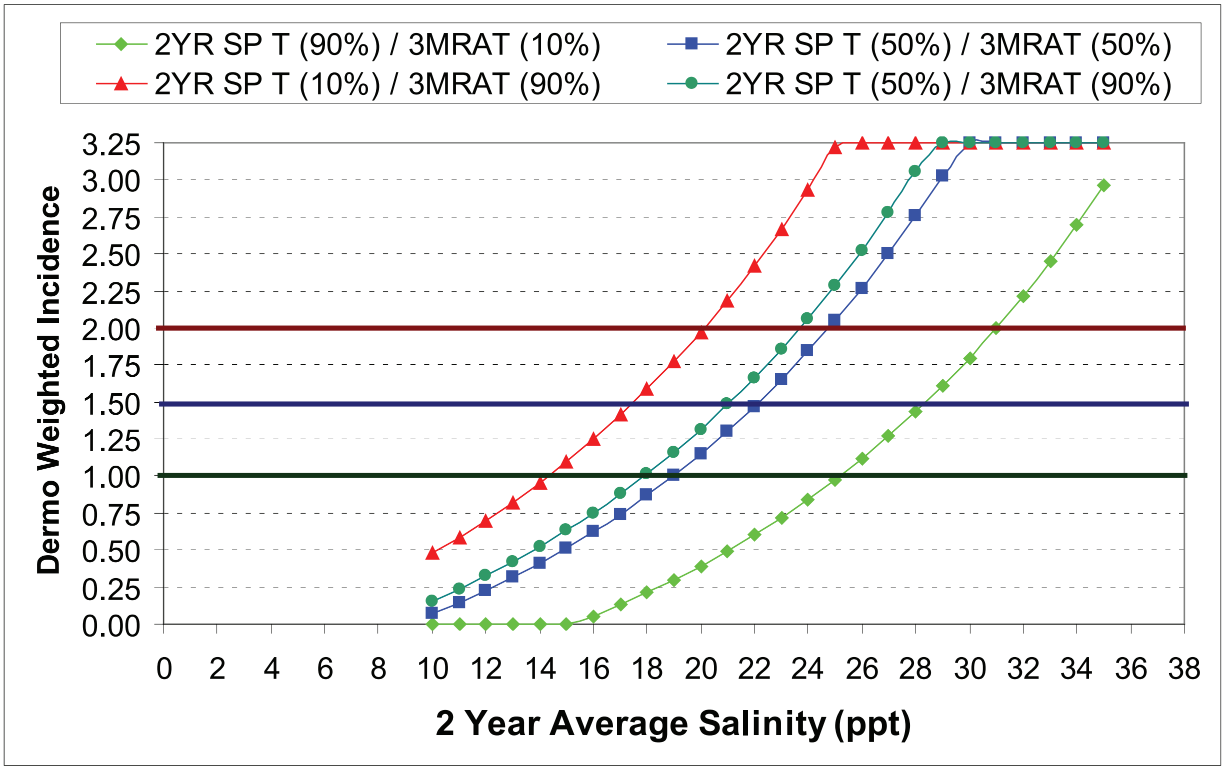


Figure 2.7.11 DCI model results: two-year rolling salinity versus predicted dermo weighted incidence for four temperature regimes (described in MBHE 2008) representing average and extreme temperature conditions. Temperature components in the model include a two-year spring temperature average term (2YR SP T) and a three-month rolling average temperature term (3MRAT). Horizontal lines represent levels of dermo weighted incidence considered to represent high quality reef condition (<1.0), slight concern (1.0–1.5), moderate condition (1.5–2.0), and poor condition (>2).

Benthic Component

The benthic analyses performed in part for the MBHE was based on long-term monitoring of benthos and involved description of benthic community structure in Matagorda Bay, characterization of benthic community variability over broad spatial scales in the bay, and benthic productivity modeling. A map of the benthic community study locations is shown Figure 2.7.12. Information regarding the benthic biomass and diversity data, principal component analysis, and non-metric multidimensional scaling (MDS) are reported by Montagna et al. (2006a, 2006b, 2008).

Integrating the results of the three benthic studies allows an assessment of the potential for changes in benthic condition that result from changes in salinity. The analysis of long-term benthic community structure data reveals strong year-to-year variability in benthic biomass and freshwater inflow, and indicates there has been a general decline in long-term biomass over the study period. These data also show strong spatial gradients of benthic biomass, productivity, community structure, and diversity related to salinity gradients. Long-term salinity values indicate two clear salinity/community zones exist: 1) a brackish and more freshwater-influenced zone (12–19 ppt) including Matagorda Bay station F, and 2) a marine-influenced zone (22–27 ppt) that includes Matagorda Bay stations C, D, and E. The characterization of benthic habitat variability indicates that conclusions based on the long-term stations generally represent the soft-bottom bay sediments throughout the entire study area. Results of the benthic productivity modeling study also show that benthic productivity is related to salinity (MBHE 2008). In particular, increases in freshwater inflow lead to greater community and functional diversity, while reduced inflow results in reduced suspension-feeder productivity and increased deposit-feeder productivity in both Lavaca and Matagorda bay.

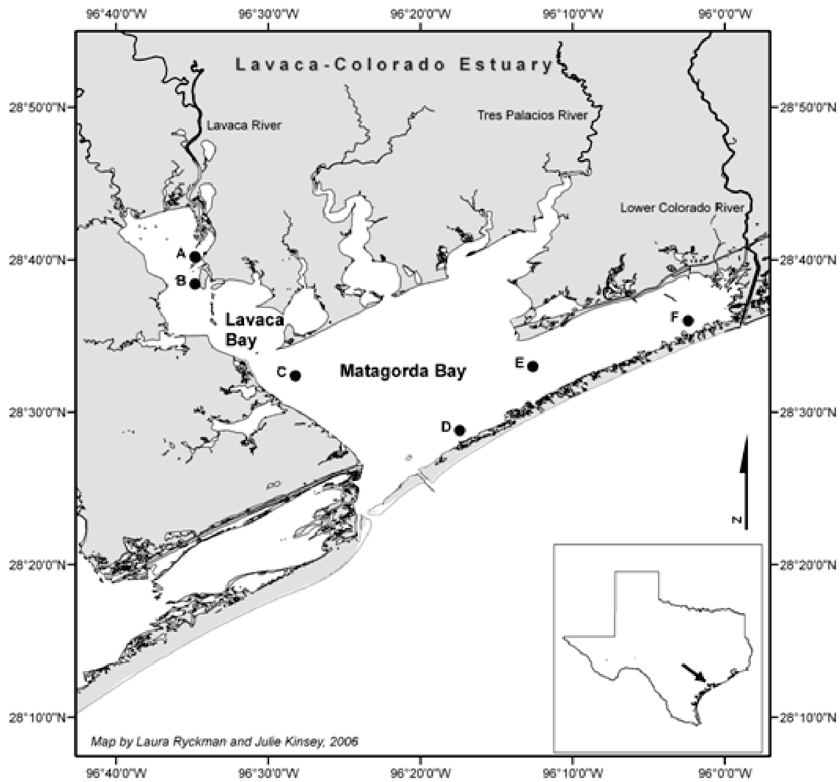


Figure 2.7.12 Map of Matagorda Bay benthic study sampling stations.

Biostatistical Component

A biostatistical analysis using the TPWD Coastal Fisheries database and hydrologic parameters was conducted as part of the MBHE (MBHE 2006d). Multivariate regressions for each organism's abundance (as the dependent variable) with both linear and non-linear regression forms were generated and analyzed to assess which, if any, yielded statistically valid and meaningful relations. These analyses were performed for different organisms, gears, and methods of estimating abundance, geographical regions, and parameterizations of inflows. Separate analyses were carried out for post-diversion data, and for biological data extending back to 1977. For some of the species, there is evidence that the statistical behavior fundamentally changed at the time of the diversion project, which must be borne in mind when pre-diversion data are considered. More detail on these aspects of the biostatistical work is given in MBHE 2006d.

There exists great residual variation of abundance data about the statistical relations solely based on inflow. As far as the key species addressed in the bio-statistical effort are concerned,

1. the annual-mean abundances are highly variable even when a variation with flow is taken into account due to a combination of intrinsic fluctuation in the field data measuring abundance and the effects of variables other than inflow; and

2. no reduction of inflow levels in the historical record has resulted in elimination of any of these species from the bay (because there are no zero values of annual-mean abundance in the data record), nor has it precluded the re-establishment of its population after that population has suffered a reduction (because they continue to exist at more-or-less historical levels).

Useful conclusions can be drawn from the available data upon which the regression relations were developed, notably the importance of freshet flows to abundance and which season is most important to a given organism. In general, significantly improved explained variance was achieved using seasonal freshet parameters, as opposed to say, annual flow. The strongest regressions were found for white shrimp (versus fall freshets) and Atlantic croaker (versus spring freshets). It is assumed that if these flows are protected then these and any other organisms that respond to these freshet flows would be protected as well.

Recommended Matagorda Bay Freshwater Inflow Regime

The recommended suite of Matagorda Bay Inflow Criteria for the Colorado River (see the following table) was adopted from the MBHE study (MBHE 2008). This freshwater inflow regime incorporates the most recent Matagorda Bay analyses, provides seasonal freshwater inflow values, allows for variability in freshwater inflow to the estuary, and should provide for a sound bay environment. The "threshold" recommendation of 15,000 ac-ft per month has not been met historically with 100% achievement. This volume condition may require the release of water from storage to supplement natural flows in dry years. The spring pulse is defined as the maximum consecutive three-month volume occurring during the January through July period. The fall pulse is defined as the maximum consecutive three-month volume occurring during the August through December period. The intervening period volume is the sum of the remaining six months' volume in a calendar year.

Table 2.7.4 Recommended freshwater inflow regime for Matagorda Bay.

	Flow Volumes (acre-feet)			Achievement Guideline†
Threshold	Maintain 15,000 acre-feet per month			100%
Regime:	**Spring**	**Fall**	**Intervening**	
MBHE 1	114,000	81,000	105,000	90%*
MBHE 2	168,700	119,900	155,400	75%*
MBHE 3	246,200	175,000	226,800	60%*
MBHE 4	433,200	307,800	399,000	35%*
Long-term Volume and Variability	Average at least 1.4 to 1.5 million acre-feet per year‡			100%

†Achievement guidelines refer to the amount of time that the flow volumes should be met or exceeded. *Based on historical frequency of occurrence.

‡Recommend projected long-term annual average flow is maintained at a level of at least 1.4 to 1.5 million acre-feet, with a coefficient of variation (CV) value above 0.8.

2.8 Lavaca Bay

Southwest view of Lavaca Bay (left). View of bay from left bank, looking southeast toward causeway (right).

View of west bank of bay, above causeway, extreme low tide (left). View of west side south of causeway (right).

General Area Description

- Main sources of freshwater: Lavaca River (27.5%), Navidad River via Lake Texana releases (51%), and Garcitas Creek (9.4%): Chocolate Bayou at times is a substantial contributor of freshwater to the lower portion of the bay
- Lavaca-Navidad watershed contributes approximately 17% of freshwater inflow to the Matagorda Bay system (Sansom 2008)
- Secondary bay of the Matagorda Bay system
- Flushes more rapidly than many other Texas secondary bays
- Salinity varies seasonally, ranging from 0 ppt during the spring to 30 ppt in late summer/fall
- Important fishery
    - Important oyster fishery for entire Texas coast. In the late 1800s to the early 1900s, 80% of oyster harvest from coast of Texas occurred here (Doughty 1984)

  - Important green turtle (sea turtle) fishery from the late 1800s to the early 1900s (Doughty 1984)
  - Continues to support important shrimp, oyster and recreational fishing industries
- Diversion from freshwater sources occurred over time for rice field irrigation
- Navidad River was impounded in 1980, creating Lake Texana, approximately 12 miles north east of Lavaca River delta
- The Navidad and Lavaca Rivers merge south of Lake Texana before flowing into Lavaca Bay. Sandy Creek and East and West Mustang Creeks flow into Lake Texana

Physical Characteristics and Nutrient Processes

The Lavaca–Tres Palacios estuary has normal tidal variation around 0.5 ft in the bay. Wind is a major factor influencing physical processes, including erosion, accretion, and other changes in the shoreline. Because of the shallow depth throughout the estuary, wind can play a major role in the generation of waves and long-shore currents. The peak influx of freshwater corresponds with spring rains. Major impacts from these inflows include overbank flooding of marsh areas, extension and building of deltas, flushing of the bay, and salinity reduction. Nutrient contributions are derived from river inflow and local runoff, and biogeochemical cycling in deltaic and peripheral salt or brackish water marshes. Detrital transport is dependent in part on the marsh inundation and dewatering process (TDWR 1981). Beseres Pollack et al. (2010) related long-term changes in the relationships between precipitation, salinity, and the El Niño Southern Oscillation in Lavaca Bay. They found the abundance, biomass, and diversity of dominant benthic organisms have declined over the past 20 years as salinity as declined over the same time.

Freshwater discharge is the primary source of dissolved organic matter throughout the Lavaca and Matagorda Bay system, which in turn drives benthic productivity (Montagna 1999).

Nutrients are less correlated with salinity than organic parameters, indicating that the organics are more highly loaded by inflows than nutrients, (Shank et al. 2009). Enhanced flushing associated with freshwater input increases turbidity due to sediment resuspension and transport.

Nutrients associated with freshwater input affect the distribution of freshwater, estuarine, and marine zooplankton (Jones et al. 1987). Zooplankton taxa diversity increased when river inflow increased to near 2,000 cfs. This flushing causes organisms with larval planktonic stages to be moved from shallow protected areas into the open bay. Barnacle nauplii and some copepods were the most abundant taxa at salinities between 22–23 ppt. Their numbers decreased when inflows increased above 2,000 cfs (Gilmore et al. 1976). There is long-term, year-to-year variability in inflow. Higher inflow adds more dissolved inorganic nitrogen to the system, which stimulates primary production. Inflow also drives the benthic community, which changes due to differences in salinity (Montagna et al. 1999).

Habitats (TPWD SWG Oyster Mapping Project Simons 2010)

The substrate of most of Lavaca Bay is shell on sand, scattered shell and oyster reef.

- Established oyster reefs occur throughout much of the bay.
- Estuarine marsh fringes much of the bay, and its freshwater tributaries.

- Wetlands fringing river freshwater sources are intertidal, dominated by palustrine, emergent, herbaceous plant species and are regularly flooded. These wetlands are dominated by *Juncus roemerianus* (Porter unpl. 1992).
- Wetlands that fringe Keller, Chocolate, Cox, and Alamo Bays are intertidal and subtidal, many with unconsolidated shore (USFWS 2010). The dominant marsh plant here is *Spartina alterniflora* (Porter unpl 1992).
- Palustrine marsh is found along the Lavaca and Navidad rivers prior to their confluence.
- Palustrine forested marsh is found between the palustrine and the estuarine marshes of all freshwater sources.
- Subsidence above the delta has led to loss of marsh and increased open water (Tremblay and Calnan 2010).
- A loss of 34% of tidal flats has occurred since 1956 (when first mapped), and has been replaced with estuarine marsh and open water. Wetland habitats have moved inland because of sea-level rise (Tremblay and Calnan 2010).

Biology

Source	Location	Biology	Observations
Montagna 2008	Lavaca Bay and other minor bays of Texas coast	Macrobenthos and association with freshwater inflow and water quality	FW inflow decreases salinity but increases nitrogen and chlorophyll. Benthic communities exhibit relatively low numbers in Lavaca Bay compared to other Texas bays
Longley 1994	Texas bays and estuaries, Lavaca Bay	Seagrasses: *Halodule*, *Ruppia*, coastal salt marsh plants: *Spartina alterniflora* (dominant), communities, major zooplankton species were discussed. The following organisms use the bay for various parts of their life cycles: Eastern oyster, brown shrimp, white shrimp, blue crab, spotted seatrout, red drum, Atlantic croaker, striped mullet, Gulf menhaden,	Seagrass, coastal marsh communities and zooplankton were dependent on salinities and freshwater inflow. Several of the fish species utilize the bay/marsh areas as nurseries for juveniles.

Source	Location	Biology	Observations
TPWD 1975	Lavaca-Matagorda Bay system	Discuss major economic fisheries, sport and commercial, (shrimp, crab, oyster),	Salt marshes act as oscillating-flow systems, hydrologic regime is essential for nutrient transport from salt marshes to adjacent estuarine systems, marsh vegetation and algae remove nutrients as soon as they become available. High water flushes algal material from the marsh and revives algal mats. Low water permits drying and sloughing of algal materials, normal water levels allow a steady but reduced exchange of nutrients from the marsh.
NOAA 1990	Lavaca Bay, *Juncus* and *Spartina* marsh use by fisheries species	Thirty five species were found in coastal sites vs. 27 at delta sites. Spotted seatrout, southern flounder, red drum occurred in both habitats. More decapod species were found at coastal sites vs. delta: brown shrimp, blue crab, white shrimp and pink shrimp were found in both habitats. Blue crab were more abundant in the delta and broken back shrimp more abundant at coastal sites. Brown shrimp were more abundant in spring, blue crab and pink shrimp in fall.	Delta marshes exhibited lower abundance of estuarine species when exposed to salinities < 2 ppt for periods longer than one month. Short term FW floods had little effect on marsh utilization. High rainfall and freshwater inflow have been associated with increased production of white shrimp (Gunter and Hildebrand 1954, Mueller and Matthews 1987)

The BBEST gathered scientists, local experts and researchers familiar with Lavaca Bay in July 2010 to elicit opinions of the importance of freshwater inflow to Lavaca Bay and the current environmental state of the bay. Specific comments regarding important species, habitats, and relationships between inflow and the bay are summarized in Table 2.8.1 below. General observations regarding the Lavaca Bay system were that the system is relatively small compared to its drainage basin and tends to have a low freshwater retention time. Experts identified oysters and emergent marsh as two key components of the ecosystem. Opinions varied regarding the health of the bay with some believing it is a stable system which returns to stability relatively quickly after flow fluctuations; others believing it was not healthy because of modifications to the flow regime; and others believing it was acceptably healthy.

Table 2.8.1 Results of Bay Expert Information provided in a meeting of bay experts on July 9, 2010 in Palacios, Texas, in telephone conversations, and e-mail correspondence
Key Species
• Benthic animals and plants, particularly clams and oysters are best indicators for ecosystem health (Montagna) • Waterfowl (Culbertson) • Bald eagles along Lavaca River tidal (Balboa) • White shrimp (Balboa, Schlicht) • Redfish and Juncus in Swan Lake (Balboa) • Spotted and alligator gar-long-lived, seemed to use the fresh/salt water interface (Hartman) • Gray snapper, a high salinity species (Hartman) • Lesser blue crab, a high salinity species (Hartman) • Rangia-in upper Lavaca Bay, at salinities less than 5 ppm • Colonial wading birds • Oysters • Grass shrimp (Hartman) • Gulf menhaden • Mantis shrimp • Redfish and spotted sea trout • Diamond-back terrapins in NW corner of bay • Juncus in Swan and Redfish lakes
Key Habitat
• Oyster reef at mouth of Keller Bay extremely productive • Seagrass (Halodule) in Keller Bay (Balboa) • Spartina marsh (Balboa) • Oysters, dead • Wetlands in upper reaches of bay • Small islands provide bird rookeries • Brackish and freshwater marsh (Balboa)
Ecological Processes
• Water Quality depended on tide, wind, diminishing freshwater inflow • Small bay relative to size of watershed, low freshwater retentiona time
Inflow Remarks
• More responsive to freshwater inflow than East Matagorda Bay (Wakefield) • Reduction of Rangia beds suggest a sensitivity to freshwater inflow (Hess) • Small bay relative to watershed size (Jensen) • Large flushing events can interrupt shrimp production • Shrimp abundance shows a positive relationship with inflow • Absence of Rangia may indicate a sensitivity to freshwater inflow • Fair amount of water diverted from Colorado River and discharged into Lavaca watershed (Jensen) • Oystering never occurred upstream of the causeway until after a big flood (Jensen) • After flooding in the 1980s, more species observed (Wakefield) • Not unsound, but reduction in Rangia and mercury contamination push its condition towards degraded (Johns) • More species collected in Sept-Oct 1986 during high flows (Wakefield)
Sound Environment
• Acceptable - not as environmentally sound as East Matagorda Bay (Hartman) • Yes - not as environmentally sound as East Matagorda Bay (Johns) • Ecosystem stressed by reduced inflow, channelization, and industrial discharge • Yes - if fish are healthy and populations are productive (Balboa and Jancek) • No (Dailey, former TPWD ecosystem leader for Matagorda Bay) • Yes (Arnold, commercial fisherman) • System is stable or returns to stability relatively quickly after disturbance (Beseres-Pollack, Palmer, and Montagna)
Threats
• Rangia declined in upper Lavaca Bay after Lake Texana built (Balboa) • Mercury contamination results in fish consumption advisories

Water Quality

TCEQ has designated Lavaca Bay (TCEQ Water Quality segment 2453) and its secondary bays with high to exceptional aquatic life use (TCEQ 2010). TCEQ's review of water quality monitoring data for Lavaca Bay, its secondary bays, and tributaries over the period from December 1, 2001 through November 30, 2008 was assessed. In general, water quality and nutrients did not exceed levels of concern. In portions of the bay, there were occasional chlorophyll a concentrations above the assessment criterion, and in Garcitas Creek tidal and the Lavaca Ship Channel, dissolved oxygen levels were sometimes lower than the criterion. There is a fish consumption advisory for certain species in a part of the bay because of legacy mercury contamination from an industrial source. At times bacterial levels are above concentrations considered safe for harvest and consumption of oysters.

Hydrology

A freshwater inflow regime consisting of a range of inflow conditions is essential for maintaining a sound environment in the Lavaca Bay ecosystem. The bay receives inflow from several sources, including inflow from rivers and streams, local tidal creeks, direct precipitation, and agricultural runoff. Many of these sources are ungaged and the volumes can only be estimated. For the purposes of freshwater inflow regime development, the inflows from the Lavaca River, Lake Texana releases, and Garcitas Creek were utilized, as these three sources usually provide the vast majority of total inflow to the system and are key drivers of salinity/habitat conditions in Lavaca Bay.

Lake Texana began impounding the Navidad River in 1982. Releases from the reservoir were summed with flows from USGS gage Lavaca at Edna (08164000), and USGS gage Garcitas Creek at Inez (08164600) for purposes of this inflow analysis. The percentiles of monthly freshwater inflows from various sources into Lavaca Bay are shown in Table 2.8.2 below. TWDB's TxRR model was used to estimate inflows for the ungaged Placedo Creek, Cox Creek, and Chocolate Bayou (TWDB 2011b). The period of November 1986–August 2006 was selected for analysis because it represented variable hydrological conditions, both hydrological and salinity data were readily available for this period, and the TWDB provided daily average salinity model output for important sites over this period.

Table 2.8.2 Percentiles of monthly ac-ft of freshwater inflow from different sources into Lavaca Bay.

Category of Data	Lavaca Rv nr Edna (USGS)	Lake Texana Releases	Garcitas Creek nr Inez (USGS)	Lavaca, Lake Texana, Garcitas	Placedo Creek (TxRR)	Cox Creek (TxRR)	Chocolate Bayou (TxRR)	TOTAL Lavaca Bay Inflow
10th	840	661	132	3,549	35	53	139	4,422
25th	2,169	2,903	606	7,524	140	300	631	9,368
50th	6,032	11,870	3,016	26,845	645	1,252	2,797	35,521
75th	26,153	54,898	9,728	96,332	2,393	4,182	10,181	109,072
90th	93,143	160,564	24,029	272,752	5,372	10,234	21,246	319,614
Average	31,262	57,967	10,669	103,636	2,110	3,542	8,084	113,634
% of Total	27.5	51.0	9.4	91.2	1.9	3.1	7.1	

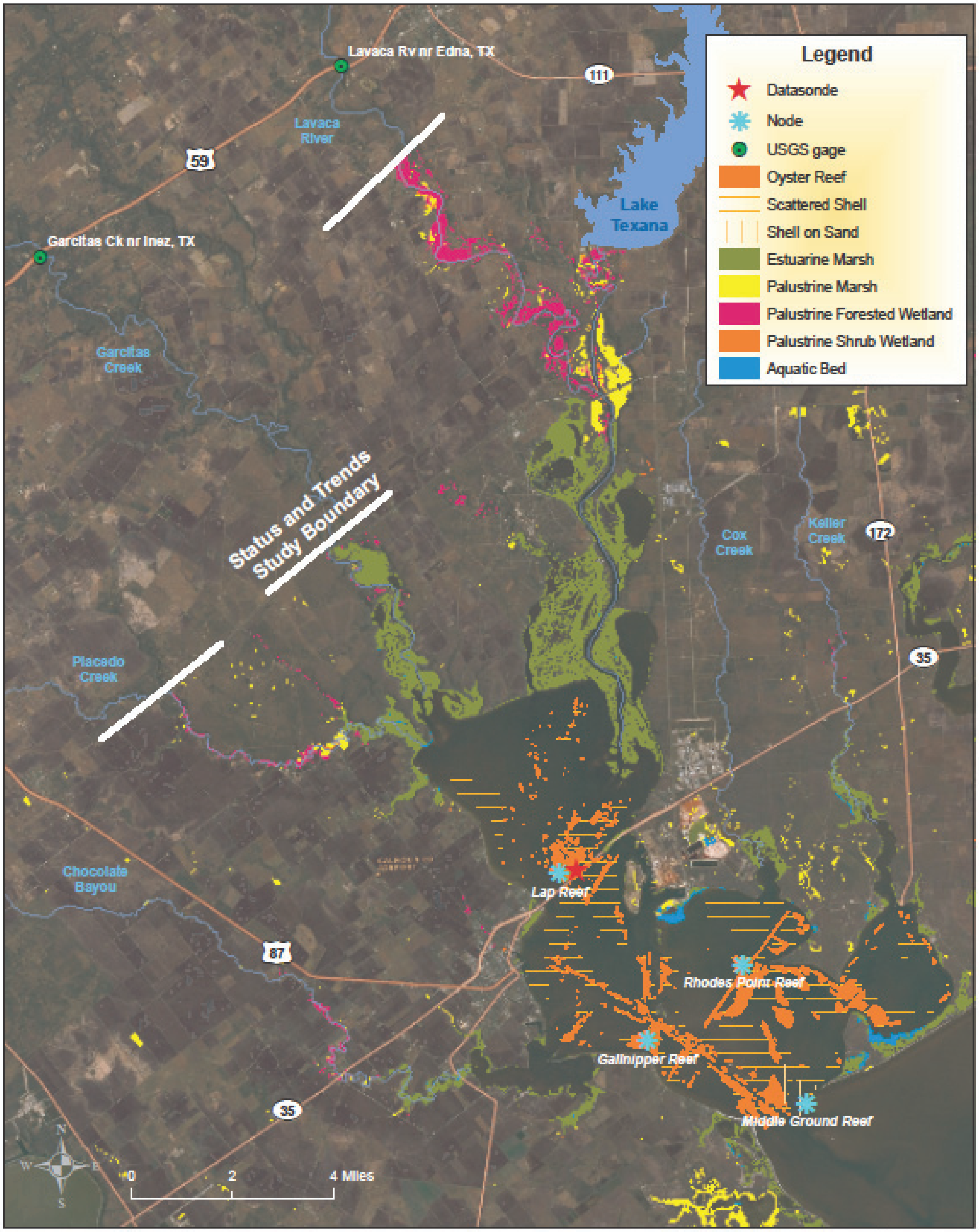
A mathematical relationship between Lavaca River, Lake Texana releases, and Garcitas Creek inflows and Lavaca Bay salinity was developed to translate the desired salinity conditions in Lavaca Bay to numerical inflow values.

Salinity

Estuarine hydrodynamic and salinity transport are essential processes that, in part, control the bay environment and its habitats (MBHE 2008). The TxBLEND hydrodynamic salinity model was used by the TWDB to produce a salinity time series at four locations in Lavaca Bay. These locations correspond with significant oysters reefs in the system (Table 2.8.3, Figure 2.8.1 (map)). These four reef systems represent 1,120 acres (38%) of the estimated oyster reef area in Lavaca Bay ranging in distance from near the freshwater inflow from the Lavaca River, Garcitas Creek, and Lake Texana to the confluence of Lavaca Bay with Matagorda Bay (Simons, et al. 2004). Substantial reefs were surveyed in these same locations during a 1913 survey of Lavaca Bay oyster reefs (Simons et al. 2004), documenting the historical persistence of oysters in these areas.

Table 2.8.3 Description of target oyster reefs used to develop salinity-inflow relationships (Simons et al. 2004)

Reef Name	Area (acres)	Distance from Lavaca River delta (miles)	Observations
Lap Reef complex	212	4	Within 500 meters of the TWDB continuous salinity monitor Largest reef complex north of the SH 35 Causeway, with one 175 acre reef
Gallnipper Reef	203	9	
Rhodes Point	357	10	
Middle Ground Reef	348	13	



Sources: Landcover - BEG 2008 Status and Trends (http://www.glo.state.tx.us/coastal/statustrends/matagordabay/index.html), Substrate - TPWD (Simons et al, 2004), Datasonde and TxBLEND nodes - D Buzan (BBEST/PBS&J), Hydrography - HNDPlus 2008. Projection: NAD83/UTMzone14N. L Hamlin Jan. 2011 TPWD Coastal Fisheries - Water Resources

Figure 2.8.1 Locations of Target Oyster Reefs (*) and TWDB salinity monitoring location (*) in Lavaca Bay.

Hydrodynamic Model

TxBLEND is a computer model designed to simulate water circulation and salinity conditions in estuaries (TWDB 2011b). The model is based on the finite-element method, employs triangular elements with linear basis functions, and simulates movements in two horizontal dimensions (hence vertically averaged). Model output includes time-varying depth and vertically-averaged horizontal velocity components of flow and salinity throughout the model domain. TxBLEND thus provides water velocity and direction, surface elevation, and salinity at each node in the model grid (see below for details about the model grid for the Lavaca-Colorado Estuary). The model does not provide information about vertical variation within the water column, but rather provides information about horizontal variation, such as salinity zonation patterns throughout the estuary. Details about model calibration and validation can be found in TWDB's 2011 report: *TxBLEND Model Calibration and Validation for the Lavaca-Colorado Estuary and East Matagorda Bay.*

Oyster Suitability

Oysters can survive in salinities ranging from about 5 to 40 ppt, but growth is stunted below 7.5 ppt (Kennedy et al. 1996). Oyster reefs that are subjected chronically or episodically to salinities that are too low due to excessive freshwater runoff may have problems ranging from complete or partial population mortality to stunted growth. Oysters grow optimally over a salinity range from approximately 10 to 25 ppt (Cake 1983). Salinities of greater than 25 ppt are not only suboptimal physiologically, but reefs that are located in regions of chronic or seasonally high salinities (>25 ppt) will have a greater mortality due to predation and to dermo, a protozoan parasite infection caused by *Perkinsus marinus* (Kennedy et al. 1996).

In southern waters, spawning occurs in all but the coldest months (Berrigan et al. 1991). Conditions generally required for spawning include water temperatures at or above 20 °C and salinity higher than 10 ppt. When these conditions persist, spawning can continue year-round (Breuer 1962). The optimal salinity for growth and reproduction is 10-28 ppt (Wilson et al. 2005). Larvae will not settle and metamorphose into spat when salinity is less than 6 ppt (Wilson et al. 2005), while adults can live in salinities up to 35 ppt (Buroker 1983).

Figure 2.8.2 below shows the relationship between salinity and oyster condition developed by Cake et al. 1983. This relationship illustrates that habitat is best in a salinity range from 10–20 ppt, with decreasing suitability both below 10 ppt and above 20 ppt.

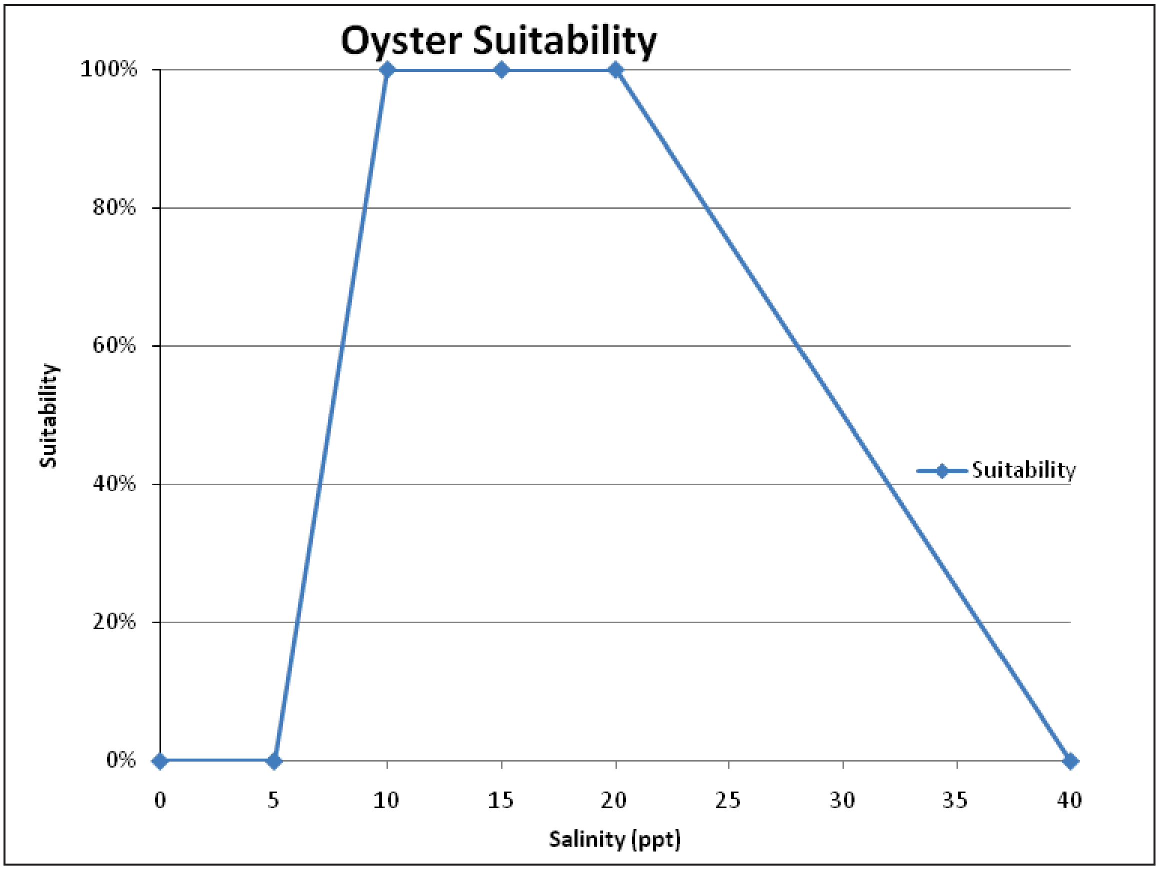


Figure 2.8.2 Relationship between salinity and oyster suitability (Cake et al. 1983).

Application

The proposed freshwater inflow recommendations for Lavaca Bay are designed to cover a full spectrum of inflow conditions—from low, subsistence conditions to higher flows that provide more suitable oyster habitat based on salinity conditions. The Eastern oyster (*Crassostrea virginica*) was selected as the target species for flow regime development. Oysters are commercially and ecologically important in the Lavaca Bay system. Oyster reefs provide important physical habitat and oyster larvae are an important food source to planktivores. Adult oysters are sessile and immobile, making them dependent upon the surrounding chemical environment. These recommendations focus on the major oyster-producing region of Lavaca Bay. Four target reefs, located throughout the bay, were used to measure the salinity/habitat response to various Lavaca River, Lake Texana releases, and Garcitas Creek inflows in this region. While oysters were used as the target species, these flow regimes are expected to create conditions suitable for all estuarine organisms that inhabit Lavaca Bay.

Salinity ranges were established to provide a range of conditions suitable to maintain oyster populations in Lavaca Bay. These ranges were designed to provide high quality habitat at higher flows while lower quality conditions were maintained during lower flow conditions. The goal of each recommendation is summarized below:

Inflow Components	Description	Salinity (ppt)
Subsistence	Maintain oyster habitat suitability of 50% in Lavaca Bay	≤30
Base low	Maintain oyster habitat suitability of 75% in Lavaca Bay	≤25
Base medium	Maintain oyster habitat suitability of 90% in Lavaca Bay	≤22
Base high	Maintain oyster habitat suitability of 100% in Lavaca Bay	Between 10 and 20

To develop freshwater inflow values supporting a sound environment, the desired salinity condition at the target reefs must be related to volumes of inflow. The TxBLEND model calculated a time series of monthly average salinity values at the four model nodes that corresponded to four target oyster reefs. The monthly average salinities were compared to the TWDB's long-term salinity sonde measurements from the datasonde maintained at the SH 35 Causeway in Lavaca Bay. Figure 2.8.3 compares monthly salinity calculated from the TWDB monitoring data and TxBLEND modeling (for Lap Reef, which is closest to the datasonde) over the November 1986 to August 2006 period. The data are highly correlated (r = .8755), indicating the TxBLEND modeled salinity is reliable for predictive purposes.

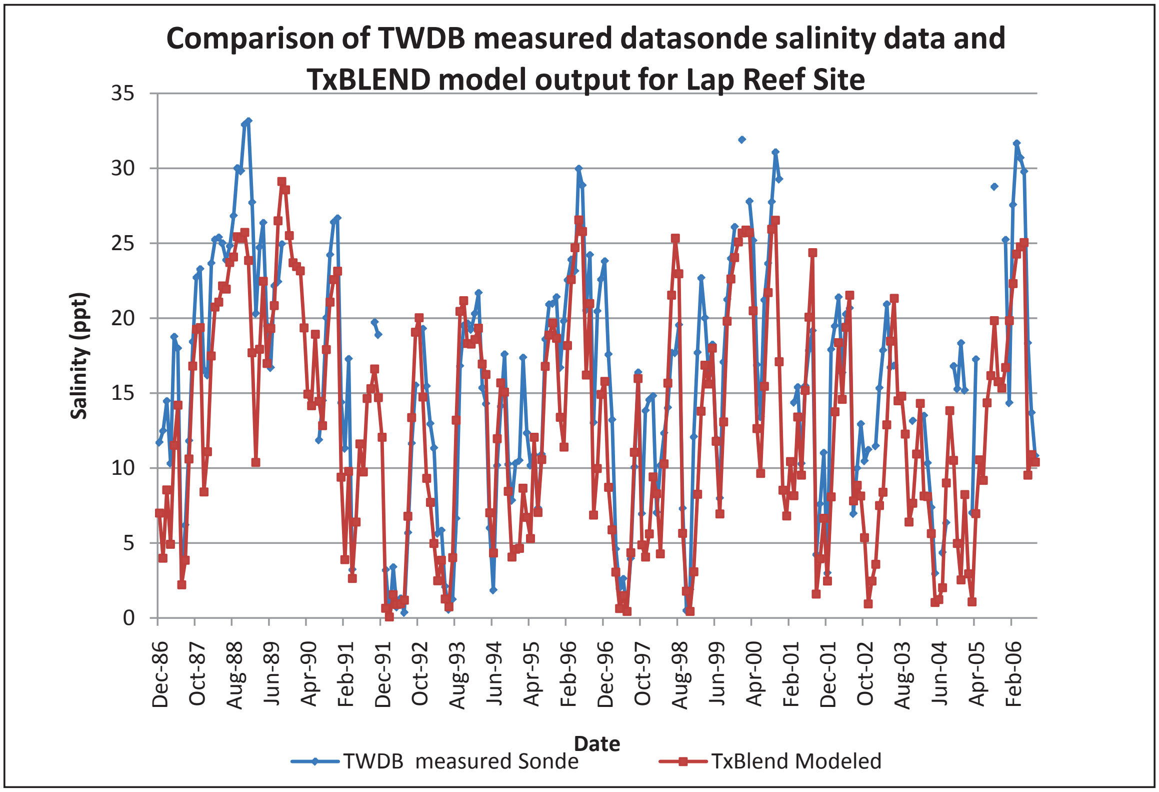


Figure 2.8.3 Comparison of TWDB measured datasonde salinity data and TxBLEND model output for Lap Reef.

Previous analysis of salinity dynamics in Lavaca Bay indicated freshwater inflows from several previous months influence monthly salinity (LCRA 2006). Several combinations of salinity and inflow were evaluated. While inflows from up to four previous months were statistically significant, inflows occurring beyond two months previous had little effect on the predicted salinity value. For this analysis, the average monthly salinity condition was described by the total monthly inflow volume in the current month and the previous month. This combination of salinity and inflows provided good predictive capability and was useable for inflow development.

The final step in developing an inflow to salinity regression relationship was to fit the monthly average salinity model output with log-transformed inflow volumes at each of the four target reefs. Analysis of these relationships allows specific flow volumes to be evaluated with respect to their ability to create salinity conditions in the table above. Regression equations describing the relationship between freshwater inflows from the Lavaca River, Lake Texana releases, and Garcitas Creek and modeled salinity are shown in Table 2.8.4 below:

Table 2.8.4 Regression equations for each target reef.

Lap Reef	$SM_i = 59.336 – 2.019 * LN(QM_i) – 2.509 * LN(QM_{i-1})$	$r^2 = .835$
Rhodes Point Reef	$SM_i = 59.060 – 1.847 * LN(QM_i) – 2.303 * LN(QM_{i-1})$	$r^2 = .815$
Gallnipper Reef	$SM_i = 59.956 – 1.931 * LN(QM_i) – 2.240 * LN(QM_{i-1})$	$r^2 = .822$
Middle Ground Reef	$SM_i = 58.058 – 1.691 * LN(QM_i) – 1.886 * LN(QM_{i-1})$	$r^2 = .782$

Where i= month'; QM_i= total monthly inflow from Lavaca River, Lake Texana releases, and Garcitas Creek (ac-ft); SM_i = average monthly salinity (ppt)

The regression equations for each site can be used to establish the Lavaca River, Lake Texana releases, and Garcitas Creek inflows needed to achieve desired salinity and oysters habitat conditions. The Middle Ground Reef equation was applied to ensure the desired salinity condition was achieved across the bay. This location is furthest from the primary freshwater inflow sources and closest to the open waters of Matagorda Bay. Thus, all the target reefs are ensured to be in the desired salinity condition by using this location. Once this flow volume was determined, salinity at Lap Reef, Rhodes Point Reef, and Gallnipper Reef were calculated to demonstrate desired salinity was achieved at these locations. Table 2.8.5 below summarizes the monthly flows needed to achieve the desired salinity and habitat conditions across the design area.

Table 2.8.5 Monthly inflow volume needed to produce the desired salinity condition across the design area.

Level	Inflow	Salinity (ppt)			
	(ac-ft/mo)	Lap Reef	Rhodes Point Reef	Gallnipper Reef	Middle Ground Reef
Subsistence	2,500	20.7	23.6	24.3	30
Base Low	10,200	17.5	20.7	21.4	25
Base Medium	23,700	13.7	17.2	17.9	22
Base High	41,400	11.2	14.9	15.6	20

The next step to specify inflow regimes is to account for the seasonal pulse flow events (freshets) that naturally occur in this system. Freshwater inflows into the Lavaca Bay system are highly variable. The timing of inflows into the system is critical to maintain productivity of the system. The MBHE extensively evaluated various methods to describe the spring and fall pulses (MBHE 2006b). Ultimately, the 3-month method was used to determine the spring and fall freshet volumes. This approach was applied to inflows into the Lavaca Bay for years with complete data in the 1986 – 2006 data period (see Table 2.8.6 below).

Table 2.8.6 Total annual freshwater inflows (total of Lavaca River, Garcitas Creek, and Lake Texana releases) and calculated 3-month maximum total flows for spring, fall and 6 intervening months in each year.

Year	Annual Flow	Max 3-mo Spring	Spring freshet flow % of total annual flow	Max 3-mo Fall	Fall freshet flow % of total annual flow	Intervening 6-mo	Intervening months flow % of total annual flow
1987	1,292,266	828,233	64.1	178,146	13.8	285,887	22.1
1988	83,620	41,866	50.1	14,498	17.3	27,256	32.6
1989	248,211	124,001	50.0	6,323	2.5	117,888	47.5
1990	193,650	94,140	48.6	24,828	12.8	74,682	38.6
1991	1,246,027	542,982	43.6	398,447	32.0	304,598	24.4
1992	2,889,866	1,584,262	54.8	133,397	4.6	1,172,207	40.6
1993	1,922,256	1,499,944	78.0	42,586	2.2	379,725	19.8
1994	1,755,023	326,172	18.6	1,337,765	76.2	91,086	5.2
1995	621,776	269,464	43.3	93,288	15.0	259,025	41.7
1996	317,920	49,780	15.7	217,883	68.5	50,257	15.8
1997	3,046,314	1,641,488	53.9	622,588	20.4	782,238	25.7
1998	2,649,653	334,334	12.6	2,049,169	77.3	266,150	10.0
1999	329,755	207,446	62.9	14,035	4.3	108,274	32.8
2000	410,071	188,125	45.9	194,257	47.4	27,689	6.8
2001	1,316,934	237,347	18.0	709,135	53.8	370,453	28.1
2002	1,438,316	232,564	16.2	986,185	68.6	219,567	15.3

Table 2.8.6 (continued)

Year	Annual Flow	Max 3-mo Spring	Spring freshet flow % of total annual flow	Max 3-mo Fall	Fall freshet flow % of total annual flow	Intervening 6-mo	Intervening months flow % of total annual flow
2003	647,023	225,915	34.9	294,387	45.5	126,720	19.6
2004	3,017,249	1,373,552	45.5	1,192,196	39.5	451,501	15.0
2005	825,685	556,390	67.4	48,071	5.8	221,225	26.8
		Mean	43.4		32.0		24.6
		Median	45.9		20.4		24.4

The historical average seasonal distribution is 45% of the annual flow during the spring freshet, 32% during the fall freshet, and 23% during the remaining 6 months. Spring is any three consecutive month period beginning with onset in February – May. Fall is any three consecutive month period with onset in August-October. The intervening period includes the six months outside of the spring and fall seasons. Table 2.8.7 below shows the annualized totals and seasonal distribution.

Table 2.8.7 Annual total (acre-feet) and seasonal distribution of freshwater inflow regime components.

Level	Inflow	Total Annual Inflow	Spring ac-ft (45% of total)	Fall ac-ft (32% of total)	Intervening ac-ft (23% of total)
	(ac-ft/ month)				
Base High	41,400	496,800	223,560	158,976	114,264
Base Medium	23,700	284,400	127,980	91,008	65,412
Base Low	10,200	122,400	55,080	39,168	28,152
Subsistence	2,500	30,000	13,500	9,600	6,900

The recommended Lavaca Bay freshwater inflow regime for gaged inflows from the Lavaca River, Lake Texana, and Garcitas Creek are shown in Table 2.8.8 below. This freshwater inflow regime incorporates input from estuary experts, analyses consistent with the recent MBHE, provides seasonal freshwater inflow values, allows for variability in freshwater inflow to the estuary, and should provide for a sound bay environment.

Table 2.8.8 Recommended Lavaca Bay Freshwater Inflow regime (acre-feet) for gaged inflows from the Lavaca River, Lake Texana releases, and Garcitas Creek.

Freshwater Inflow Regime (Acre-Feet)				
Onset Month	**Subsistence**	**Base Low**	**Base Medium**	**Base High**
Spring February March April May	13,500 3 consecutive months	55,080 3 consecutive months	127,980 3 consecutive months	223,560 3 consecutive months
Fall August September October	9,600 3 consecutive months	39,168 3 consecutive months	91,080 3 consecutive months	158,976 3 consecutive months
Intervening Six Months	6,900 Total for 6 month period	28,152 Total for 6 month period	65,412 Total for 6 month period	114,264 Total for 6 month period

Frequency of Occurrence

The frequency in which various freshwater inflows occur is an important aspect of the inflow regime. To address frequency, the historical monthly flow records were evaluated to determine the frequency in which all of the seasonal components (spring, fall, intervening) of the recommendation were met or exceeded in the same year over the period from 1940 through 2009. Table 2.8.9 below summarizes the results. It is assumed that the existing productivity of Lavaca Bay will be maintained if the frequencies of these historical inflow levels are not substantially altered.

Table 2.8.9 Historic occurrence of flow regime components.

Regime Component	Historical Occurrence (%)
Subsistence	97
Base Low	86
Base Medium	56
Base High	37

High Flow Pulse

In addition to the base flow recommendations in Table 2.8.8 above, a high flow pulse that drops salinity to < 5 ppt for up to 2 weeks every 5 to 10 years will substantially reduce the presence of dermo, other oyster parasites, and predators like oyster drills and stone crabs which tolerate salinities above 15 ppt. A high flow pulse volume of at least 450,000 ac-ft within a one month period and within any season is recommended. Dermo and oyster predators are most damaging during extended periods of drought and high water temperatures. The high flow pulse acts as a reset mechanism for the reef. Although elevated oyster mortality is expected during at these low salinities, oyster spat should recolonize the reefs relatively quickly. Conditions are also expected to be favorable for oyster growth and development after these events as salinity conditions recover and remain in optimal suitability ranges and oyster disease infestation and predation mortality is low.

Since 1980, several freshwater inflow recommendations for Lavaca Bay have been developed. The Table 2.8.10 below compares those freshwater inflow recommendations to the flow regime developed by the Colorado-Lavaca BBEST in this report.

Table. 2.8.10 Comparison of Colorado-Lavaca BBEST's Lavaca Bay environmental flow regime to previous freshwater inflow recommendations for Lavaca Bay

Source	Average monthly inflow	Spring	Fall	Intervening months	Total annual flow	% years from 1940-2009 with total annual flow below this annual value	Comments
	Acre-feet						
Colorado-Lavaca BBEST Environmental Flow Regime description 2011	41,400	223,560	158,976	114,264	496,800	53	Base High
	23,700	127,980	91,008	65,412	284,400	30	Base Average
	10,200	55,080	39,168	28,152	122,400	11	Base Low
	2,500	13,500	9,600	6,900	30,000	2	Subsistence
Brandes and Sullivan 1991	61,000	231,000	185,000	317,000	733,000	70	Spring: Mar-May, Fall: Sep-Nov; based on historical inflows from 1940 - 1979 and senior water rights exercised above Lake Texana and Lake Texana in operation
	54,000	212,000	165,000	268,000	645,000	60	Spring: Mar-May, Fall: Sep-Nov; based on historical inflows from 1940 - 1979
Mueller and Mathews 1987	71,000	239,000	238,000	373,000	850,000	80	Spring: Mar-May, Fall: Sep-Nov; intended to protect established salinity bounds
	189,000	681,000	457,000	1,133,000	2,271,000	100	Spring: Mar-May, Fall: Sep-Nov; intended to enhance shrimp harvest
TDWR 1980	35,000	160,000	109,000	150,000	419,000	47	Spring: Mar-May, Fall: Sep-Nov; intended to maintain salinities
	61,000	236,000	250,000	251,000	738,000	70	Spring: Mar-May, Fall: Aug-Sep; maintain fisheries harvest
	62,000	340,000	109,000	291,000	740,000	70	Spring: Mar-May, Fall: Sep-Nov; maximize commercial shrimp harvest
LCRA 2006	49,000	185,000	103,000	305,000	593,000	59	

Figures 2.8.4, 2.8.5, 2.8.6, and 2.8.7 below depict predicted salinities at target reefs at subsistence, base low, base medium, and base high freshwater inflows, respectively.

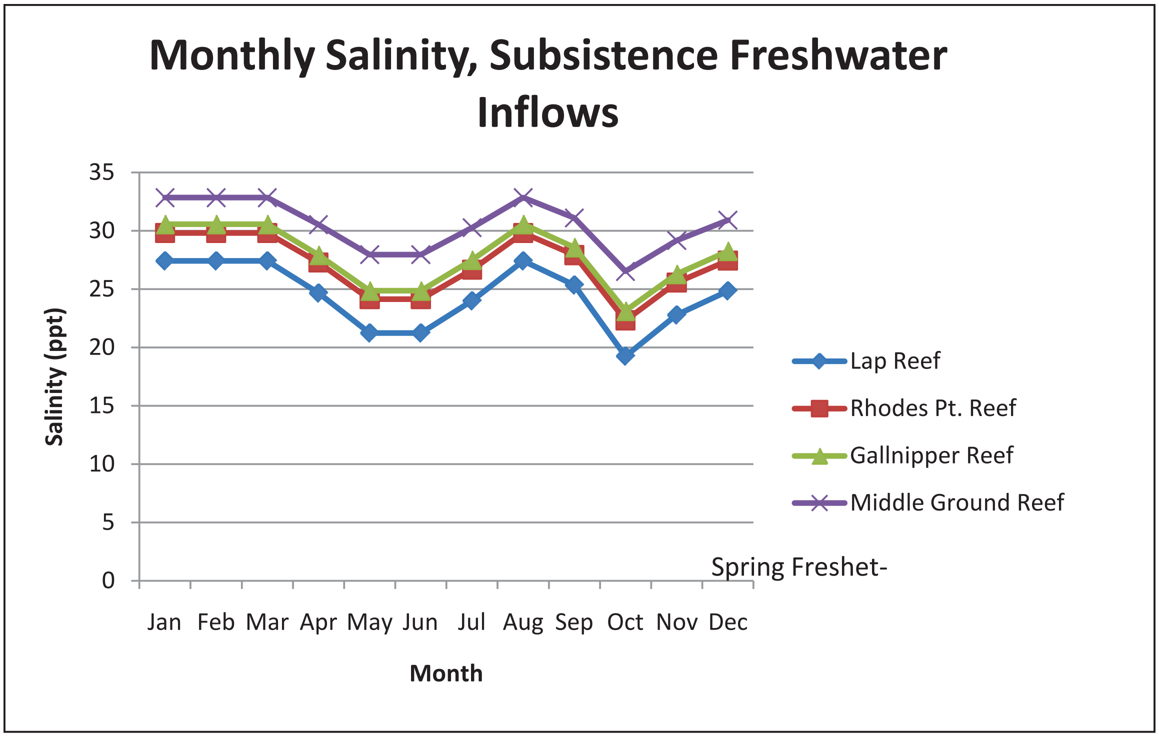


Figure 2.8.4 Monthly salinity at Subsistence freshwater inflows.

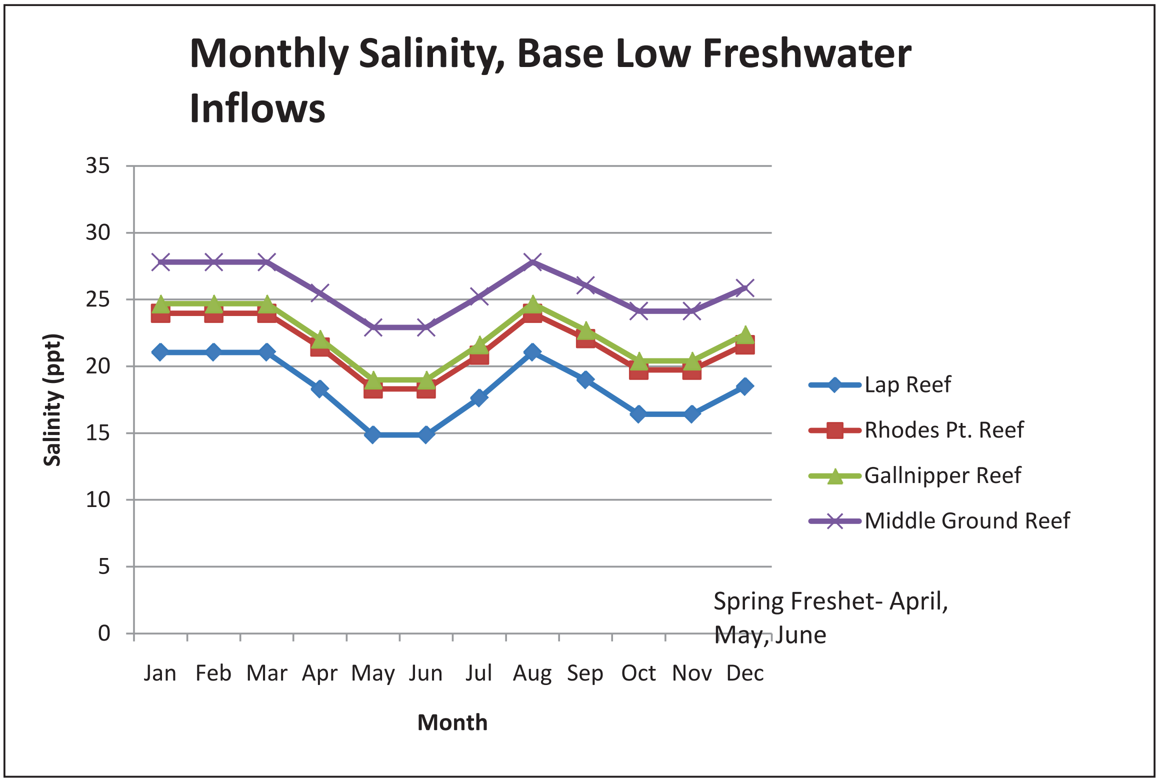


Figure 2.8.5 Monthly salinity at Base Low freshwater inflows.

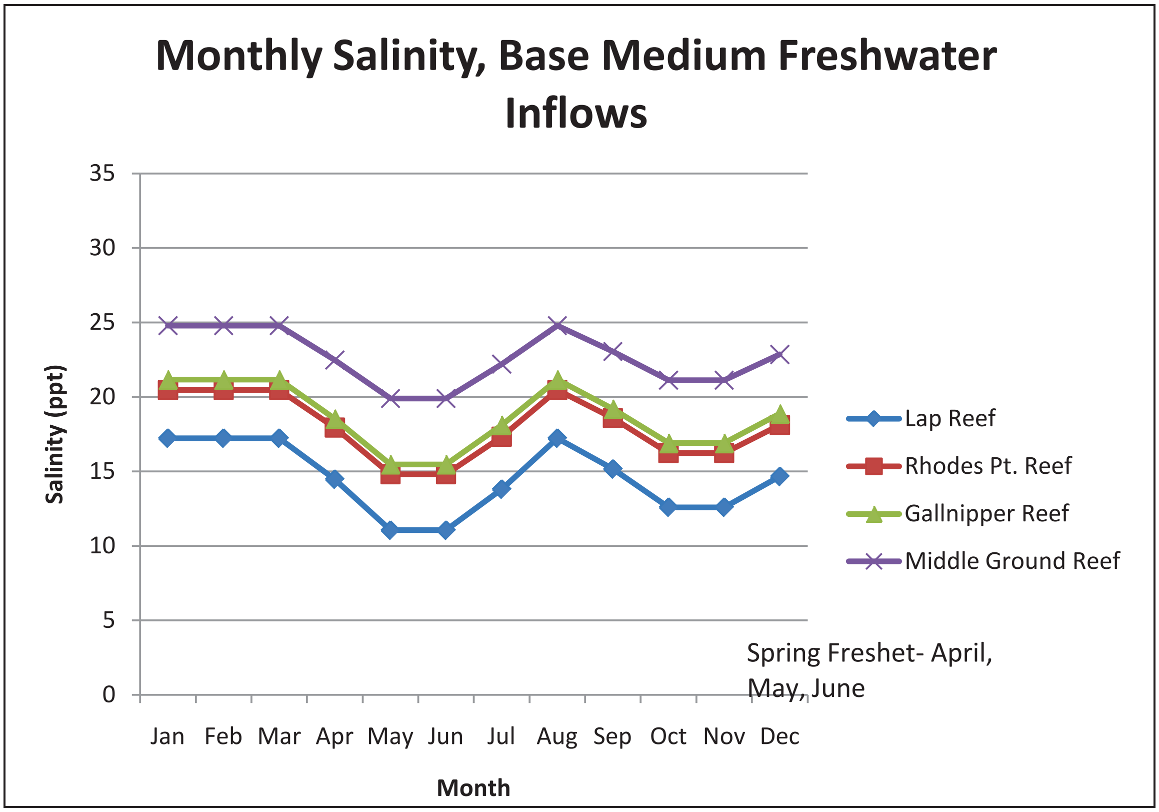


Figure 2.8.6 Monthly salinity at Base Medium freshwater inflows.

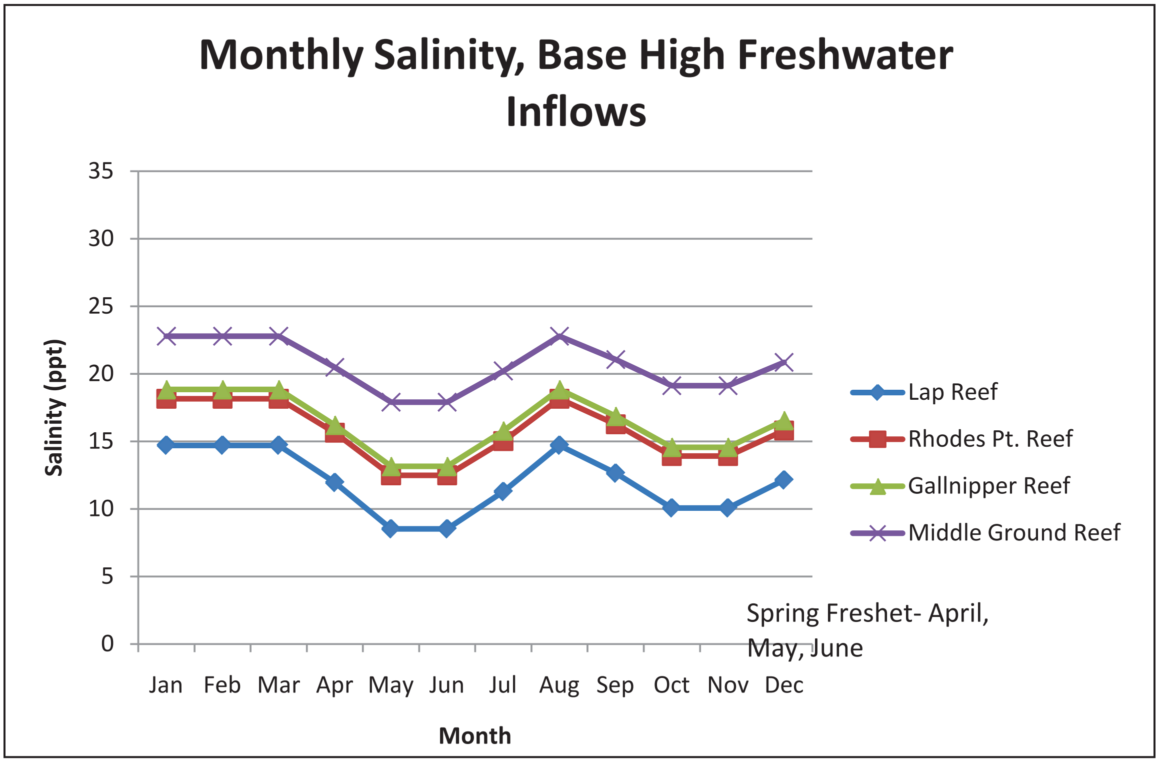


Figure 2.8.7 Monthly salinity at Base High freshwater inflows.

Environmental Flow Regime Evaluation with Other Species

The freshwater inflow regime is designed to produce salinity conditions suitable to maintain oyster populations in Lavaca Bay. These conditions are also expected to be suitable for other estuarine organisms. The MBHE (2008) study evaluated habitat suitability for juvenile shellfish (blue crab, brown shrimp, white shrimp) and juvenile finfish (Gulf menhaden, Atlantic croaker).

White shrimp, *Litopenaeus setiferus*

White shrimp tolerate a wide range of salinities and can be considered euryhaline (Zein-Eldin and Griffith 1969). However, they are generally found in lower salinity waters than brown shrimp (Turner and Brody 1983). White shrimp have been shown to have a preference for low salinity nursery grounds, with postlarval shrimp most abundant at 5–10 ppt in Texas (Muncy 1984, cited from Gunter 1967), though they have been collected in salinities as low as 0.42 ppt (Perez-Farfante 1969) and as high as 37.4 ppt. In Texas, postlarvae enter nursery areas from April to November (Kilma et al. 1982). Juveniles appear to tolerate lower salinities ranges, less than 10 ppt (Zein-Eldin and Renaud 1986) and have been found upstream in rivers and tributaries (Patillo et al. 1997), in some cases as far as 160 kilometers in Louisiana (Perez-Farfante 1969).

Brown shrimp, *Farfantepenaeus aztecus*

Brown shrimp are an estuarine species typically found in higher salinity waters than white shrimp. Zein-Eldin and Aldrich (1965) concluded from laboratory experiments that higher salinities are more favorable for brown shrimp. Salinities of 20 ppt or greater were considered optimum in data from Louisiana (Barret and Gillespie 1973) and the highest densities of brown shrimp in Galveston Bay were found in salinities greater than 15 ppt (Clark et al. 2004).

Blue crab, *Callinectes sapidus*

Variations in salinity, temperature, pollutants, predation, disease, habitat loss, and food availability all affect blue crab survival. Overall populations are limited by post-settlement biotic processes that influence survival of small juveniles. The recruitment and dispersal of juvenile crabs into the estuary is influenced by factors such as freshwater inflow, causing flushing, salinity declines, and low dissolved oxygen (Posey et al. 2005). Environmental conditions, such as temperature and salinity, can influence blue crab reproduction by affecting the timing of molting and the spatial and temporal distribution of adult crabs in the estuary (Chazaro-Olvera and Peterson 2004). Adults show a differential distribution by sex and salinity, with males found in the lower salinity waters of the upper estuary, and females migrating along the salinity gradient between mating in the upper estuary and spawning in the high salinity waters of the lower estuary (Kennedy 2007).

Figure 2.8.8 below displays the chemical habitat suitability for juvenile shellfish utilized in the MBHE study. The blue rectangle includes the salinity range provided by the freshwater inflow regime from subsistence to high base flow.

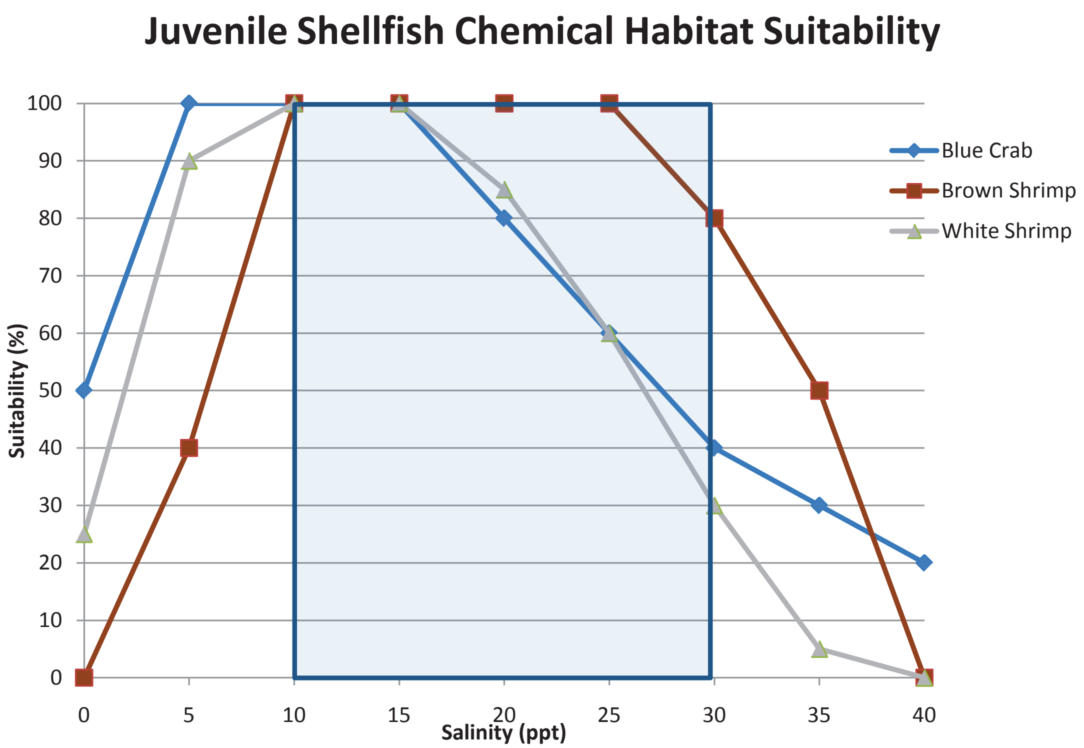


Figure 2.8.8 Relationship between salinity and suitability for juvenile shellfish. Blue rectangle represents the salinity range provided by the Lavaca Bay freshwater inflow regime.

Atlantic croaker, *Micropogonias undulatus*

Atlantic croaker salinity preferences are similar to those of blue crab in Texas and Louisiana bays. Juveniles and adults have been documented as most abundant in salinities less than 15 ppt (Pulich et al. 2002). Higher abundance of juveniles is typically associated with salinities ranging from oligohaline to mesohaline (0.5–12.0 ppt) (Weinstein et al. 1980).

Gulf menhaden, *Brevoortia patronus*

As an inhabitant of both estuarine and marine waters, Gulf menhaden have adapted to a wide range of temperature and salinity tolerances. Nearshore bays and estuaries inhabited by adults range from 5 to 15 ppt, whereas offshore marine waters are characterized by higher salinities, greater than or equal to 30 ppt (Christmas et al. 1982). In general, postlarvae and juveniles also occupy a wide range of salinities, from 5 to 30 ppt (Patillo et al. 1997).

The figure below displays the chemical habitat suitability for juvenile forage fish utilized in the MBHE study. The blue rectangle includes the salinity range provided by the freshwater inflow regime from subsistence to high base flow.

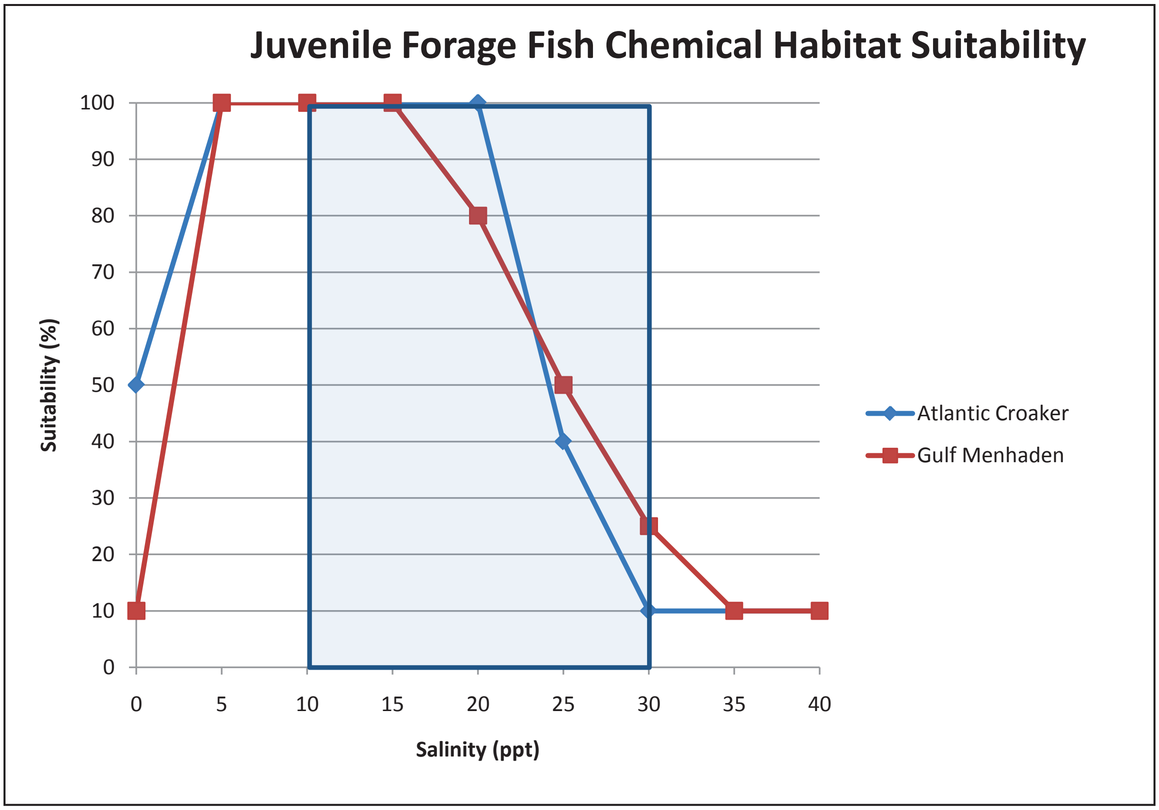


Figure 2.8.9 Relationship between salinity and suitability for juvenile shellfish. Blue rectangle represents the salinity range provided by the Lavaca Bay freshwater inflow regime.

Table 2.8.11 below summarizes the suitability for juvenile shellfish and finfish at each inflow regime component for the various species. Salinity at Middle Ground Reef is used to illustrate conditions across the oyster producing region of the bay. Brown shrimp maintain high suitability across all inflow levels. Subsistence flow maintains low levels of habitat for all species while Base high flows maintain 100% suitability for all species.

Table 2.8.11 Suitability for juvenile shellfish and finfish species each flow regime component.

		Suitability (%)				
Component	**Middle Ground Reef Salinity**	**Blue Crab**	**Brown Shrimp**	**White Shrimp**	**Atlantic Croaker**	**Gulf Menhaden**
Subsistence	30	40	80	30	10	25
Base Low	25	60	100	60	40	50
Base Medium	22	72	100	75	75	68
Base High	20	100	100	100	100	100

It should be noted that physical habitat (e.g. marsh) is critical for juvenile shellfish and forage fish growth and development in Lavaca Bay and the majority of this habitat is located near the major freshwater inflow sources (Lavaca River, Lake Texana releases, Garcitas Creek). Thus, salinity conditions are expected to be lower in much of the emergent marsh in this region of the bay, resulting in highly suitable habitat for juvenile species that prefer lower salinities (e.g., white shrimp, blue crab). Table 2.8.12 below illustrates salinity condition at Lap Reef (as a proxy to the upper bay condition) compared to salinity at Middle Ground Reef. For example, at subsistence flow, when salinity is 30 ppt at Middle Ground Reef (furthest from the inflow sources), salinity at Lap Reef is 20.7 ppt. High chemical habitat suitability is maintained for all species in this important portion of the bay across the inflow regime volume, indicating a protective inflow regime.

Table 2.8.12 Suitability for juvenile shellfish and finfish species at each flow regime component in the upper bay region.

			Suitability (%)				
Component	Middle Ground Reef Salinity	Lap Reef Salinity	Blue Crab	Brown Shrimp	White Shrimp	Atlantic Croaker	Gulf Menhaden
Subsistence	30	20.7	77	100	82	92	76
Base Low	25	17.5	90	100	84	100	90
Base Medium	22	13.7	100	100	100	100	100
Base High	20	11.2	100	100	100	100	100

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3. Instream Flow Analysis

3.1 Geographic Scope

Background

The BBEST was tasked with developing environmental flow recommendations for the Colorado and Lavaca River basins, which also include the coastal river basins lying between the Lavaca and Colorado River Basins and between the Lavaca and Guadalupe River Basins (Colorado-Lavaca Coastal River Basin and Lavaca-Guadalupe Coastal Basin respectively). Accordingly, the geographic extent of the area reviewed by the BBEST team varied from the far reaches of west Texas, which receives as little as 15 inches of precipitation per year, to the southeast portion of the study area near the Texas Gulf Coast, which receives as much as 50 inches of precipitation per year.

Methodology

The SAC Guidance on geographic scope (SAC 2009) provides the basis the BBEST used to determine locations in which the environmental recommendations were made. Specifically, USGS's Core Network streamflow gage information was reviewed for all four river basins. Gage locations that contained streamflow data for periods of record of at least 20 years were initially selected. Information like existence of upstream reservoirs, historic changes in flow, and ability to represent different ecological and flow conditions at each site was evaluated to determine each site's ability to represent the significant water courses, ecoregions, and basin management divisions in the basins.

Additional sites were suggested by the public, stakeholders, and water supply interests in the basins, and all sites were carefully considered. Gage information for sites not included in the Core Network were also reviewed and several sites were selected for the purposes of extending the period of record for sites in the Core Network that did not have a period of record that included the 1950s drought. Initially, 32 sites were selected for developing environmental flow recommendations. Review of literature for all sites was conducted and available data were inventoried to ensure information was available to address the various overlay activities envisioned by the study.

Brady Creek at Brady, Beaver Creek at Mason, Barton Creek at Austin, and Placedo Creek were eliminated from consideration because overlay data were limited and/or they represented a type of stream similar to one or more streams considered. After the team conducted most of the overlay work in the later phase of the study, it was determined that several of the sites that were located on the same watercourse did not offer any new or unique information regarding environmental flow needs. Therefore many of the upstream locations on several tributaries were eliminated. Two upstream sites on the Llano River, and one upstream site on each of the Pedernales and San Saba rivers was therefore dropped from the list. The furthest downstream site on each of these rivers was maintained for analysis.

The final list of sites was ultimately reduced from the 32 initial sites to 22 sites deemed, in combination, to reasonably represent the geographic extent of the entire study area. The Colorado River at Austin was dropped from consideration because flow at that reach is highly influenced by variation in reservoir and wastewater discharges. Additionally an environmental flow regime has already been described for this site (BIO-WEST 2008a). The Colorado River at Bay City was used to evaluate freshwater inflows into the east arm of Matagorda Bay and an environmental flow regime is not provided for this site. The table below summarizes the final selected sites. The river basin maps below depict the locations of the final selected sites.

Table 3.1.1 List of Gaging Stations Selected for BBEST Analysis

LIST OF GAGING STATIONS USED IN COLORADO/LAVACA BBEST ANALYSIS								
COLORADO RIVER BASIN								
GAGE IDENTIFICATION				GAGE NAME	DRAINAGE AREA Sq. Mi.	PERIOD OF AVAILABLE RECORDS	PERIOD FILLED IN FROM NEARBY RECORDS	PERIOD USED IN HEFR ANALYSIS
USGS NO.	WAM CPID	BASIN	BBEST I.D.					
08123850	B20000	COL	1	Colorado R abv Silver	14,910	1967 - Present (1)	1957-1966	1957-2009
08126380	D40000	COL	2	Colorado R nr Ballinger	16,358	1907-Present		1940-2009
08127000	D30000	COL	3	Elm Ck at Ballinger	450	1932-Present		1940-2009
08128000	C30000	COL	4	South Concho R at Christoval	413	1930-Present		1940-2009
08136500	C10000	COL	5	Concho R at Paint Rock	6,574	1915-Present		1940-2009
08143600	F20000	COL	6	Pecan Bayou nr Mullin	2,073	1967-Present (2)	1940-1966	1940-2009
08146000	E10000	COL	7	San Saba R at San Saba	3,046	1915-Present		1940-2009
08147000	F10000	COL	8	Colorado R nr San Saba	31,217	1915-Presenet		1940-2009
08151500	G10000	COL	9	Llano R at Llano	4,197	1939-Present		1940-2009
08153500	H10000	COL	10	Pedernales R. nr Johnson City	901	1939-Present		1940-2009
08158700	J50000	COL	11	Onion Ck near Driftwood	124	1980-Present		1980-2009
08159200	J30000	COL	12	Colorado R at Bastrop	39,979	1960-Present (3)	1900-1936	1900-1936
08161000	J10000	COL	13	Colorado R at Columbus	41,640	1916-Present		1917-1936
08162000	K20000	COL	14	Colorado R at Wharton	42,003	1938-Present (4)	1917-1936	1917-1936
08162500	K10000	COL	15	Colorado R nr Bay City	42,240	1948-Present		NONE-B&E ONLY
LAVACA RIVER BASIN								
08164503	WSG800	LAV	16	West Mustang Creek nr Ganado	178	1977-Present (5)	1940-1976	1940-2009
08164504	NONE	LAV	17	East Mustang Creek nr Louise	54	1996-Present (6,7)	40-80; 81-95	1940-2009
08164390	NONE	LAV	18	Navidad nr Edna	579	1996-Present (8,9)	40-80; 81-95	1940-2009
08164450	GS1000	LAV	19	Sandy Creek nr Ganado	289	1977-Present (10)	1940-1976	1940-2009
08164000	GS300	LAV	20	Lavaca nr Edna	817	1938-Present		1940-2009
COLORADO AND LAVACA COASTAL BASINS								
08162600	GS1300	COLLAV	21	Tres Palacios nr Midfield	145	1970-Present (11)	1940-1976	1940-2009
08164600	GS1200	LAVGUAD	22	Garcitas Creek nr Inez	91	1970-Present (12)	1940-1976	1940-2009

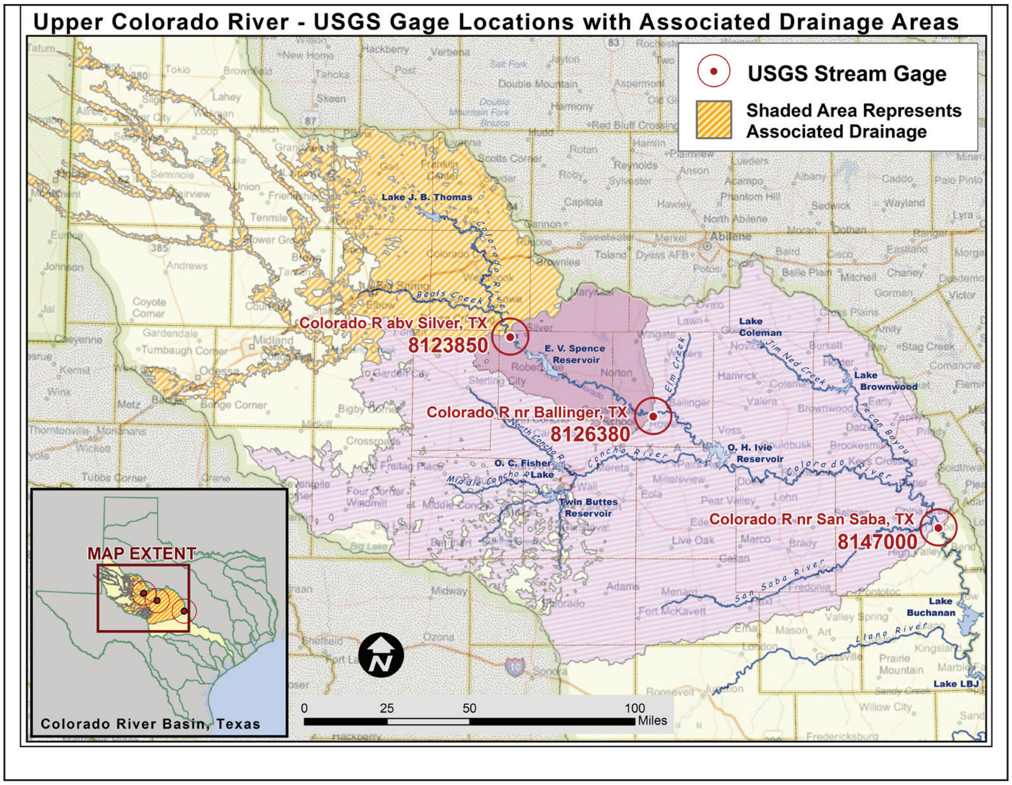


Figure 3.1.1 Upper Colorado River

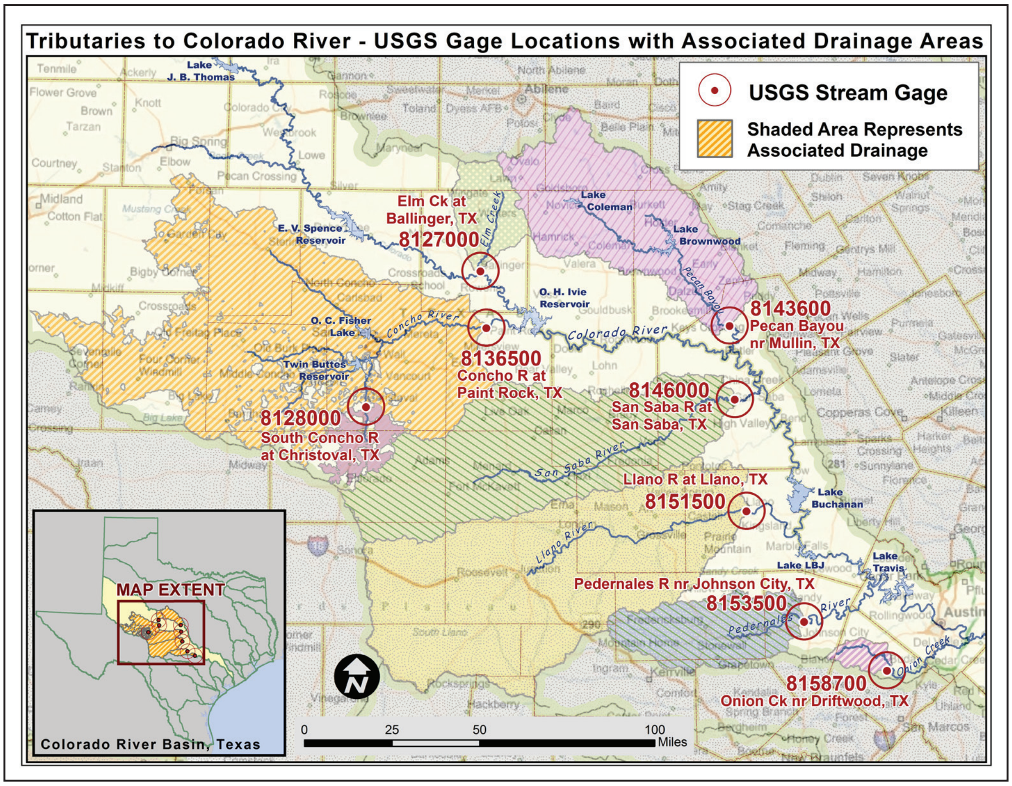


Figure 3.1.2 Tributaries to Colorado River

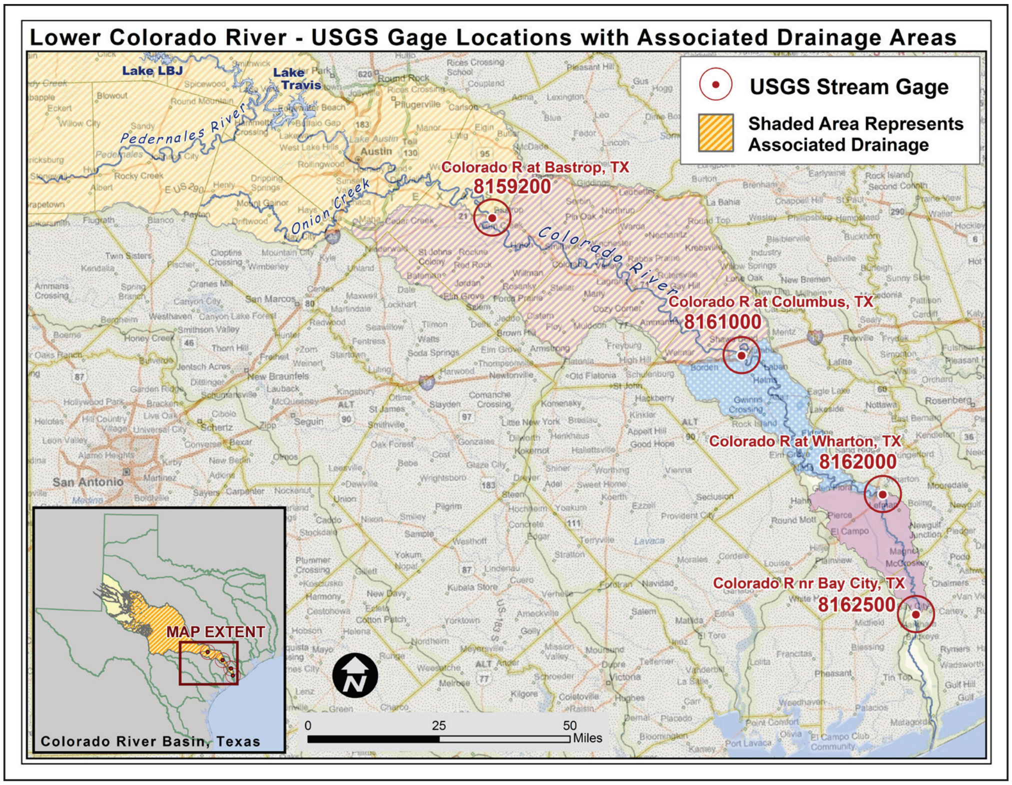


Figure 3.1.3 Lower Colorado River

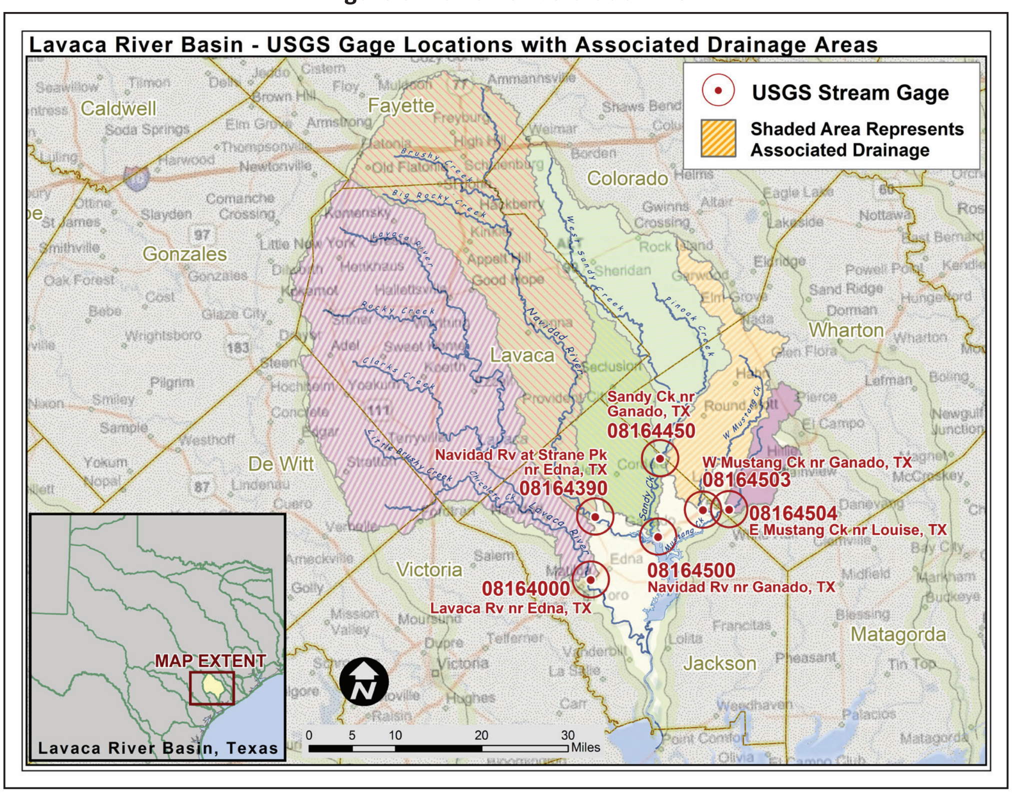


Figure 3.1.4 Lavaca River Basin

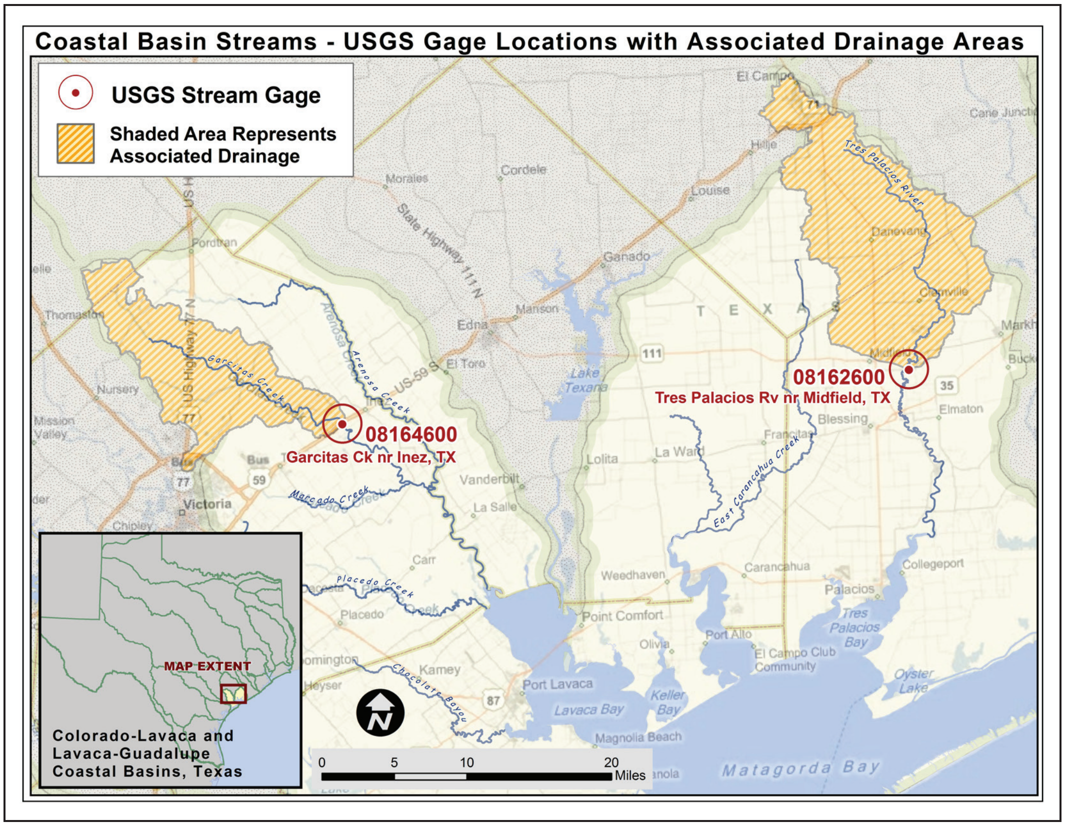


Figure 3.1.5 Coastal Basin Streams

3.2 Seasons

Healthy aquatic ecosystems contain species with different life histories and different physical and chemical needs. Temperature, amount of daylight, and the natural flow regime are characteristics of ecosystems to which fish and other animals and plants have adapted their life cycles.

A shallow riffle, the preferred habitat of some minnows, during the winter may change to a deep, slow-flowing run in the spring after rainfall has increased the flow. Some species such as gizzard shad and spotted bass spawn when temperature is rising. Greenthroated and orangethroated darters may start spawning when temperatures and flow are declining. Species such as the shoal chub are stimulated to spawn by flood pulses. Largemouth bass and green sunfish spawn when water temperatures rise above 15 °C.

Spring pulses and high base flows also raise the water table near the river, supporting riparian vegetation at the beginning of the growing season. Spring pulses also distribute seeds of riparian plant species and foster germination.

The TIFP (TWDB 2008) stated that base flows should protect habitat conditions "…which 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." The SAC (2009) reiterated the SB 3 legislative mandate in its guidance on using biological data to evaluate flow regimes, "SB 3 … defined a regime as a schedule of flow quantities that reflects seasonal and yearly fluctuations."

Understanding relationships between needs of aquatic plants, animals, flow, temperature, and light is one step in evaluating an ecologically sound flow regime. Biologically meaningful seasons are used to identify flow components in HEFR when fish are spawning and plants are growing. Designation of seasons helps describe flow variations sustaining healthy aquatic communities and their habitats.

The following steps were taken to identify seasons.

1. Spawning patterns of typical fish species in the Colorado and Lavaca-Navidad river basins were reviewed to identify:

    - Months when certain fish spawn,
    - Temperatures at which certain fish begin spawning,
    - Flow conditions that may stimulate spawning.
    - Historic flow data were checked to identify the months when peak flows typically occurred.
    - Daily average flow records were reviewed for each site (see detailed summaries in Section 2) to find months when periods of no flow and low flow occurred.
    - Monthly average water temperature was calculated for streams representing the upper Colorado River Basin (Colorado River at Ballinger), the lower Colorado River Basin (Colorado River at Columbus), and the Lavaca-Navidad Basin (Lavaca River at Edna). Temperature data were obtained from the USGS web page for each site. The temperature of 15 °C was selected as the temperature representing the transition from winter to spring because large-

mouth bass and green sunfish begin spawning in the late winter and spring when water temperature reaches 15 °C (Table 3.2.1). It was determined that if winter ended when temperature began to exceed 15 °C, it may be appropriate to use 15 °C as the end of fall and beginning of winter.

Review of fish spawning information for these river basins indicates most species spawn during periods including May (26 species) and June (24 species). The number of species that is reported to spawn in a particular month increases from February (8 species spawning) through May and then declines from June through September (9 species spawning). Five species use October and November for spawning and only three species are reported to spawn in December and January. This table illustrates relationships between seasons and fish in the Colorado-Lavaca watersheds (http://www.bio.txstate.edu/~tbonner/txfishes).

Table 3.2.1 Table of Typical Fish of the Colorado-Lavaca Basins and Their Spawning Behavior

Species	Spawning Periods	Spawning temperatures (°C)	Spawning stimuli
Gizzard shad	Apr to Jun	19.4	Rising temp
Central stoneroller	Feb to July		
Ribbon shiner	Spring and summer		
Ghost shiner	Feb to Oct		
Pugnose minnow	Feb through summer		
Fathead minnow	May through Sep		
Smallmouth buffalo	March to Sep	13.9 to 27.5	
Blackstripe topminnow	Late spring to summer		
Largespring gambusia	All year		
Green sunfish	Spring through summer	15-31	
Bluegill	March to Sep		
Longear sunfish	Late spring to early summer		
Largemouth bass	Late winter to early spring	15-24	Temp exceeds 15.5
White crappie	Late March to early May		
Blacktail shiner	Feb through Nov		
Texas shiner	Mar through Nov		
Weed shiner	Late spring early summer		
Bullhead minnow	mid-May to Sep		
Spotted bass	mid-April to Jun	17.2 to 25.6	
Greenthroat darter	Nov to May		
Orangethroat darter	mid-Oct through July		

Table 3.2.1 Table of Typical Fish of the Colorado-Lavaca Basins and Their Spawning Behavior (continued)

Species	Spawning Periods	Spawning temperatures (°C)	Spawning stimuli
Red shiner	Mid-April to Sept		
Shoal chub	May to Jun		Flood pulses
Blue catfish	Late spring to early summer	16 to 24	
Channel catfish	Late spring to early summer		
Guadalupe bass	Early Mar through Jun	18 to 26	
Freshwater drum	May and June		

Flow patterns over the year are summarized below:

- Peak flows occurred more frequently in May or June than in any other month of the year.
- In the Colorado River Basin upstream of San Saba, August through October had relatively high numbers of peak flows (Figure 3.2.1).
- The Colorado River Basin downstream of Austin and the Lavaca-Navidad streams had relatively high numbers of peak flows from September through November (Figure 3.2.1).
- Minimum flows typically occurred in July and August except for some sites in the Lavaca-Navidad Basin that receive irrigation return flow during July and August.
- Most no-flow periods in the upper Colorado basin began in July.
- Flows below the 50th percentile flow were higher during November through February than during July and August at sites from Onion Creek upstream in the Colorado River Basin.
- Flows below the 50th percentile were generally lower during December through February than during July and August in the Colorado River downstream of Austin and in the Lavaca-Navidad Basin.

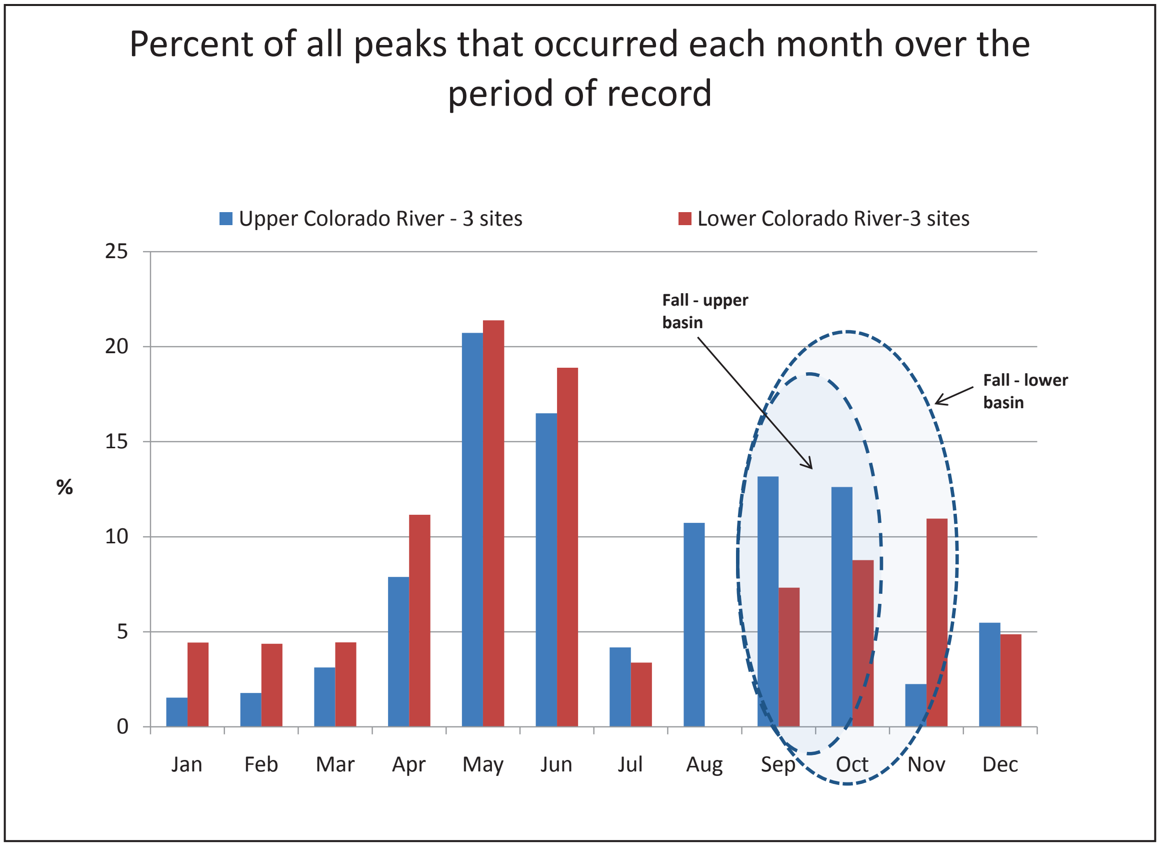


Figure 3.2.1 Months with most peak flows. The values in the graph are percents calculated by dividing the number of peak flows in each month by the total number of peak flows recorded. The Upper Colorado River data includes all peak flow data for the Colorado River at Silver, Ballinger, and San Saba. The Lower Colorado River data includes all peak flow data for the Colorado River at Bastrop, Columbus, and Wharton.

Temperature data showed (Figure 3.2.2):

- Daily average temperature for each month from November through February was at or below 15 °C at the Colorado River at Ballinger.
- December through February were the only months with daily average temperatures for each month at or below 15 °C at the Colorado River at Columbus and the Lavaca River at Edna,.
- Highest daily average temperatures occurred during August at the Colorado River at Columbus and the Lavaca River at Edna.
- Highest daily average temperature occurred during July at the Colorado River at Ballinger.

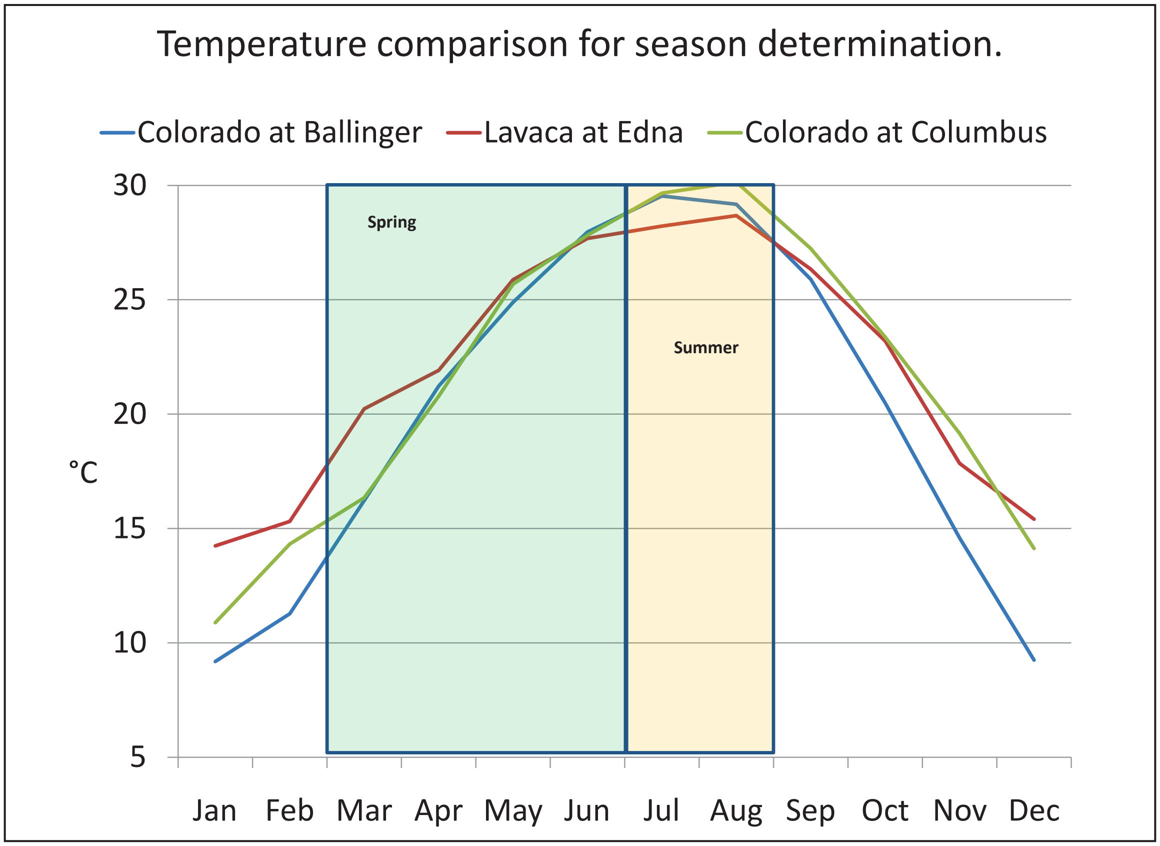


Figure 3.2.2 Monthly average temperatures.

Seasons were described based on the preceding analysis as:

Winter

- Daily average water temperature for the month at or below 15 °C
- Few flow pulses and relatively low flow.
- Few species of fish spawn

Spring

- Daily average temperatures for the month above 15 °C and rising in succeeding months
- Frequent pulses in flow
- Numerous species of fish spawn

Summer

- Highest daily average temperatures
- Lowest flows and relatively few flow pulses
- Fair number of fish spawn

Fall

- Temperatures dropping from summer high temperatures
- Frequent pulses in flows
- Few species spawn

Calculations of environmental flow components in HEFR are therefore based on the separation of months into the seasons shown below.

For all sites

- Spring (4 months): March through June because of rising temperatures and frequent pulse flows. Period most used by fish species for spawning
- Summer (2 months): July and August because of high temperatures and low flows. Period used by a substantial number of fish species for spawning

Upper Colorado River Basin upstream from Lake Travis

- Winter (4 months): November through February
- Fall (2 months): September and October

Lower Colorado River Basin downstream of Lake Travis and the Lavaca-Navidad River Basin

- Winter (3 months): December through February
- Fall (3 months): September through November

November was the only month that changed seasons between the upper basin and lower basin sites. November was placed in the Fall (September through November) in the lower basin because water temperatures tend to be higher than at sites upstream of Austin (daily average temperatures above 15 °C) and flow pulses occur more frequently than in the upper basin.

Comparison of Traditional and BBEST Seasons

HEFR calculations based on the BBEST seasons are compared to HEFR calculations based on traditional seasons at 4 of the BBEST sites (Table 3.2.2 and 3.2.3). The traditional seasons for this analysis are winter – December through February; spring – March through May; summer – June through August; and fall – September through November. In about 20% of the season pulse comparisons, the values calculated using traditional and BBEST seasons are within ±10% of each other. Summer pulses are always higher in magnitude using the traditional seasons and are usually higher in the spring using BBEST seasons. These differences result from including June which typically has relatively frequent pulse flows in the spring during the BBEST season and removing it from the traditional summer.

In about three-fourths of the base flow comparisons, the traditional and BBEST season values are within ±10% of each other. Some of the traditional summer season values were higher than BBEST base flow values. Again, these higher summer values probably result from inclusion of June, which has relatively frequent pulse flows, in the traditional summer.

Table 3.2.2 Effect of Season Selection on HEFR Results for Seasonal Pulses. Traditional season used for preliminary HEFR analysis at all sites included: Winter: Dec-Feb, Spring: Mar-May, Summer: Jun-Aug, Fall: Sep-Nov. BBEST seasons used for the final HEFR analysis included: For the Colorado at Ballinger and the Llano River, Winter: Nov-Feb, Spring: Mar-Jun, Summer: Jul-Aug, and Fall: Sep-Oct; and for the Colorado River at Columbus and the Lavaca River, Winter: Dec-Feb, Spring: Mar-Jun, Summer: Jul-Aug, and Fall: Sep-Nov. Values shaded in pink are higher than the BBEST season value plus 10% of the traditional value. Values shaded in blue are higher than the traditional season value plus 10% of the BBEST value.

Seasonal Pulses	Colorado River near Ballinger		Lavaca River near Edna		Llano River at Llano		Colorado River at Columbus	
	Traditional	BBEST	Traditional	BBEST	Traditional	BBEST	Traditional	BBEST
Winter 1 pulse per season	70	96	4,490	4,500	719	1,100	10,400	12,200
Winter 2 pulses per season		27	1,990	2,010	273	391	4,610	4,800
Spring 1 pulse per season	3,820	3,240	5,700	6,770	2,820	4,790	19,200	37,900
Spring 2 pulses per season	1,550	1,300	3,610	4,630	941	1,840	9,070	23,800
Summer 1 pulse per season	3,260	625	3,210	421	2,070	558	9,200	5,580
Summer 2 pulses per season	1,430	128	973	88	620	No value	3,740	2,030
Fall 1 pulse per season	2,940	1,510	4,570	4,590	2,110	1,380	14,500	38,800
Fall 2 pulses per season	1,190	249	1,600	1,640	580	369	4,880	11,700

Table 3.2.3 Effect of Season Selection on HEFR Results for Base Flows. Traditional season used for preliminary HEFR analysis at all sites included: Winter: Dec-Feb, Spring: Mar-May, Summer: Jun-Aug, Fall: Sep-Nov. BBEST seasons used for the final HEFR analysis included: For the Colorado at Ballinger and the Llano River, Winter: Nov-Feb, Spring: Mar-Jun, Summer: Jul-Aug, and Fall: Sep-Oct; and for the Colorado River at Columbus and the Lavaca River, Winter: Dec-Feb, Spring: Mar-Jun, Summer: Jul-Aug, and Fall: Sep-Nov. Values shaded in pink are higher than the BBEST season value plus 10% of the Traditional value. Values shaded in blue are higher than the traditional season value plus 10% of the BBEST value.

Seasonal Threshold	Colorado Rv nr Ballinger		Colorado Rv at Columbus		Lavaca Rv nr Edna		Llano Rv at Llano	
	Traditional	BBEST	Traditional	BBEST	Traditional	BBEST	Traditional	BBEST
Winter High Base	15	14	1,400	1,300	89	90	194	200
Winter Med Base	9	9	905	910	51	52	152	150
Winter Low Base	5	5	606	620	29	29	112	110
Spring High Base	23	19	2,100	2,400	95	97	205	200
Spring Med Base	10	9	1,500	1,500	58	58	149	140
Spring Low Base	4	3	966	950	31	31	104	98
Summer High Base	35	14	2,150	1,200	61	48	143	130
Summer Med Base	13	6	1,800	890	36	31	101	92
Summer Low Base	4	2	1,400	610	21	19	72	67
Fall High Base	25	17	1,510	1,500	53	58	184	180
Fall Med Base	13	10	1,100	950	32	34	130	120
Fall Low Base	6	4	707	610	20	20	90	87

3.3 Flow Regime Components

The hydrology-based environmental flow regimes at each stream location are comprised of four of the six flow regime components shown in Table 1.2 of this report. The four basic flow regime components are intended to protect flow variability across a natural range of flow conditions. The four basic flow regime components selected for recommendation by the BBEST are:

- Subsistence flows
- Base flows
- High flow pulse events
- Overbank flow events

Chapter 3 of this report describes the hydrologic considerations and tools used to prepare flow recommendations for the four basic flow regime components. This section documents the decision points used by the BBEST to select and refine the hydrology-based environmental flow regime.

3.3.1. No-Flow Periods

Some stream reaches may naturally experience periods of zero-measured stream flow. All recommended subsistence flow levels by the BBEST are greater than zero. Decision points for arriving at subsistence flow recommendations are described in section 3.3.2. The BBEST recognizes no-flow periods as a natural feature of some streams within the study area. It is not the BBEST's recommendation that naturally occurring no-flow periods should be artificially alleviated. Rather, the intention of subsistence flow recommendations greater than zero is to prevent removal of extreme low flows below the subsistence level during dry or drought conditions.

The only streams with continuous flow during the time for which records are available were the Colorado River downstream of Austin, the South Concho River, and Tres Palacios Creek. Some streams, usually with substantial spring flows like the Llano River or relatively large drainage basins like Pecan Bayou, only stopped flowing for relatively few, short periods during the drought of the 1950s. The Colorado River and streams in drier west Texas along with streams in the Lavaca River basin with relatively small drainage basins experienced more frequent and longer periods of no flow.

No-flow periods were determined by reviewing the daily average flow values for each stream. A no-flow period started when the daily average flow was zero and lasted until the daily average flow was above zero. The number of days with no flow represents the duration of a no-flow period. The number of no-flow periods in a season is the count of all the no-flow periods that started during that season for the period of record. Several no-flow periods may have started in the same season of the same year. Zero-measured daily average stream flow in the historical record is not necessarily an indication that the stream contained no water. Streams may retain pools of water that support viable aquatic habitat during no-flow periods.

3.3.2 Subsistence Flows

Natural flow variability results in flows below any of the base flow levels during dry periods. Some stream reaches may naturally experience periods of zero-measured stream flow. The BBEST subsistence flow recommendation is not intended to require artificial increases in stream flow up to the subsistence level. Instead, the subsistence level recommendation is intended to be a minimum level of natural stream flow protection during dry periods. Subsistence flow recommendations are provided for all stream flow locations.

Multiple measures (metrics) of subsistence flow are available for selection. The BBEST agreed on three low flow protection metrics from which to select. The maximum of the three low flow metrics was selected by the BBEST as the subsistence flow recommendation as expressed in the following formula:

Subsistence flow = Maximum (1.0 cfs, TCEQ Critical Low Flow or Seasonal 95% Exceedance Flow)

The formula results in a minimum of 1.0 cfs being the lowest possible flow selected as a subsistence flow recommendation at any site. Naturally occurring no-flow periods are permissible and recognized by the BBEST. A minimum recommendation of 1.0 cfs is intended to prevent removal of extreme low flows during dry or drought conditions.

The TCEQ Critical Low Flow values were taken from the June 2010 publication of *Procedures to Implement the Texas Surface Water Quality Standards* (TCEQ 2010). The TCEQ Critical Low Flow is computed as the maximum of either 0.10 cfs, the 95% exceedance flow for the period of record used by TCEQ for the analysis, or the 7Q2 flow. The TCEQ period of record at each site does not necessarily correspond with the BBEST period of record. The TCEQ period of record typically covers the most recent 30 years of available flow data.

The seasonal 95% exceedance flow was used as the third component in the subsistence flow selection formula. The BBEST's computation of the 95% exceedance flow covered the BBEST defined season and the BBEST defined period of record at each location. Unlike the TCEQ computation of 95% exceedance for the TCEQ Critical Low Flow, the BBEST computation includes data, when available, that is older than the most recent 30 years of record.

The subsistence flow recommendation formula was not used where more detailed studies are available that represent the best available science at the time of this report. Site-specific studies of subsistence flows are available at the following USGS gages on the main stem of the Colorado River and the BBEST used these studies for recommending subsistence flow requirements:

- San Saba (BIO-WEST, Inc. 2010)
- Bastrop (BIO-WEST, Inc. 2008a)
- Columbus (BIO-WEST, Inc. 2008a)
- Wharton (BIO-WEST, Inc. 2008a)

3.3.3 Base Flows

Three levels of recommended base flows were generated using HEFR for each site. Details of the HEFR applications are described further in Section 3.2.5 of this report. However, daily average stream-flow data below the 25% exceedance, on a seasonal basis, was considered as base flow data for the hydrologic analysis performed with HEFR.

The recommended base flow components of the flow regime are expected to be engaged on a continuous basis. Base flow recommendations are not considered events with a fixed duration or total flow volume. Rather, the BBEST recommendations for base flows are magnitudes only and are varied on a seasonal basis.

The LSWP instream flow study (BIO-WEST, Inc. 2008a) provides site-specific base flow recommendations for the main stem Colorado River at the USGS gages near Bastrop, Columbus, and Wharton. The BBEST opted to adopt the base flow recommendations from the LSWP report in lieu of the analysis using HEFR.

Numerical results from HEFR were adjusted for significant digits and for seasonal consistency. Base flow results from HEFR that were less than 10 cfs in magnitude were rounded to one significant digit of precision. Base flow results that were greater than 10 cfs in magnitude were rounded to two significant digits of precision. If the base flow magnitude between adjacent seasons for the same base flow level were within a 10% difference, the magnitudes were averaged. The average was rounded for significant digit precision and applied as the base flow recommendation for the pertinent seasons and base flow level.

If any of the base flows were found to be lower than the subsistence flow, calculated as described above, the base flow was raised to the magnitude of the subsistence flow level.

3.3.4 High Pulse Flow Events

Five levels of pulse flow events were selected by the BBEST from the HEFR analysis. The five levels of pulse flow events were categorized as seasonal or annual frequency events. Because the high pulse flows are episodic events, the BBEST adopted criteria that are to be used in conjunction with the HEFR generated high pulse flow recommendations. The adopted criteria describe the qualifications for meeting a high pulse flow event and the criteria for allowing higher-level pulse flow events to satisfy the yet unmet annual or seasonal pulse flow events that exist at lower pulse flow or overbank levels.

A qualifying flow pulse or overbank event begins when flow exceeds the prescribed threshold flow magnitude. It continues (which means flows are passed up to that flow magnitude) until the prescribed volume is passed. If the prescribed volume is not met by the associated prescribed duration (calculated as the upper prediction interval of the duration regression in HEFR), the event is considered as being meet. If during a qualifying event at one magnitude, flows increase to a magnitude that triggers a new pulse event, the flow magnitude, volume, and duration of the higher qualifying flow pulse controls the flow regime and the first event is initially ignored. In this case, the higher flow events are considered to satisfy lower flow events in the same season, e.g. an overbank event satisfies a one-per-season event and one two-per-season event.

Numerical results from HEFR were adjusted for significant digits and for seasonal consistency. Pulse flow results from HEFR that were less than 10 cfs in magnitude were rounded to one significant digit of precision. Pulse flows greater than 10 cfs and less than 10,000 cfs in magnitude were rounded to two significant digits of precision. Pulse flows greater than 10,000 cfs were rounded to three significant digits of precision. If the pulse flow magnitude between adjacent seasons for the same pulse level were within a 10% difference, the magnitudes were averaged. The average was rounded for significant digit precision and applied as the pulse flow recommendation for the pertinent seasons and pulse flow level.

3.3.5 Overbank Flow Events

The BBEST did not make separate overbank flow event recommendations. Of the five levels of high pulse flow events, those events in which the flow rate equaled or exceeded the NWS flood stage were labeled as overbank events. Therefore, some sites may contain more than one high flow pulse event that is labeled as overbank. Where the NWS flood stage flow exceeds the highest high flow pulse level considered in the BBEST HEFR analysis, no overbank events are noted.

The NWS flood stage flow is an instantaneous flow rate. It is chosen by the NWS to correspond to a water surface elevation that exceeds the channel banks or poses hazards to human safety including the potential for property and road damage. The flow data used by the BBEST is the daily average USGS stream flow rather than the daily maximum instantaneous flow. The daily average USGS flow used by the BBEST was assumed to have a similar correspondence to the water surface elevation considered in setting the NWS flood stage flow. However, a daily average flow will be lower than the instantaneous peak on that day. Therefore, some events whose daily average may have been less than the NWS flood flow may have peaked during that day above the NWS flood flow level. Overbank values were adjusted for numerical precision in the same manner that pulse flows were adjusted.

3.3.6 Channel Maintenance Flows

The relationship between flow and channel maintenance was evaluated at three locations, the Colorado River at San Saba, the Colorado River at Columbus, and the Lavaca River at Edna. These sites were chosen to help understand sediment transport and effective discharge in the upper Colorado, lower Colorado, and Lavaca basins. The analyses focused on hypothetical withdrawals of water under specific circumstances to determine the reduction in average annual flow that may cause changes in channel shape. Detailed descriptions of those analyses are in Section 3.10.

3.4 Hydrographic Separation

Hydrographic or base flow separation is a technique used to categorize flow levels or flow events within the hydrograph. In some project settings, this analysis is accomplished by attempting to divide the source of water, typically groundwater versus storm water-derived. In SB 3, the hydrographic separations are "a hydrological activity for an ecological purpose and is therefore not synonymous with traditional base flow separation methodologies." The primary ecological functions of different flows are summarized in Section 1.3 of this report. According to this conceptual model, subsistence and base flow components are associated with low and average flow conditions while the high flow pulses and overbank flows are associated with high flow conditions. Preliminary estimates of these values are produced by HEFR. The first step in this methodology is the application of a specific hydrologic separation technique as described in the paragraph below. These topics are discussed in detail in the both the SAC guidance documents and the TIFP Technical Overview document.

In its review of the TIFP, the National Research Council (NRC 2005) found that flow estimates based on unseparated flows "may lead to inconsistent and unreliable protection of base flows while generally under-protecting high flow pulses and overbank flows." The SAC has proposed two tools for performing the hydrologic separation: Indicators of Hydrologic Alteration (IHA) and the Modified Baseflow Index with Thresholds (MBFIT). Both tools can be used to characterize base flows based on the flow magnitude and rate of change, though the rate-of-change algorithms are different. Generally, flows are first characterized as low or high, based on whether they are above or below user-defined magnitude thresholds, and then flows between those magnitudes are classified as base or pulse flows based on their rate of change. For example, the BBEST could decide that all flows below the 25th percentile be classified as low flows and all flows above the 75th be classified as high flows. The remaining flows, between the 25th and 75th percentiles, would then be classified as either base flows or pulse flows based on their rate of change from one day to the next. There is sufficient flexibility within the two tools to weight the magnitude or rate of change differently. For instance, the magnitudes could be set at the maximum and minimum flows on record, which would make the rate of change the only parameter relevant for the classification. Conversely, the upper and lower threshold could be set at identical values, which would mean the classification is defined solely by the magnitude. While these two tools may classify individual days or pulse events differently, it is worth noting that either can be parameterized to produce essentially the same results. Understanding the conceptual model of how different flows provide different ecological functions is critical to this analysis. (See SAC 2009a p. 38-41 for more complete discussion)

The BBEST hydrology subcommittee met on several occasions early in the Colorado-Lavaca BBEST process to develop a proposal for the full BBEST. The committee selected seven control points to investigate the tools and options for setting the relevant parameters to be used for the hydrographic separation. A range of options were investigated based on lessons learned from previous BBESTs and applications of hydrographic separation that have been employed in other studies or water rights applications. Individuals with regional expertise provided input on parameters based on their experience. It was generally easier to define a specific value or flow rate to describe magnitude thresholds than to define the rate of change for triggering a flow classification change between base flow or pulse flow. Preliminary HEFR results calculated from the alternative separations were compared.

The subcommittee reached a consensus to recommend to the full BBEST that base flow separation be performed based on the 75th percentile magnitude flow. All flow below that value would be classified as low flow (subsistence or base) and all flow above that value as high (pulse or overbank). The committee based this decision on several considerations including:

- the reasonableness of the results which generally conformed to the regional experts expectations,
- the difference between the various alternative were small,
- no obvious reason to select one over another, and
- the application of methodological parsimony, i.e., choosing the simplest and easiest-to-explain method unless there is a compelling rational to develop something more complex.

A refinement was made after a preliminary HEFR analysis was performed. In this analysis, the HEFR program did not produce estimates of two per season high flow pulses in some seasons at several sites. The BBEST decided to refine the base flow separation and execute the algorithm on seasonal rather than annual 75th percentile flows. This decision resolved some, but not all, occurrences of results that lacked a two per season event in some seasons and at some sites. Rather than continue to adjust parameters in the base-flow separation algorithm, the BBEST decided to address this issue in the overlay application phase of the process. The seasonal thresholds by site are presented in the table below.

Table 3.4.1 Low/High Flow Separation Threshold Based on Seasonal* 75th Percentile Values (cfs)

Gage	Name	Winter	Spring	Summer	Fall
08123850	Colorado Rv abv Silver	15	31	20	28
08126380	Colorado Rv nr Ballinger	25	56	39	50
08127000	Elm Ck at Ballinger	11	17	3	7
08128000	S Concho Rv at Christoval	45	45	45	45
08136500	Concho Rv at Paint Rock	52	49	28	49
08143600	Pecan Bayou nr Mullin	22	117	18	23
08146000	San Saba Rv at San Saba	146	178	88	123
08147000	Colorado Rv nr San Saba	344	825	355	506
08151500	Llano Rv at Llano	272	318	191	267
08153500	Pedernales Rv nr Johnson City	136	190	100	90
08158000	Colorado Rv at Austin	1,370	2,750	1,493	2,000
08158700	Onion Ck nr Driftwood	75	77	18	14
08159200	Colorado Rv at Bastrop	1,416	2,847	1,545	2,070
08161000	Colorado Rv at Columbus	2,705	4,540	1,968	3,030
08162000	Colorado Rv at Wharton	2,793	4,595	1,984	3,056
08162500	Colorado Rv nr Bay City	2,760	3,430	1,460	1,930
08164000	Lavaca Rv nr Edna	160	188	79	109

Table 3.4.1 Low/High Flow Separation Threshold Based on Seasonal* 75th Percentile Values (cfs) (continued)

Gage	Name	Winter	Spring	Summer	Fall
08164390	Navidad Rv at Strane Pk nr Edna	155	161	152	169
08164450	Sandy Ck nr Ganado	81	80	72	95
08164503	W Mustang Ck nr Ganado	47	52	56	62
08164504	E Mustang Ck nr Louise	20	22	24	27
08162600	Tres Palacios Rv nr Midfield	34	39	38	39
08164600	Garcitas Ck nr Inez	14	15	6	10

* Seasons were defined in Upper Colorado Basin: Colorado at San Saba and sites upstream, Llano and Pedernales as Winter: November through February; Spring: March through June; Summer: July and August; and Fall: September and October. For the Lower Colorado Basin (including Onion Creek) and Lavaca/Navidad Basin, they were defined as Winter: December through February; Spring: March through June; Summer: July and August; and Fall: September through November.

The full BBEST decided visual checks should be performed to verify that the selected base flow separation algorithm produces results that confirm the conceptual model. Dr. Thom Hardy developed a tool for inspecting and reclassifying individual days as either a base flow or a pulse flow. Hardy and Dave Buzan applied professional judgment resulting in the reclassification of between 428 to 2,169 days out of a 33,968 day record at the Colorado River at Columbus gage for example.

Reclassification was also performed on the flow record for the Lavaca River, Llano Rive at Llano, and the Colorado River at Ballinger based on the following guidelines:

- A 1-day pulse or base flow should be rare.
- Most 1-day pulses were changed to 3-day pulses (a rise on the day before the peak, the peak, and the day after the peak) and in some cases (particularly Ballinger), 2-day pulses (usually the peak and the day after).
- One-day base flow values usually occurred between the declining limb of one pulse and the rising limb of a following pulse. In these cases, the base flows were nearly always changed to pulse flows.
- Base flows should be extended periods, preferably seven days or more. The initial consideration of the period extension was based on preserving the time between pulses for a nesting fish trying to spawn during the spring. However, there was not strict adherence to this approach and base flow periods as short as three days (rarely two days) were allowed in some cases.
- In general, pulse flows were changed to base flows when the decline in flow slowed and the value on the next day was at least 50% of the value on the preceding day. This addressed the question of switching from a pulse to a base flow classification.
- Pulse events were considered to be a relatively rapid increases (and in some cases, decrease) in flow. Gage-height data for each gage was reviewed and changes in gage height to changes in flow were compared. This relationship changes over time. However, it was considered the best available indication of how a change in flow would appear in the river. For example, a rapid increase (in one or two days) in flow of at least 30 cfs was

considered to constitute a pulse at the Lavaca River at Edna and the Colorado River at Ballinger. At Colorado River at Columbus, it required a rapid increase in flow of at least 1,000–1,500 cfs. At the Columbus gage, there were times when the flow would increase by 100 cfs every day or two for a week or two, until the flow had increased 1,500 cfs. These were not considered pulses (and they typically were not identified as pulses by the 75th percentile separation).

The following are observations that were made after applying the above guidelines for base flow and pulse event separation:

- A single base flow or pulse value that appeared to be an obvious error was rarely found.
- There were times when the seasonal change created base flows higher than pulse flows on the following day. These conditions seemed to occur most frequently at seasonal boundaries, for example when moving from August to September and from November to December. Issues like this did not occur every year and these types of issues may occur in less than half the years.
- There is some concern that the base flow and pulse event separation process cuts off the declining limb of the pulse flow too early. This opinion is based on review of some of the scientific literature on riparian trees, which suggests their success in establishment may be related in part to a slowly declining limb of the pulse. Example: Fremont cottonwoods may require the change in water elevation to be less than 1 inch/day as the seedlings are sinking their roots (Mahoney and Rood 1998). Of course, this may be more indicative of the need for large floods once every several years which scour, creating habitat for seedlings to establish, and then slowly decline.
- This manual effort required 1–2 hours or more per site to complete the work, longer at sites with long periods of record.

Preliminary HEFR estimates were calculated using the results from the manual hydrographic separation. Although the exercise demonstrated that automated hydrographic separations resulted in misclassification of flows on individual days, the effect on the results produced by HEFR as compared to those produced by the manual separation were considered minimal. HEFR values produced by the two methods were compared and in all cases, the differences were either less than 10% or less than 10 cfs. This exercise served as verification for the BBEST and resulted in a consensus to apply the automated approach using the 75^{th} percentile seasonal thresholds for all sites.

3.5 Period of Record

For each selected site, upstream water resource development was considered using information from TCEQ's naturalized flows process, published literature, knowledge of BBEST member familiar with the areas. The years that major water supply reservoirs were constructed upstream of a site and the water volume capacities of the reservoirs were documented. In addition, years when other impacts to stream flow like NRCS flood control installation and saltcedar infestations were considered. Table 3.5.1 lists the BBEST sites with the major historical upstream impact information noted.

Table 3.5.1 Pertinent Data Related to USGS Gages Selected for BBEST Analysis

GAGE IDENTIFICATION		GAGE NAME	DRAINAGE AREA	PERIOD OF AVAILABLE RECORDS	PERIOD FILLED IN FROM NEARBY RECORDS	PERIOD USED IN HEFR ANALYSIS	MAJOR UPSTREAM RESERVOIRS	
USGS NO.	WAM CPID		Sq. Mi.	RECORDS	RECORDS	ANALYSIS	NAME	DATE BUILT
COLORADO RIVER BASIN								
08123850	B20000	Colorado R abv Silver	14,910	1967 - Present (1)	1957-1966	1957-2009	Natural Dam	????
							Red Draw Dam	1985
							Mitchell Co. Res.	1993
							J.B. Thomas	1952
							Colorado City	1949
							Sulphur Draw	1992
							Champion Creek	1959
08126380	D40000	Colorado R nr Ballinger	16,358	1907-Present		1940-2009	Oak Creek	1952
							Ballinger	1947
							EV Spence	1969
08127000	D30000	Elm Ck at Ballinger	450	1932-2009		1940-2009	Old Lake Winters	????-1983
							Lake Winters	1983
08128000	C30000	South Concho R at Christoval	413	1930-Present		1940-2009	none	not applicable
08136500	C10000	Concho R at Paint Rock	6,574	1915-Present		1940-2009	Twin Buttes	1963
							Nasworthy	1930
							O.C.Fisher	1951
08143600	F20000	Pecan Bayou nr Mullin	2,073	1967-Present (2)	1940-1966	1940-2009	Clyde	1970
							Hords Creek	1948
							Coleman	1966
							Brownwood	1933
08146000	E10000	San Saba R at San Saba	3,046	1915-Present		1940-2009	Brady Creek	1963
08147000	F10000	Colorado R nr San Saba	31,217	1915-Presenet		1940-2009	O.H. Ivie	1990
08151500	G10000	Llano R at Llano	4,197	1939-Present		1940-2009	none	not applicable
08153500	H10000	Pedernales R. nr Johnson City	901	1939-Present		1940-2009	none	not applicable
08158700	J50000	Onion Ck near Driftwood	124	1980-Present		1980-2009	none	not applicable
08159200	J30000	Colorado R at Bastrop	39,979	1960-Present (3)	1900-1936	1900-1936	Buchanan	1938
							Inks	1938
							LBJ	1951
							Marble Falls	1952
							Travis	1942
							Austin	1941
							Ladybird	?
							Bastrop	1964
							Decker	1967
08161000	J10000	Colorado R at Columbus	41,640	1916-Present		1917-1936	Fayette	1965
08162000	K20000	Colorado R at Wharton	42,003	1938-Present (4)	1917-1936	1917-1936	No additional	n/a
08162500	K10000	Colorado R nr Bay City	42,240	1948-Present		NONE-B&E ONLY	No additional	n/a
LAVACA RIVER BASIN								
08164503	WSG800	West Mustang Creek nr Ganado	178	1977-Present (5)	1940-1976	1940-2009	none	not applicable
08164504	NONE	East Mustang Creek nr Louise	91	1996-Present (6,7)	40-80; 81-95	1940-2009	none	not applicable
08164390	NONE	Navidad at Strane Park	579	1996-Present (8,9)	40-80; 81-95	1940-2009	none	not applicable
08164450	GS1000	Sandy Creek nr Ganado	289	1977-Present (10)	1940-1976	1940-2009	none	not applicable
08164000	GS300	Lavaca nr Edna	817	1938-Present		1940-2009	none	not applicable
COLORADO AND LAVACA COASTAL BASINS								
08162600	GS1300	Tres Palacios nr Midfield	145	1970-Present (11)	1940-1976	1940-2009	none	not applicable
08164600	GS1200	Garcitas Creek nr Inez	91	1970-Present (12)	1940-1976	1940-2009	none	not applicable

Note: See Table 3.5.2 for Gage Information Used to Extend Hydrology to Represent Full Range of Hydrologic Conditions.

Sites With Published Environmental Studies

Published site-specific environmental flow analyses were determined acceptable for use by the BBEST in determining environmental flow regimes. These studies used different periods of record than used by the BBEST for the majority of sites.

For the Colorado River near San Saba, instream flow analysis was completed in early 2010 by BIO-WEST, Inc. for the purposes of developing instream flow guidelines for river diversions associated with LCRA's Lometa Water System (see section 2.1.3). The study only addressed subsistence flows and used the entire period of record for the site, 1916–2009.

For the sites downstream of Mansfield Dam on the Colorado River (Colorado River at Bastrop, Colorado River at Columbus, Colorado River at Wharton), an instream flow analysis was completed in 2008 by BIO-WEST, Inc to develop instream flow recommendations associated with the proposed LSWP. The period of record used to develop the LSWP's recommended flow regime included years with data up to the late 1930s when the Highland Lakes were constructed.

Sites Without Published Environmental Studies

For sites without specific environmental flow studies, information related to the year in which major upstream impact occurred along with the observed period of record available at each site was analyzed (Table 3.5.1). Based on this information, up to four distinct historical periods were identified and the observed flows at each site were subdivided into these periods:

- Pre Impact: The first year of observed record until major upstream impact occurred
- Post Impact: The first year of observed record after major upstream impact occurred through 2009
- Current period: 1970–2009
- Entire period: the entire period of record for the gage

Separate HEFR matrices were developed to the extent possible for each of the four periods for each site, to understand effects of large upstream changes like reservoirs and the importance of wet and dry years in the period of record being analyzed. Review of these simulations indicated that the period of record selected for the development of HEFR matrices was greatly influenced by the following:

- The length of the period for each historical division (all divisions)
- Whether or not the pre-impact, post-impact, and entire periods of record contained the 1950s period

The BBEST decided the period of record from 1940 to 2009 would best reflect the entire range of hydrologic conditions across the basin and provide a consistent period of analysis between sites. The BBEST agreed by consensus to use that period to conduct HEFR analyses.

Since several of the recommended sites did not have observed flow back to 1940, the BBEST decided that stream flow records for these sites should be estimated for the period before the gage's recorded records back to the year 1940, if possible. To accomplish this, a review of nearby stream flow gages was made and comparable stream flow gage locations were used to estimate the flows that would have likely occurred at the BBEST gage site had the site been in operation.

Drainage area ratios were used to estimate flows for the missing periods and this approach was later supported with additional correlation techniques. Table 3.5.2 contains the historical gage information used to extend records back to 1940 for all but two of the recommended sites. For the Colorado River above Silver and the Onion Creek near Driftwood, no suitable gage could be found that could be used to estimate flows back to 1940.

Table 3.5.2 USGS Gages Used to Extend Records of Gages Selected for BBEST Analysis

USGS GAGE USED TO EXTEND RECORDS OF BBEST GAGE		PERIOD OF AVAILABLE RECORDS	PERIOD USED FOR FILL-IN RECORDS	BBEST GAGE# FILLED IN
USGS NO.	GAGE NAME			
08123900	Colorado R nr Silver	1957-1969	1957-1966	Colorado River above Silver
08143500	Pecan Bayou at Brownwood	1924-1982	1940-1966	Pecan Bayou near Mullin
08158000	Colorado R at Austin	1899-Present	1900-1936	Colorado River at Bastrop
08161000	Colorado R at Columbus	1916-Present	1917-1936	Colorado River at Wharton
08164500	Navidad Rv nr Ganado	1940-1980	1940-1976	West Mustang Creek near Ganado
08164500	Navidad Rv nr Ganado	1940-1980	1940-1980	East Mustang Creek near Louise
08164503	West Mustang Creek nr Ganado	1977-Present	1981-1995	East Mustang Creek near Louise
08164500	Navidad Rv nr Ganado	1940-1980	1940-1980	Navidad at Strane Park
08164503	West Mustang Creek nr Ganado	1977-Present	1981-1995	Navidad at Strane Park
08164500	Navidad Rv nr Ganado	1940-1980	1940-1976	Sandy Creek near Ganado
08164000	Lavaca nr Edna	1938-Present	1940-1969	Tres Palacios Creek near Midfield
08164000	Lavaca nr Edna	1938-Present	1940-1969	Garcitas Creek near Inez

3.6 HEFR Flow Component Determinations

Preliminary estimates of flow regime components were calculated by applying the HEFR (SAC 2009) based on the season selection, period of record and hydrographic separation described in Sections 3.2, 3.4, and 3.5.

High flow pulse and overbank flows were estimated using the frequency option for calculating episodic events in HEFR. This algorithm determines the flow magnitude for user-specified recurrence intervals. The recurrence intervals selected in this study included three annual flows (one per 5 years, one per 2 years and one per year) and two sets of seasonal flows (one per season and two per season).

Peak magnitudes are calculated by tallying historical daily average peaks of individual pulse or overbank events and determining the lowest flow rate that on average would be exceeded at the user-specified recurrence interval. For example, if a particular gage includes 50 years of data and the one per 2-year event is reported as 60 cfs, this means that in those 50 years there were 25 high flow events that exceeded 60 cfs or an average one every two years. A one per 2-year event does not mean that this is the flow expected to occur every other year. In the 50 years of historical data it is likely that there were more than two events in some years and that there would have been consecutive years in which this peak did not occur.

Although there was some variation by site, the episodic events calculated in HEFR generally covered a range from smaller in-channel pulses to larger out-of-bank floods. This was confirmed by comparing these magnitudes with flood stage discharges published online by the National Weather Service. The recommended environmental flow regimes in this report designate whether a particular flow peak magnitude is an in-channel high flow pulse or an overbank flow. Overbank flows exceed the National Weather Service flood stage discharge.

For each peak magnitude, the HEFR software also reports an associated event duration and volume. These statistics along with their one standard deviation confidence bounds, were derived from a log-log regression between the peak magnitudes and the volumes and durations of the events coincident with these peaks.

High, average, and low base flow reported by HEFR are the 75th, 50th and 25th percentile of historic low flows, as classified by the hydrographic separation. HEFR automatically provides calculations of these values by month and by season where the seasonal estimates are based on the flows that have occurred in a given season and not the average of the months in that season. The program also computes the historical frequency at which each of these values has occurred. The calculation is based on the complete, unseparated flow record. So while the high base flow was exceeded 25% of the time by flows that were below the 75^{th} percentile of all daily average flows, it was exceeded about 40% of the time when compared to all daily average flows (including some pulse flows). Similarly, the base average flows were exceeded about 56%-60% of the time and the base low about 60%-70% of the time. Because of the way the hydrographic separation was conducted in this study, these frequencies are fairly consistent across sites and seasons.

Subsistence flows were computed by HEFR using the Q95 option, which calculates the flow rate that was exceeded 95% of the time in a given season. For some sites in the western part of the basin, the Q95 reported is zero. This means that for at least 5% of the period of record used, the gages at these sites reported no flow. The attainment frequencies for subsistence flows determined in this manner are either 95% for values above zero or 100% of the time when the Q95 is zero.

3.7 Aquatic Biology, Habitat, and Flow Relationships

3.7.1 Description of Methodologies/Assumptions

Natural Flow Paradigm

The guiding principle applied to the Colorado-Lavaca BBEST's instream flow analyses and associated methodologies is the concept of the 'Natural Flow Regime,' which is founded on the theory that the integrity of flowing water systems depends largely on their natural dynamic character (Poff et al. 1997). The Instream Flow Council, an organization that represents the interests of state and provincial fish and wildlife management agencies in the United States and Canada dedicated to improving the effectiveness of their instream flow programs, has adopted this principal as a cornerstone of riverine resource stewardship (Annear et al. 2004; Locke et al. 2009). The natural flow regime was also a central principle for the scientific basis of the TIFP as well as the associated technical approaches for quantification of instream flows (TIFP 2008). Both the conceptual foundation and technical approaches proposed by the TIFP were critically reviewed by the National Academy of Science National Research Council's *Committee on Review of Methods for Establishing Instream Flows for Texas Rivers* (NRC 2005). The committee soundly supported the underpinnings of the natural flow regime as the scientific basis of the program as well as concurring with the breadth of technical approaches identified for addressing instream flow needs within Texas and at a national level.

The paradigm of the natural flow regime relates five critical components of flow characteristics that are known to regulate ecological processes in river ecosystems: the magnitude, frequency, duration, timing, and rate of change in flow (Poff and Ward 1989, Richter et al. 1996, Walker et al. 1995, Annear et al. 2004, NRC 2005, Locke et al. 2009). The five components represent attributes of the entire range of flows, such as floods or low flows. The flow regime is the master variable of central importance in sustaining the ecological integrity of flowing water systems (Poff and Ward 1989). The five components of the flow regime influence ecological integrity both directly and indirectly, through their effects on other primary regulators of ecosystem integrity (Figure 3.7.1). Therefore, modification of any of the components of the flow regime can have cascading effects on the ecological integrity of rivers.

Aquatic biota have life history strategies that have been adapted to these flow regime characteristics that include such things as initiation of migration or spawning that is cued to changes in the seasonal flow regime, and they generally respond differentially to low, base, and high flow components of the flow regime. The annual (and inter-annual) variations of the flow regime are directly and indirectly linked as key determinants of aquatic community structure and stability (Poff and Ward 1989, Poff et al. 1997, Richter et al. 1996, Dilts et al. 2005). Alteration of the natural flow regime has been documented to modify the ecological function and overall characteristic of the ecosystem in riverine habitats throughout the world (Bunn and Arthington 2002, Postel and Richter 2003, Poff and Zimmerman 2009, Robinson et al. 1998, Tyus et al. 2000).

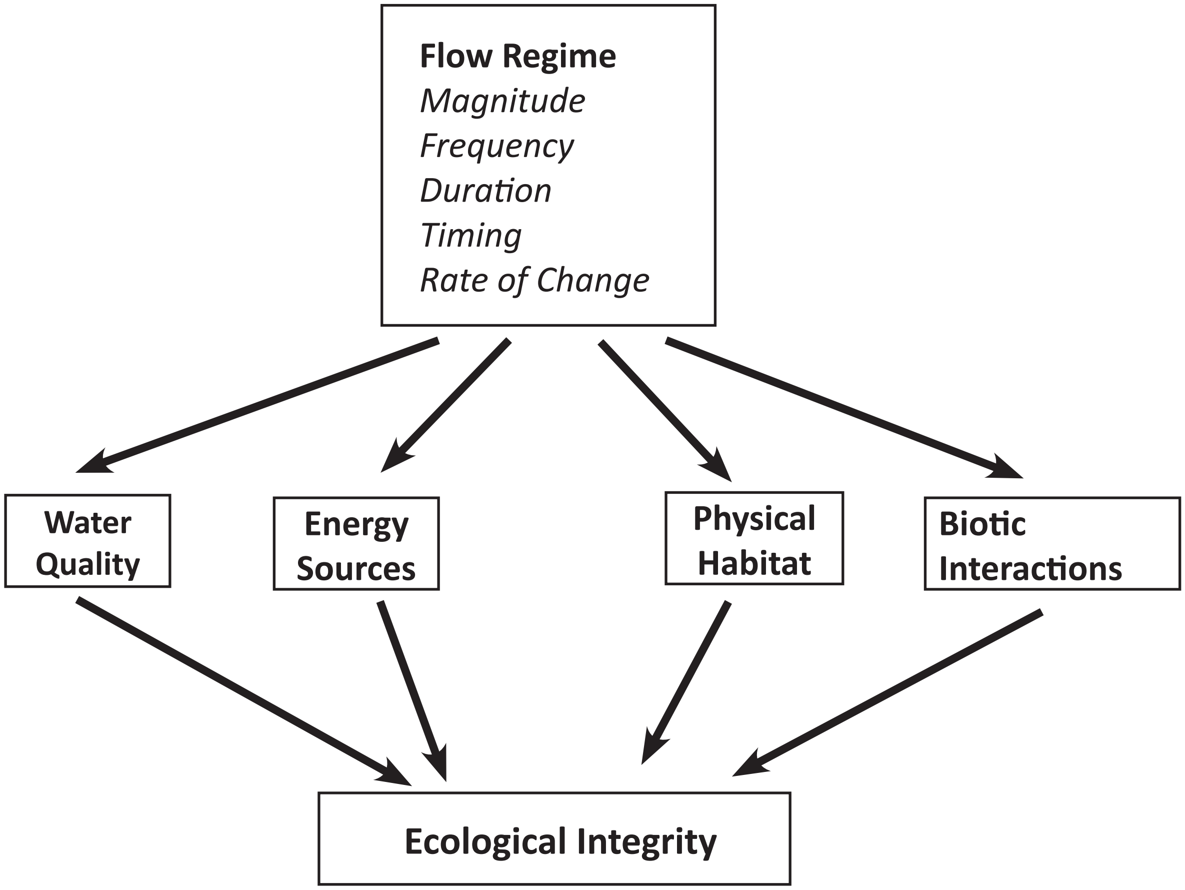


Figure 3.7.1 The five components of the natural flow regime that directly and indirectly affect the ecological integrity of river ecosystems (adapted from Poff et al. 1997).

3.7.2 Quantification of Flow Regime Components

Excellent reviews of instream flow approaches in the United States can be found in Reiser et al. (1989), EPRI (1986), Gore (1989), and Hardy (1998). Annear et al. (2004) and NRC (2005) synthesize additional work over the past decade and elucidate the multidisciplinary philosophies and application level challenges associated with the assessment of instream flows. A broader view of the status and future directions of instream flow science at the international level can be found in Harby et al. (2004). This later effort reviews the existing status of instream flow science used throughout the European Union and is comprehensive in its coverage of sampling, hydrology, hydraulic, water quality, temperature, and aquatic habitat modeling approaches. Methods developed for assessing habitat availability vary in data requirements, cost, predictive ability, legal defensibility, and biological realism (Annear et al. 2004). While some methods require rigorous, site-specific data collection and computer modeling, others rely more heavily on simplified approaches such as application of summary hydrologic-based statistics. Although the application of rigorous site-specific methodologies typically occurs for high-intensity instream flow studies, many management objectives can be achieved with less intensive efforts, especially for early project screening or broad level watershed planning (Stalnaker et al. 1995, NRC 2005).

Several widely applied screening methods allow practitioners to estimate flow requirements with no, or a minimum of, field-data collection efforts such as the Tennant Method and the New England Aquatic Base Flow method (Annear et al. 2004). Many of these approaches, however, vary in their ability to integrate or relate site-specific data with biological criteria in the assessment process. Some recent efforts to develop alternative methodologies for habitat assessment can be found in Jowett (1990, 1992, 1998), Lamouroux, Capra, and Pouilly (1996), and Annear et al. (2004).

While physical habitat modeling has a long track record of application to impact assessments in riverine systems, it is not without limitations. Intense data collection and analysis requirements have typically limited its application to those studies where legal, institutional, or political sensitivities are high (Annear et al. 2004). Some have criticized physical habitat modeling approaches for lacking biological realism (Orth 1986) and for not properly representing the pertinent biological mechanisms important in river ecosystems (Mathur et al. 1985). Despite criticisms, the analytical approach and the resultant flow recommendations have proven defensible (Beecher et al. 1993, Cavendish and Duncan 1986, Gore and Nestler 1988, Jowett 1992) and a critical element of state-of-the-art instream flow programs (NRC 2005).

Based on the recommendation of the National Research Council (NRC 2005), and consistent with Maidment et al. (2005), the SAC (2009) implemented the HEFR Methodology. HEFR relies on a framework that quantifies key attributes of four components of the flow regime intended to support a sound ecological environment. These instream flow regime components are: subsistence flows, base flows, high flow pulses, and overbank flows (SAC 2009). For each of these flow regime components, HEFR was designed to assist in characterizing their attributes in terms of magnitude, duration, timing, frequency, and rate of change. HEFR results are then integrated with overlays of biology that include fisheries (i.e., physical habitat) and riparian components as well as overlays of water quality and geomorphology. A description of the ecological function of these flow components can be found in Richter et al. (2006), Richter and Thomas (2007), TIFP (2008) and SAC (2009).

Flow regimes vary over time from between specific seasons to even decadal periods (or longer) in response to larger scale spatial and temporal patterns of climatic variability (i.e., precipitation and temperature). This variation is in response to such factors as the shorter term El Nino and La Nina conditions that comprise the ENSO and the PDO, which is an ENSO-like pattern of climate variability affecting both the tropics and the north Pacific and North American regions but which varies on a much longer time scale than ENSO. These variations lead to flow regimes that are often characterized as drought, normal and wet hydrologic conditions. This is important ecologically in terms of overall aquatic community dynamics that naturally exhibit variability in response to these very different hydrologic conditions. For example, a low base-flow regime might provide favorable conditions for species that inhabit slow shallow habitats at the expense of deep fast water species while conversely at a high base-flow regime the opposite would occur. At the extreme, a single base-flow regime could result in the complete loss of a specific component of the aquatic community because there is no longer the necessary variability within the flow regime that provides favorable conditions for its life history requirements. This range in variability is accommodated for within the HEFR-based analyses, which can partition the base flow component of the flow regime into low, medium, and high states.

3.7.3 Linking the Hydrologic Regime to Riverine Habitat

Physical heterogeneity of riverine systems influences species richness and abundance (Thienemann 1954, Hynes 1970, Vannote et al. 1980, Elwood et al. 1983, Ward 1989). Furthermore, in riverine systems, the physical habitat structure (microhabitat and mesohabitat scales) is one of the critical factors that determine the distribution and abundance of aquatic organisms. In general, as spatial heterogeneity increases at the scale of aquatic organisms, there is greater microhabitat and hydraulic diversity that leads to greater biotic diversity. This variability in physical habitat from the microhabitat to mesohabitat scales is primarily derived from the physical processes of flow and sediment both within the channel as well as the lateral connectivity of floodplain habitats. The diversity and availability of these habitats are in turn maintained by variability in the flow regime which is a key process in the evolutionary response of aquatic species life history traits that allow them to exploit this variable and dynamic habitat mosaic. In many instances, the successful completion of various life history requirements requires use of different habitat types. For example, spawning and egg incubation may occur in riffles (turbulent velocities in conjunction with appropriate substrate sizes); upon hatching, the fry move to the slow side margins of the stream, while non-spawning adults may primarily inhabit deep pools. This variability in space and time of the habitat mosaic directly (or indirectly) influences the distribution and abundance of riverine species as well as overall ecosystem function (Poff and Allan 1995, Schlosser 1990, Sparks 1992, Stanford et al. 1996).

Several investigators have quantified the range of conditions and resources that various riverine fishes inhabit, particularly with respect to depth and velocity (Lobb and Orth 1991, Aadland 1993, Bain et al. 1988, Bowen et al. 1998). They have identified species and life-stage guilds that use the gradients of depth and velocity in a similar manner. Guilds typically use a set of environmental conditions or resources similarly, but typically differ in the temporal or spatial use of these resources or differ along other niche dimensions to coexist (i.e., food utilization). Because stream flow is one of the key factors that controls the temporal and spatial availability of stream hydraulics (interaction of depth and velocity), substrate, cover, food, and, to a lesser extent, temperature (e.g., Statzner 1986), stream flow within a given river system controls the abundance and diversity of physical habitat and ultimately the diversity of species that can exist. Ecological flow regimes are aimed at maintaining the natural diversity of habitats (i.e., riffles may only represent seven percent of available habitat types) rather than the often false assumption that flow regimes should optimize diversity. Optimizing habitat diversity is not the same as maintaining habitat diversity, which is required to maintain ecological integrity of aquatic ecosystems. One method of quantifying the effects of stream flow on riverine biota is to quantify the diversity of habitat types (types inhabited by typical riverine fish guilds) versus flow (e.g., Aadland 1993, Bowen et al. 1998, BIO-WEST, Inc. 2008a). The diversity of the habitat types, particularly key bottleneck habitats that may affect recruitment of fishes at various times of the year (e.g., nursery habitat), can be used to identify stream flows that maintain habitats for a diversity of species and life stages (Bain et al. 1988, Scheidegger and Bain 1995, Nehring and Anderson 1993).

In addition, fish use different microhabitats (depth, velocity) in different mesohabitats (pools, riffles, eddies) (Jackson 1992, Moody and Hardy 1992) and use different microhabitats at different flows (e.g., Shrivell 1994). They also use different habitats depending on localized predation threats (e.g., Powers 1985; Schlosser 1982), during different seasons (e.g., Baltz et al. 1991) and during different parts of a day (night vs. day). Fish swimming capabilities change with temperature (Brett and Glass

1973, Smith and Li 1983, Addley 1993) and the velocities that they use is dependent on temperature. Temperature in rivers varies dramatically between seasons, within seasons, and daily; therefore, habitat use varies on these same time scales. What these studies underscore is the importance of maintaining the range of flow variability inherent in the natural flow regime to ensure the full complement of habitat diversity is available over spatial and temporal scales necessary to support a sound ecological environment.

3.7.4 Development of Habitat Guilds and Selection of Focal Species

As a first step in defining the linkage between the aquatic resources and the physical habitat mosaic at each site, the Instream Flow Workgroup developed a framework for evaluating potential target focal species and defining habitat guilds within the basin. The framework is based on classification of the physical habitat across a gradient of depth and velocity to derive five primary riverine habitat types or guilds as described below:

- Riffle
- Deep Run
- Shallow Run
- Deep Pool
- Shallow Pool

Published literature on fish distribution and status within the basins were reviewed as a starting point for selection of focal species and associated habitat guilds (Leavy and Bonner 2009). The team discussed other factors such as causative mechanisms for observed trends and their relative significance. Other considerations included distribution, status, trophic position, reproductive strategies, sensitivity to flow regime changes and/or water quality, etc. Selection of the focal species also considered their suitability for use in monitoring responses at the fish community level under an adaptive environmental monitoring and management program.

Habitat Suitability Criteria

Suitability criteria generated from fish observations in a river system are typically used to quantify the range of suitable depth, velocity, and substrate for target species and life stages. However, generation of suitability criteria is fraught with many difficulties. Some of the most serious of these are logistics constraints affecting the size, timing, and quality of the sample data. This includes biases in habitat availability, predation/competition, low abundance, sampling gear bias, etc. As a result, even though it is generally known that fish habitat use changes with fish size, season, temperature, activity, habitat availability, presence and abundance of competitors and predators, discharge, and changes between years (Orth 1987, Shrivell 1989, Heggenes 1990, Shrivell 1994, Smith and Li 1983, Bozek and Rahel 1992, Everest and Chapman 1972, Moore and Gregory 1988, Modde and Hardy 1992) practical data collection constraints dictate that suitability criteria are generated from a finite number of fish observations over a small range of conditions.

Typically, data are collected for a discrete range of fish sizes (e.g., fry), during one or two seasons, in a range of different habitat types and at the flows, fish densities, predator and competitor densities, and temperatures available in the river at the time of sampling. These data are then lumped together to create, for example, fry suitability criteria. These data are only an approximation of the gradient of suitable depths, velocities, and substrates useable by fry. Some investigators who have dealt with the problems outlined above have suggested that envelope curves are a practical solution.

Bozek and Rahel (1992) found differences in the suitability and preference criteria (corrected for habitat biases) of young cutthroat trout between years and between rivers. They found that composite envelope curves (combining data from rivers and years) provided a practical solution for representing the gradient of usable depth and velocity. Jowett (1991) found that using enveloped suitability criteria from four rivers performed almost as well as stream-specific criteria, and very much better than functions developed at one river and applied to another. Based on his data, Jowett advocated the use of generalized envelope criteria. Now, properly defined envelope curves appear to be one of the most practical approaches for describing the gradients of depth, velocity, and substrate of species/life stages where robust, high quality (properly developed) site-specific data are not available.

To protect the integrity of the aquatic system, the needs of the entire aquatic community should be considered. In diverse, warm-water systems such as the Colorado and Lavaca river basins, flow-habitat relationships would need to be developed for many species and potentially different life stages of species, complicating the analysis and interpretation of a multitude of flow-habitat curves. To simplify interpretation of these relationships (e.g., reducing the number of response variables), habitat guilds—groups of species using similar habitats—are used to represent the diversity of mesohabitat types found in the streams and rivers in a basin. Habitat guilds also allow for the representation of rare species or species for which no habitat suitability data is available. Because of these reasons, many recent instream flow assessments have used habitat guild-based criteria as input to physical habitat-based assessments of instream flows (Lenoard and Orth 1988, Vadas and Orth 2001, Lamouroux and Souchon 2002, BIO-WEST, Inc. 2008, Persinger et al. 2010; and others). Habitat Suitability Criteria (HSC) for each guild were developed using an envelope curve approach based on individual relationships of depth, velocity, and substrate of species-specific curves.

Selection of Focal Species and Habitat Guilds

The initial process of selecting focal species and assigning them to habitat guilds was conducted through dialogue at the BBEST meetings and during Instream Subcommittee conference calls [October 1, 2010, and December 14, 2010]. Based on a review of available information on historical fish distribution and best professional judgment, species were placed into four habitat guilds: slackwater (pool and backwater), deep run, shallow run, and shallow riffle. The focal species list was keyed to subbasins within the Colorado and Lavaca river basins. During this step of the process, there was an effort to select 2–4 species per guild per location. The initial list of focal species and habitat guilds (Table 3.7.1) was provided to TPWD staff in November 2010 with instructions to develop habitat suitability criteria for each guild using the envelope curve approach. Guilds from all sites were to be combined, eg. riffle guilds from the Colorado and Lavaca basins were combined, and any changes in guild assignments documented. Guidance on minimum depths and maximum velocities was also provided. Reassignment of a species (or specific life stage) to a different guild was based on empirical data and professional judgment.

Table 3.7.1 Colorado-Lavaca BBEST initial focal species list and guilds. An 'X' represents which species were to be considered at that locality for the biological overlay.

Species by habitat guild Common Name	Scientific Name	Upper Colorado	Middle Colorado-Elm	South Concho	Concho	Pecan Bayou	San Saba	Llano	Pedernales	Lower Colorado	Lavaca/Navidad	Onion Creek, Driftwood
Slackwater (backwater, pools)	-											
gizzard shad	*Dorosoma cepedianum*	X	X							X	X	
central stoneroller	*Campostoma anomalum*			X								
ribbon shiner	*Lythrurus fumeus*										X	
ghost shiner	*Notropis buchanani*		X									
mimic shiner	*Notropis volucellus*						X	X	X			X
pugnose minnow	*Opsopoeodus emiliae*										X	
fathead minnow	*Pimephales promelas*	X										
river carpsucker	*Carpiodes carpio*									X		
smallmouth buffalo	*Ictiobus bubalus*						X	X	X	X	X	
blackstripe topminnow	*Fundulus notatus*					X				X		
western mosquitofish	*Gambusia affinis*									X		
largespring gambusia	*Gambusia geiseri*			X								
sailfin molly	*Poecilia latipinna*									X		
green sunfish	*Lepomis cyanellus*			X		X				X		
bluegill	*Lepomis macrochirus*			X			X	X	X	X		X
longear sunfish	*Lepomis megalotis*		X		X					X		
largemouth bass	*Micropterus salmoides*				X	X	X	X	X	X	X	X
white crappie	*Pomoxis annularis*									X	X	
Shallow Runs												
red shiner	*Cyprinella lutrensis*	X	X		X	X				X	X	
blacktail shiner	*Cyprinella venusta*			X	X		X	X	X	X	X	X
Texas shiner	*Notropis amabilis*			X			X	X	X			X
weed shiner	*Notropis texanus*										X	
bullhead minnow	*Pimephales vigilax*	X	X		X	X				X		
blackstripe topminnow	*Fundulus notatus*					X						
spotted bass	*Micropterus punctulatus*			X		X						
Texas logperch	*Percina carbonario*						X	X	X	X		X

Table 3.7.1 Colorado-Lavaca BBEST initial focal species list and guilds. An 'X' represents which species were to be considered at that locality for the biological overlay (continued)

Species by habitat guild Common Name	Scientific Name	Upper Colorado	Middle Colorado-Elm	South Concho	Concho	Pecan Bayou	San Saba	Llano	Pedernales	Lower Colorado	Lavaca/Navidad	Onion Creek, Driftwood
<u>Shallow Riffles</u>												
greenthroat darter	*Etheostoma lepidum*			X								
orangethroat darter	*Etheostoma spectabile*			X			X	X	X	X		X
dusky darter	*Percina sciera*									X	X	
Concho water snake	*Neroidea paucimaculata*	X	X		X							
red shiner	*Cyprinella lutrensis*	X	X			X						
bullhead minnow	*Pimephales vigilax*	X	X		X	X						
channel catfish, juv.	*Ictalurus punctatus* , juvenile						X	X	X	X	X	X
flathead catfish, juv.	*Pylodictis olivaris* , juvenile										X	
central stoneroller	*Campostoma anomalum*						X	X	X	X		X
<u>Deep Runs</u>												
shoal chub	*Macrhybopsis hyostoma*										X	
gray redhorse	*Moxostoma congestum*						X	X	X	X		X
blue catfish	*Ictalurus furcatus*										X	
channel catfish, adult	*Ictalurus punctatus, adult*	X	X	X	X	X	X	X	X	X	X	X
Guadalupe bass	*Micropterus treculii*						X	X	X	X		X
freshwater drum	*Aplodinotus grunniens*		X			X						

Using existing life history information and the derived species-specific habitat suitability criteria HSC (see below), the following changes were made to the species list and habitat guild assignments:

- The slackwater guild was split into shallow pool and deep pool, based primarily on depth HSC. The slackwater guild proposed by the BBEST was intended to cover both pools and backwater habitats. The shallow pool and deep pool guilds still cover backwater-type habitats, but only the term 'pool' is used in the analysis to refer to these habitat types. Shallow and deep pool guilds are consistent with recent assessments on the lower Colorado (BIO-WEST, Inc. 2008a) and lower San Antonio rivers (draft data).
- Ribbon shiner, largespring gambusia, greenthroat darter, Concho water snake, and fathead minnow were not used in the analysis given the lack of data in the compiled database.
- Ghost shiner, mimic shiner, and central stoneroller were moved from the slackwater guild to the shallow run guild, based primarily on velocity HSC.
- Guadalupe bass was moved from shallow riffle to shallow run, based on its velocity suitability criteria, and it was removed from the deep run guild, based on its depth suitability criteria.
- Blackstripe topminnow was removed from the shallow run guild, based upon its use of lower

velocity habitat.

- Spotted bass was moved from the shallow run to the deep run guild, based on its depth suitability criteria.
- Freshwater drum was moved from deep run to shallow run, based on its depth suitability criteria.
- Smallmouth buffalo was included in the deep run as well as the deep pool guild because it was abundant in both types of habitat.
- Flathead catfish juvenile was moved from the shallow riffle to the deep run, based upon its depth suitability curve.
- Burrhead chub (*Macrohybopsis marconis*) was used as a surrogate for shoal chub (*M. hyostoma*). These species were considered synonymous until recently. Based on burrhead chub affinity for shallow and fast habitats and supported by this analysis, this species was moved from deep run to riffle.
- Texas logperch was moved from shallow run to riffle, based on its velocity suitability criteria.
- Red shiner, bullhead minnow, and central stoneroller were removed from the riffle guild, based on their depth and velocity suitability criteria.

After modifications, five guilds were developed and consisted of the species listed in Table 3.7.2.

Table 3.7.2 Colorado-Lavaca BBEST initial focal species list and guilds.

Shallow Run	Deep Run	Shallow Pool	Deep Pool	Riffle
central stoneroller	smallmouth buffalo	blackstripe topminnow	smallmouth buffalo	burrhead chub
red shiner	gray redhorse	river carpsucker	gizzard shad	channel catfish, juvenile
blacktail shiner	blue catfish	western mosquito-fish	white crappie	orangethroat darter
Texas shiner	channel catfish	sailfin molly	largemouth bass	dusky darter
ghost shiner	spotted bass	Bluegill		Texas logperch
weed shiner	freshwater drum	longear sunfish		
mimic shiner	flathead catfish, juvenile	green sunfish		
bullhead minnow		pugnose minnow		
Guadalupe bass				

3.7.7 Key Life History Characteristics of Guild Species

For each of the defined habitat guilds, the following species were used to develop species-specific habitat suitability criteria. As noted below, these species-specific habitat suitability criteria were used as the basis to define the overall habitat guild envelope curves. It should be noted that these are not the same as the focal species described above, which were selected based on a broad range of criteria that included the consideration of future monitoring under the adaptive management program. The use of the species below was based on the need to estimate the overall hydraulic suitability of the specific habitat guilds based on available quantitative data from fisheries collections. The species were selected based on species' historic and current abundance and having sufficient information available to be considered in the quantitative habitat-based analysis. Species were combined into groups to form five habitat guilds. Species-specific life history information is derived from the Texas Freshwater Fishes website (http://www.bio.txstate.edu/~tbonner/txfishes/index.htm).

Riffle Guild

Shoal chub and Burrhead chub - *Macrhybopsis* spp.

The species complex previously known as the speckled chub *Macrhybopsis aestivalis* is distributed throughout the Mississippi River drainage and Gulf Coastal drainages. However, recent analyses have split this complex into five species west of the Mississippi River, two of which (shoal chub *M. hyostoma* and burrhead chub *M. marconis*) occur in the Colorado River (Eisenhour 2004). Because these two species were only recently differentiated, no attempt was made to distinguish them in field collections, and given that they occupy similar habitats, they were grouped as one ecological unit for guild analysis. These fish inhabit moderate to swift flowing waters over sandy and gravelly substrates in large rivers. They spawn throughout the summer months and eggs develop as they drift in the current. In the Colorado River, *Macrhybopsis* are relatively abundant in shallow riffles over sand and small gravel throughout the river (BIO-WEST, Inc. 2008a).

Dusky darter - *Percina sciera*

The dusky darter is a fairly large darter (maximum size ≈ 110 mm) found in Gulf of Mexico drainages. Dusky darters usually occur in riffles and raceways of moderate to large streams over gravel substrates, often associated with some type of cover such as boulders or logs (Miller and Robison 1973). They feed on a variety of aquatic insects and spawn from February through June in the Colorado River over gravelly substrates. Eggs and larvae of dusky darters can survive at temperatures between 22 °C to 27 °C (Hubbs 1961).

Texas logperch - *Percina carbonaria*

The Texas logperch is a relatively large darter (maximum size ≈ 112 mm) endemic to the Brazos, Colorado, Guadalupe, and San Antonio rivers of Texas. Due to its small native range, little life history information has been published on this species. However, they are assumed to be similar in habitat use and biology to the closely related and more widely distributed logperch *Percina caprodes*. Logperch inhabit rocky riffles, feed on a variety of aquatic insect larvae, and spawn demersal adhesive eggs in moderate current over gravel substrates (Boschung and Mayden 2003). Hubbs (1961) found that Texas logperch spawn from January through June in the Colorado River, and eggs and larvae can tolerate temperatures between 22 °C to 26 °C.

Channel catfish (Juveniles <180 mm) - *Ictalurus punctatus*

The channel catfish is a native species in Texas, including the Colorado and Lavaca River Basins. Due to their popularity as a game and food fish, introductions of channel catfish into new areas have expanded their range. This widely adaptable fish occupies a variety of habitats including rivers, reservoirs, and ponds. After fry leave the nest, they form tight schools for several weeks until they reach fingerling size (Robison and Buchanan 1988). Such schools of juvenile channel catfish are abundant in riffle habitats over gravel and cobble substrates throughout the Colorado River in the late summer and fall (BIO-WEST, Inc. 2008a). Conversely, adults are more common in deeper areas and were thus included in the Deep Run guild.

Orangethroat darter - *Etheostoma spectabile*

The orangethroat darter is a small percid (maximum size ≈ 60 mm) that ranges from central Texas to the north and east. They inhabit shallow, moderately fast, gravel riffles where they feed on a variety of aquatic insects and fish eggs. Eggs are deposited in the gravel substrate, and spawning usually occurs from November through July in Texas (Page 1983, Hubbs 1985). In the Colorado River, orangethroat darters are fairly common on shallow gravel riffles from Austin downstream to Columbus (BIO-WEST, Inc. 2008a). Their abundance decreases downstream most likely due to increased turbidity and decreasing amounts of gravel riffle habitat.

Deep Run Guild

Smallmouth buffalo - *Ictiobus bubalus*

The smallmouth buffalo is a large catostomid fish native to large Gulf Coast drainages. They are common in deep slow pools and runs of rivers throughout their range. Spawning occurs in early to middle spring when adhesive eggs are scattered over the substrate or onto submerged vegetation. Smallmouth buffalo are a large long-lived fish with a maximum life span of approximately 15 years and maximum size approaching 70 pounds (Robison and Buchanan 1988, Mettee et al. 1996, Boschung and Mayden 2003). They are also common in deep runs throughout the Colorado River and thus were included the Deep Run guild.

Gray redhorse - *Moxostoma congestum*

The gray redhorse is a large catostomid fish endemic to streams of the Edwards Plateau region of Texas. Results from a study of fish collected in a Texas Hill Country stream and a central Texas reservoir indicated that *M. congestum* spawns over two distinct periods: first in late February or early March and again in late April or early May (Bean 2006, Bean and Bonner 2008). Feeding seems non-selective; individuals consume foods in the abundances in which they occur in their environment. Adult gray redhorse tend to use deep runs in the Colorado River from Austin downstream to Columbus (BIO-WEST, Inc. 2008a).

Blue catfish - *Ictalurus furcatus*

In Texas, the blue catfish ranges throughout the state and is normally found in open waters of reservoirs and in main channels of rivers where there is strong current and the water is somewhat turbid (Burr and Warren 1986). Blue catfish are nest spawners in a cavernous nest dug out by the male. In the Colorado River, adult blue catfish were collected from a variety of habitats; however, they were most abundant in deeper runs often near some type of cover.

Channel catfish (Adults) - *Ictalurus punctatus*

The channel catfish is native to the Gulf Slope drainages, including the Colorado River. Channel catfish can live in a wide variety of habitats and can withstand a broad range of temperatures. In rivers, adults usually occupy deep pools near cover and overhanging banks during the day and venture out to feed in shallower areas at night. Spawning usually occurs from May to July in a cavernous nest dug out by the male along an undercut bank or under logs or other debris. In the Colorado River, adult channel catfish were collected from a variety of habitats; however, they were most abundant in deeper runs often near some type of cover (BIO-WEST, Inc. 2008a).

Spotted bass - *Micropterus punctulatus*

In Texas, the spotted bass occurs in the eastern half of the state from the Guadalupe River Basin northeastward to the Red River Basin. Spotted bass are most abundant in clear to moderately turbid streams and rivers. Although the young can be captured from a variety of shallow water habitats, adult spotted bass typically inhabit deep runs and pools. They are more common in swift water than largemouth bass, which prefer slow pools and other lentic areas (Ryan et al. 1970). Like most centrarchids, spotted bass use aquatic vegetation, submerged logs, rocks, and riprap for cover. Spawning occurs from April to June with water temperatures ranging from 17.2 °C to 25.6 °C. Males make shallow nests, usually over rock or gravel substrate, and guard them until the fry hatch (Hassan-Williams and Bonner 2007, Simon 1999). Spotted bass are a popular gamefish in Texas streams and reservoirs, which can be very sporting on light tackle. Although they do not have particularly flow-sensitive life history or habitat requirements, spotted bass often inhabit deep backwaters or eddies beneath swift-flowing riffles and runs, where they move into current briefly to feed, and then move back into slack water refuges. Maintenance of sufficient flow to maintain such habitat complexity is important.

Freshwater drum - *Aplodinotus grunniens*

The freshwater drum is found throughout Texas except in the Panhandle. It is found in turbid to clear lakes and rivers, but does occur in a wide variety of habitats (Fremling 1980). It occurs in benthic habitats in large bodies of water typically in deep water. Spawning season is May and June. Drum spawn in open water and release buoyant eggs. Primarily a benthic feeder, consuming insect larvae, crustaceans, fish, clams, and snails; molar-like pharyngeal teeth aid in masticating mollusks (Fremling 1980). They may live more than 20 years.

Flathead catfish (Juveniles <300 mm) - *Pylodictis olivaris*

The flathead catfish usually inhabits deep holes of medium to large rivers. Young-of-the-year live in rocky riffles until the fish get between 2 to 4 inches in length and then begin to distribute among other river habitats. Flathead catfish are also speleophils; nests are constructed under logs or other concealing cover (Breder and Rosen 1966).

Shallow Run Guild

Central stoneroller - *Campostoma anomalum*

The central stoneroller is a wide-ranging herbivorous cyprinid that occurs throughout the Colorado River. Stonerollers are most abundant in small generally clear streams over gravel substrates. Spawning occurs in riffle areas during spring at water temperatures of about 15 °C (Robison and Buchanan 1988). After hatching, small stonerollers occupy slow stream margins and backwaters until they reach larger sizes and move into the main flow. In the Colorado River, stonerollers were most commonly collected in shallow, gravel riffles of moderate current from Austin downstream to Columbus (BIO-WEST, Inc. 2008a).

Red shiner - *Cyprinella lutrensis*

The red shiner occupies a wide range of habitats from sluggish backwaters to swift riffles over a variety of substrates. They are classified as crevice spawners that reproduce from April through September by attaching their adhesive eggs to crevices in rocks, wood, or onto submerged vegetation. They have also been known to broadcast their eggs over the nests of various sunfishes. They live approximately two years and reach a maximum size of about 75 mm (Robison and Buchanan 1988, Mettee et al. 1996). The red shiner's ability to persist under a wide variety of habitats and environmental conditions as well as their high reproductive potential make them one of the most abundant species in many large rivers within their range. They are one of the most abundant species in the Colorado River (BIO-WEST, Inc. 2008a) and are collected in a wide variety of habitats over various substrates throughout the river. In data compiled for this analysis, red shiner seemed to use shallow areas with moderate current and therefore were placed in the Shallow Run guild.

Blacktail shiner - *Cyprinella venusta*

This species, which is a close relative of the red shiner, occurs in a variety of habitats over varied substrates from fast gravel riffles to silty reservoirs (Robison and Buchanan 1988, Mettee et al. 1996). In central Texas they reproduce from April through September by expelling adhesive eggs into crevices in the substrate. Blacktail shiners can live up to four years (Ross 2001), and reach sizes of approximately 150 mm. They are a very abundant species in the Colorado and Lavaca rivers, and occur in a variety of habitats; however, they seem to be most abundant in shallow runs with moderate current.

Bullhead minnow - *Pimephales vigilax*

The bullhead minnow is a common inhabitant of large Gulf Slope streams and rivers of Texas. Although sometimes found in strong currents, they are most common in sluggish currents over sand and silt substrates. Bullhead minnows feed in schools along the bottom on aquatic insects, snails, and plant material. Reproduction takes place in late spring and summer when eggs are laid on the undersides of rocks, logs, or other structures.

Mimic shiner - *Notropis volucellus*

The mimic shiner is found in large Gulf slope streams and rivers. Mimic shiners are commonly collected in schools near the surface or midwater over sand and gravel substrates. Spawning reportedly occurs between April and August (Robison and Buchanan 1988, Mettee et al. 1996). Mimic shiners are an abundant species throughout the Colorado River and are often found in shallow runs in association with blacktail shiners and red shiners (BIO-WEST, Inc. 2008a).

Texas shiner - *Notropis amabilis*

This minnow is found from the Rio Grande to the Colorado River primarily in Edwards Plateau streams. Texas shiners are typically found in springs and headwater tributaries, where they may be very common; limited numbers may occur in larger streams (Gilbert 1980a). They are often found in moderately large schools in streams with moderately fast currents and can be found in the upstream ends of pools below riffle areas, in the swift waters along gravel bars and in moderately flowing pools. Spawning typically occurs from February through September in Texas. Texas shiners are probably broadcast spawners and live up to two years (Littrell 2006). This species is an invertivore drift predator (Goldstein and Simon 1999) feeding primarily in the water column on aquatic insects (Littrell 2006).

Weed shiner - *Notropis texanus*

The weed shiner is distributed in low gradient streams in the eastern part of the state from the Nueces Basin northward to the Red River (Hubbs et al. 2008). This minnow is found mainly in sandy low-gradient streams and in high-gradient streams over coarse substrates; they may also occur in oxbows, ponds and reservoirs, especially in shallow weedy coves (Ross 2001). Population cycles may be tied to periods of flooding. Ross and Baker (1983) indicate abundance of weed shiners increases in years of spring flooding, and decreases in those years having relatively low flow in the spring. Weed shiner appear to spawn from May to June in Texas. Little information is available on reproduction. Maximum life span is up to four years. This minnow is a detritivore but may also consume animal prey.

Ghost shiner - *Notropis buchanani*

Widely spread across the eastern two-thirds of Texas from the lower Rio Grande to the Red River, ghost shiners occur in low gradient sections of large creeks and rivers in clear to turbid water and in larger pools and protected backwaters (Gilbert 1980b). They spawn in sluggish riffles over sand or fine gravel. Reproductive season in the lower Brazos River is from May through September (Williams 2010). Ghost shiners are invertivores and live < 3 years (Williams 2010).

Guadalupe bass - *Micropterus treculii*

The Guadalupe bass is endemic to the Edwards Plateau region of central Texas, including portions of the Brazos River, Colorado River, Guadalupe River, and San Antonio River basins (Hubbs et al. 2008). These fish most commonly inhabit swift runs and pools (Perkin et al. 2010) below riffles where they prey on insects, crayfish, and small fish. In the Colorado River, Guadalupe bass inhabit shallower and often somewhat slower areas than specimens from other localities (BIO-WEST, Inc. 2008a).

Deep Pool Guild

Smallmouth buffalo - *Ictiobus bubalus*

See description in deep run. Note that some species commonly inhabit more than one guild.

Gizzard shad - *Dorosoma cepedianum*

The gizzard shad is a common inhabitant of large rivers and reservoirs throughout Texas. They are a pelagic schooling species usually found in deep calm water, although they are often found in strong currents as well. Spawning occurs from April through June when adults congregate in open water and simultaneously release eggs and sperm. The adhesive eggs become attached to the substrate or float in the current for a few days until they hatch. Young gizzard shad provide an important food source for many predatory species. Gizzard shad can live up to six years and grow to approximately 20 inches in length (Robison and Buchanan 1988, Mettee et al. 1996). Gizzard shad are abundant in deep runs and pools over a variety of substrates throughout the Colorado and Lavaca Rivers.

White crappie - *Pomoxis annularis*

White crappie is a popular game fish in Texas reservoirs. It occurred naturally in the eastern two-thirds of Texas, but stocked populations are found almost statewide (Hubbs et al. 2008). It is found in streams, lakes, ponds, and slow-moving areas of large rivers (Lee 1980). This species was rare in river channel samples but abundant in oxbow lakes of the Brazos River (Zeug et al. 2005). White crappie are nest spawners using plant material as a substrate. Spawning season in Texas is late March to early May. Insects and forage fish are the main food source for crappies. The maximum life span is about 8 years reaching a maximum size of 510 mm (Carlander 1977).

Largemouth bass - *Micropterus salmoides*

Largemouth bass are native to eastern North America including most of Texas, and are arguably the most popular freshwater game fish in the United States. This popularity as a sport fish has led to their introduction into many areas outside their native range. Although they are most abundant in reservoirs, lakes, and ponds, largemouth bass are also common in low velocity habitats of rivers such as pools and backwaters. They are a predatory species, which feed on a variety of fish and invertebrates. They spawn over nests excavated by the male in shallow still water during the spring, usually from February to May. Eggs and fry are protected by the male bass for several days after hatching. Largemouth bass commonly live 10+ years and can grow to sizes exceeding 20 pounds (Robison and Buchanan 1988, Mettee et al. 1996).

Shallow Pool Guild

Blackstripe topminnow - *Fundulus notatus*

The blackstripe topminnow is a small surface-dwelling fish, which inhabits pools and margins of slow low gradient streams and rivers. The majority of their diet is comprised of terrestrial insects taken from the surface; however, aquatic insects and crustaceans are also consumed. Spawning occurs in late spring and early summer when the female deposits 20-30 unguarded eggs on vegetation or detritus (Robison and Buchanan 1988, Mettee et al. 1996).

River carpsucker - *Carpiodes carpio*

River carpsucker are native to the Western Gulf Slope drainages in Texas. They are most common in medium to large rivers over sand and silt bottoms in slow current where they browse along the bottom feeding on attached algae, small crustaceans, molluscs, and small aquatic insects. Spawning occurs from May to August when adhesive eggs are broadcast over the substrate. River carpsuckers can live up to 10 years and grow to sizes of approximately 10 pounds (Robison and Buchanan 1988, Mettee et al. 1996). They are abundant throughout the Colorado River, especially downstream of Columbus where sand is the predominant substrate (BIO-WEST, Inc. 2008).

Western mosquitofish - *Gambusia affinis*

The western mosquitofish is a small surface-dwelling fish that inhabits shallow areas of little to no current in streams, rivers, ponds, lakes, and swamps. Mosquitofish can tolerate an extremely wide range of environmental conditions, often occurring in areas of low dissolved oxygen, elevated temperatures, and high salinities. Western mosquitofish are abundant in shallow vegetated stream margins, pools, and backwaters throughout the Colorado and Lavaca Rivers.

Sailfin molly - *Poecilia latipinna*

The sailfin molly is a surface-dwelling poeciliid fish distributed in brackish waters. Inland freshwater populations exist in Texas, Louisiana, and Florida. The species gets its name from the large, elongate, and colorful dorsal fins present on males. Sailfin mollies, like mosquitofish, can tolerate a wide range of salinities and can occur in ditches and small pools with high temperatures and very little dissolved oxygen. Sailfin mollies feed on algae, vascular plants, and small invertebrates; however, they become more herbivorous as they grow (Boschung and Mayden 2003). Although not particularly abundant in the Colorado River, sailfin mollies are common in shallow pools and weedy backwaters throughout the river (BIO-WEST, Inc. 2008a).

Bluegill - *Lepomis macrochirus*

Bluegill are common in rivers, lakes, and ponds throughout the eastern United States and south into Mexico. Since they provide an excellent forage species for the widely introduced largemouth bass, and are also popular with fishermen, bluegill have been extensively introduced outside their native range. In rivers, they are most commonly found in slow-moving pools and backwaters. They reproduce during late spring and summer in shallow colonial nesting sites similar to other sunfish. They can live up to six years and grow to sizes of approximately 10 inches (Robison and Buchanan 1988, Mettee et al. 1996). Bluegill are common in shallow pools throughout the Colorado River, often in association with other *Lepomis* species (BIO-WEST, Inc. 2008a).

Longear sunfish - *Lepomis megalotis*

The longear sunfish is a small centrarchid found throughout Texas. They are common in pools of small streams and large rivers where they feed on a variety of aquatic invertebrates, terrestrial insects, and the occasional small fish. They spawn in late spring and summer in shallow slow-moving water where the male builds a small saucer shaped nest in the substrate. Spawning often takes place in colonies, with several nests located in close proximity to each other.

Green sunfish - *Lepomis cyanellus*

Green sunfish are native to the central United States from the Great Lakes south to the Gulf Coast; however, introductions have greatly expanded their range in North America. They are tolerant of a wide range of environmental conditions and are often found in stagnant creeks and ditches where other sunfish species cannot survive. In rivers and streams, they are most common in slow-moving pools and backwaters where they feed on aquatic and terrestrial insects, small fish, and crayfish. Similar to other sunfish, they spawn in shallow saucer-shaped nests during late spring and summer. Growth rates are faster than those of other sunfish, and green sunfish can quickly overpopulate small ponds and lakes. Green sunfish are common in pools and backwaters throughout the Colorado and Lavaca Rivers, often in association with other sunfish species.

Pugnose minnow - *Opsopoeodus emiliae*

Pugnose minnow is found throughout the Mississippi Valley; in Texas it is found primarily in streams of the coastal plain. It is usually in slow-moving rivers and streams (Hubbs et al. 2008) and quiet, weedy backwater areas of lakes, swamps, oxbows (Page and Burr 1991). It is more common in clear than turbid waters. Pugnose minnow spawn in nests usually under flat rocks or in cavities; spawning season appears to be late February through at least the summer. This minnow is a detritivore but may also consume small invertebrates and fishes. The maximum lifespan is 2–3 years and the maximize size is 55 mm (Edwards 1977).

3.7.5 Species-specific HSC

TPWD and BIO-WEST, Inc. staff compiled existing fish abundance-habitat association data from a number of studies conducted in Texas rivers and streams to develop species-specific HSC. Although individual study goals may have differed, collections were targeted that sampled fishes in relatively homogeneous, habitat-specific patches and measured velocity, depth, substrate, and other habitat conditions. Sources included TIFP baseline fish sampling from the middle and lower Brazos, lower San Antonio, and lower Sabine rivers conducted between 2006–2008; unpublished TIFP fish habitat suitability samples from the lower San Antonio River and lower Cibolo Creek conducted during 2009–2010; Blanco River data from a recent master's thesis (Littrell 2006); and data from studies in the upper (BIO-WEST, Inc. 2009) and lower Colorado River (BIO-WEST, Inc. 2008a) as well as studies on the lower San Antonio River (BIO-WEST, Inc. 2008b) and its tributaries (BIO-WEST, Inc. 2008c). In addition to providing a robust dataset, compiling collections from these river systems increased the data available for rare/under-sampled species supporting development of HSC for those species. In total, 1,338 fish abundance-habitat data points covering a broad range of systems, habitats, and flow conditions were used to develop species-specific HSC.

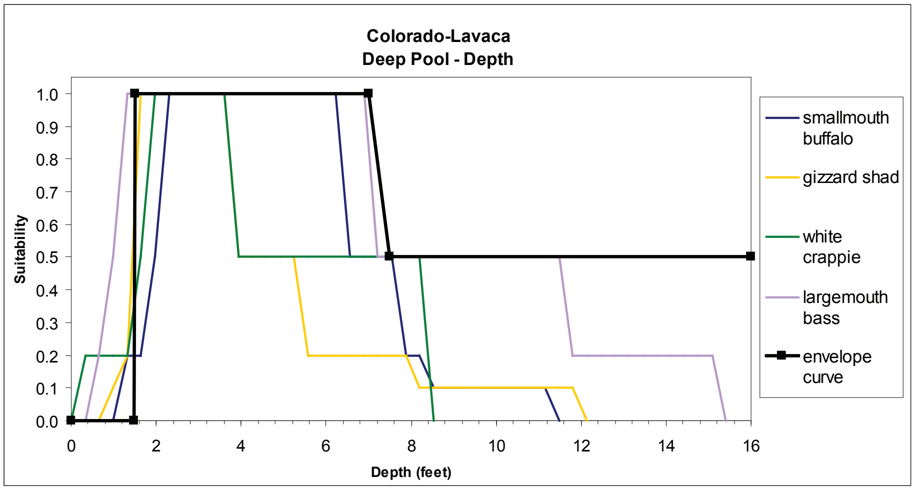
Habitat data for each species were combined to generate frequency histograms for the continuous variables such as depth and velocity. Data were divided into equal increments for depth and velocity. HSC were then developed using nonparametric tolerance limits (NPTL), based on the central 50%, 75%, 90%, and 95% of the data (Bovee 1986) at the 0.95 confidence level. Tolerance limits for the central 50% of the data were used as cutoffs for the most selected habitat and the range of data between these two points were given a suitability of one. Data between the 50% tolerance limits and the 75% tolerance limits was given a suitability of 0.5. Data between the 75% tolerance limits and the 90% tolerance limits was given a suitability of 0.2, and the data between the 90% tolerance limits and the 95% tolerance limits received a suitability of 0.1. Data points falling outside the 95% tolerance limits were considered outliers and given a suitability of zero. HSC for the categorical variable substrate were developed using normalized frequencies. The substrate with the highest frequency (most used) received a suitability value of 1.0. All other substrates received a lower suitability depending on their relative frequency.

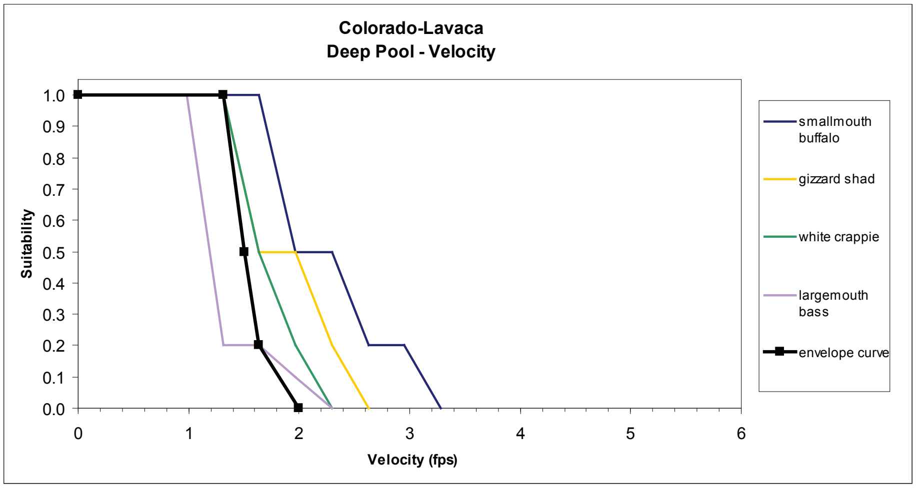
3.7.6 Development of Guild Specific Habitat Suitability Curves

Envelope curves for each habitat guild are presented in Figures 3.7.2 through 3.7.6 and the corresponding tabular values are provided in Table 3.7.3. Depth, velocity, and substrate suitability curves were plotted for the individual species representing each guild. Using the HSC Development Tool software package authored by Dr. Thom Hardy (River Systems Institute, Texas State University), envelope curves were drawn to reflect the range of depth and velocity used by all species included in the guild. An envelope curve did not necessarily encompass or enclose the full range of each parameter. Based on Instream Committee guidance, the minimum depth for each habitat guild was constrained by at least 1.5 times the body depth of the deepest-bodied species to support fish passage and current velocity was checked against a potential maximum swimming velocity (i.e., 4-6 times the total length of the smallest fish in the guild); no adjustments in velocity criteria were needed. Further, the depth envelope curves for deep pool, shallow pool, and deep run guilds were extended beyond the available data, given the characteristics of these habitats, the known life history information available for deep-habitat species (e.g. 20 ft depths should be suitable for deep pool species although the available data only covered depths to around 15 ft) and sampling bias in deep pools (i.e., difficulty in quantitatively sampling deep water habitats). Specifically, for deep-water habitats, the tail of the depth criteria was extended at 0.5 suitability and for the tail of the shallow pool depth criteria, a suitability of 0.2 was used.

Suitability values for substrate classes were also assigned for each guild. A constraint in application of the HSC in the CCM (described below) required standardization of codes between existing fisheries collection data and substrate classifications within the CDM reference database (Table 3.7.4). To accomplish this standardization, clay and silt HSC were combined into one class (clay/silt); the greatest value of the two was chosen for each species. Six substrate classes were used in this analysis: clay/silt, sand, gravel, cobble, boulder, and bedrock. The substrate class with the greatest suitability across all species in a guild was set to 1.0 and the remaining substrate types were normalized as a fraction of this maximum. However, a minimum value of 0.1 was used for substrates with any defined suitability greater than 0.0.

To validate guild membership and to look for potential problems or outliers in the range of depth and velocity criteria, final envelope curves were compared to species data collected to date (January 3, 2011) from the online survey of fish experts being conducted by TPWD and Texas State University (http://rsi-db.its.txstate.edu/fishhabitatsurvey/). No adjustments were necessary based on this information.





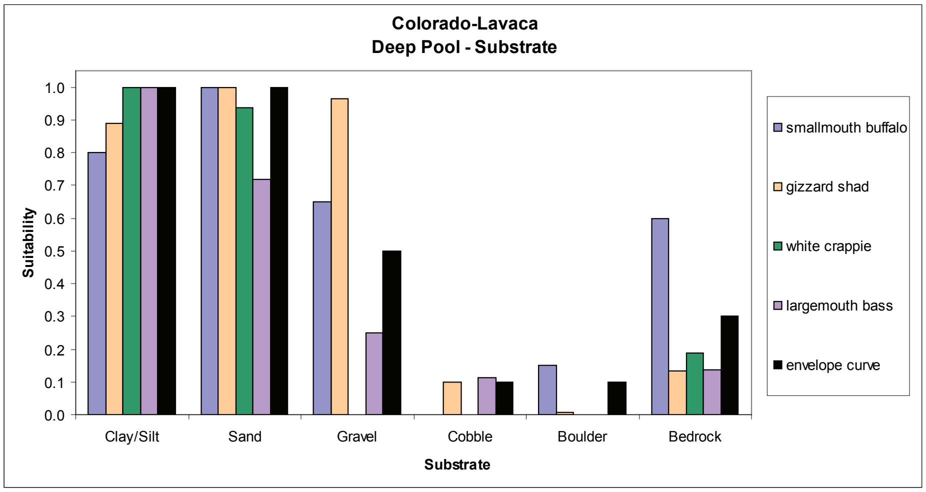
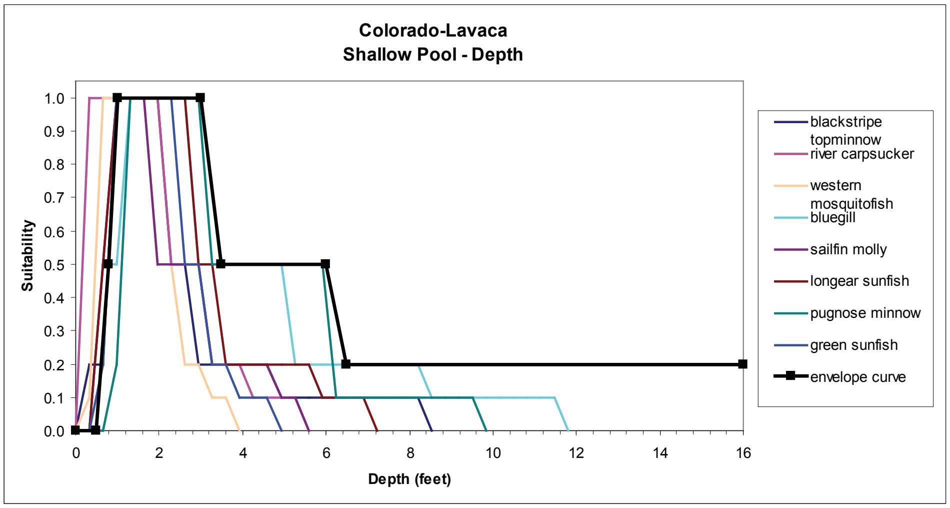
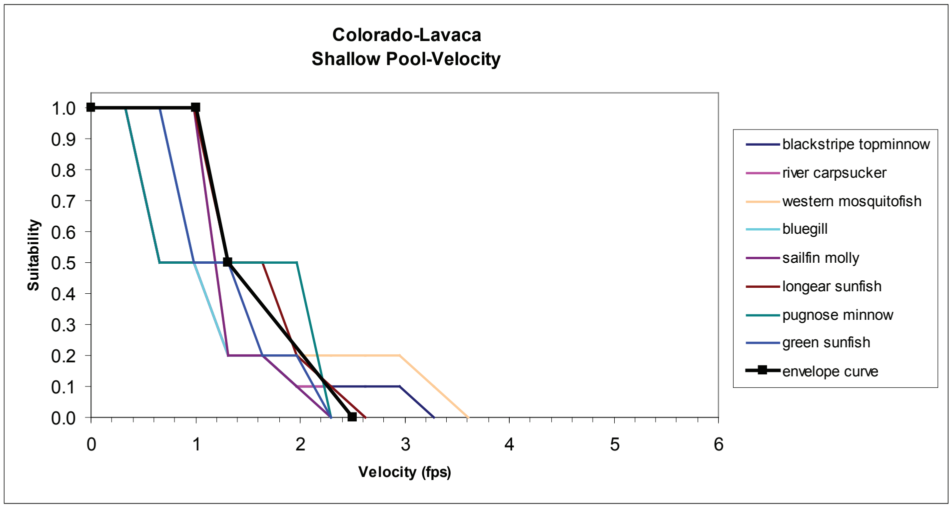


Figure 3.7.2 Envelope and species-specific habitat suitability curves for Colorado-Lavaca fish in the Deep Pool habitat guild.





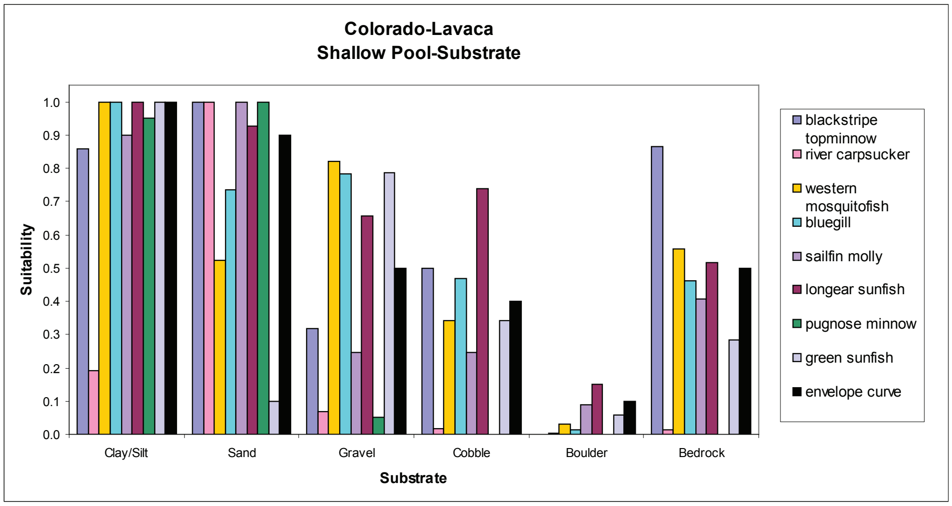
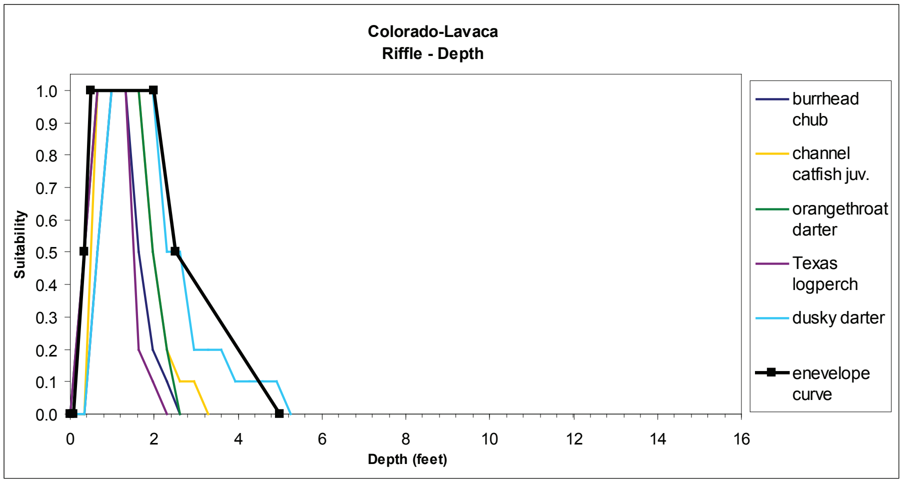
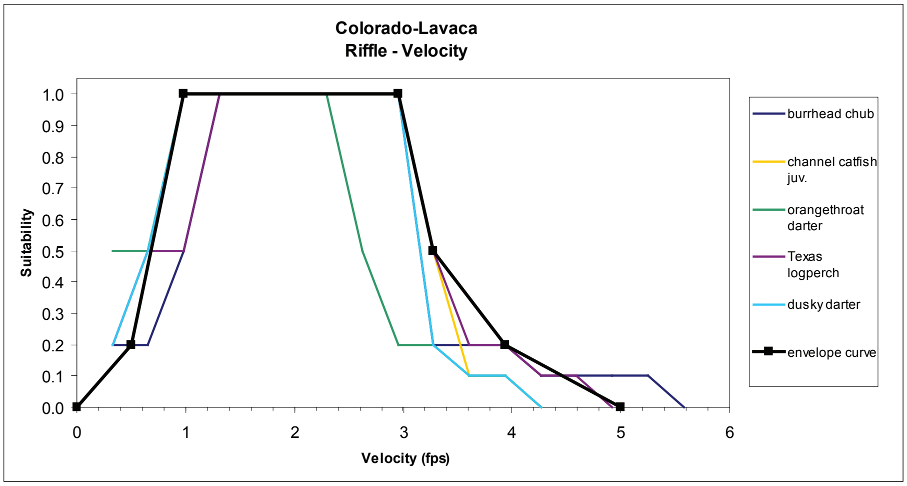


Figure 3.7.3 Envelope and species-specific habitat suitability curves for Colorado-Lavaca fish in the Shallow Pool habitat guild.





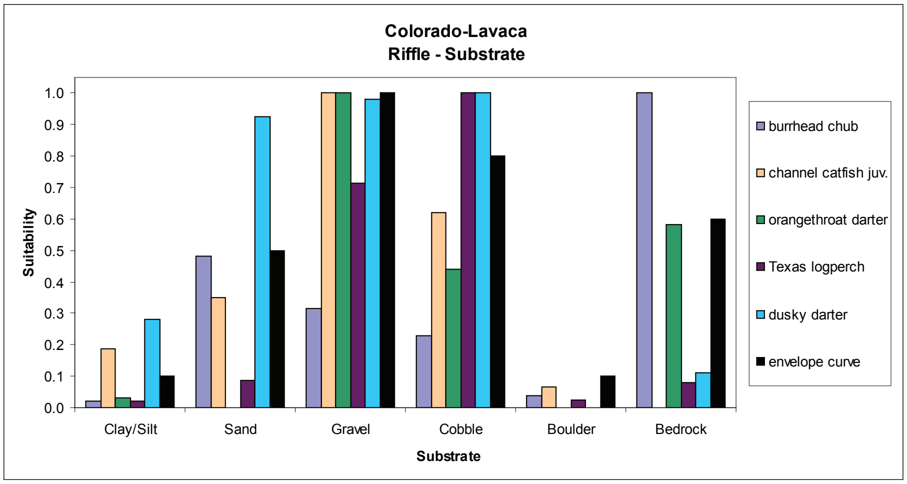


Figure 3.7.4 Envelope and species-specific habitat suitability curves for Colorado-Lavaca fish in the Riffle habitat guild.

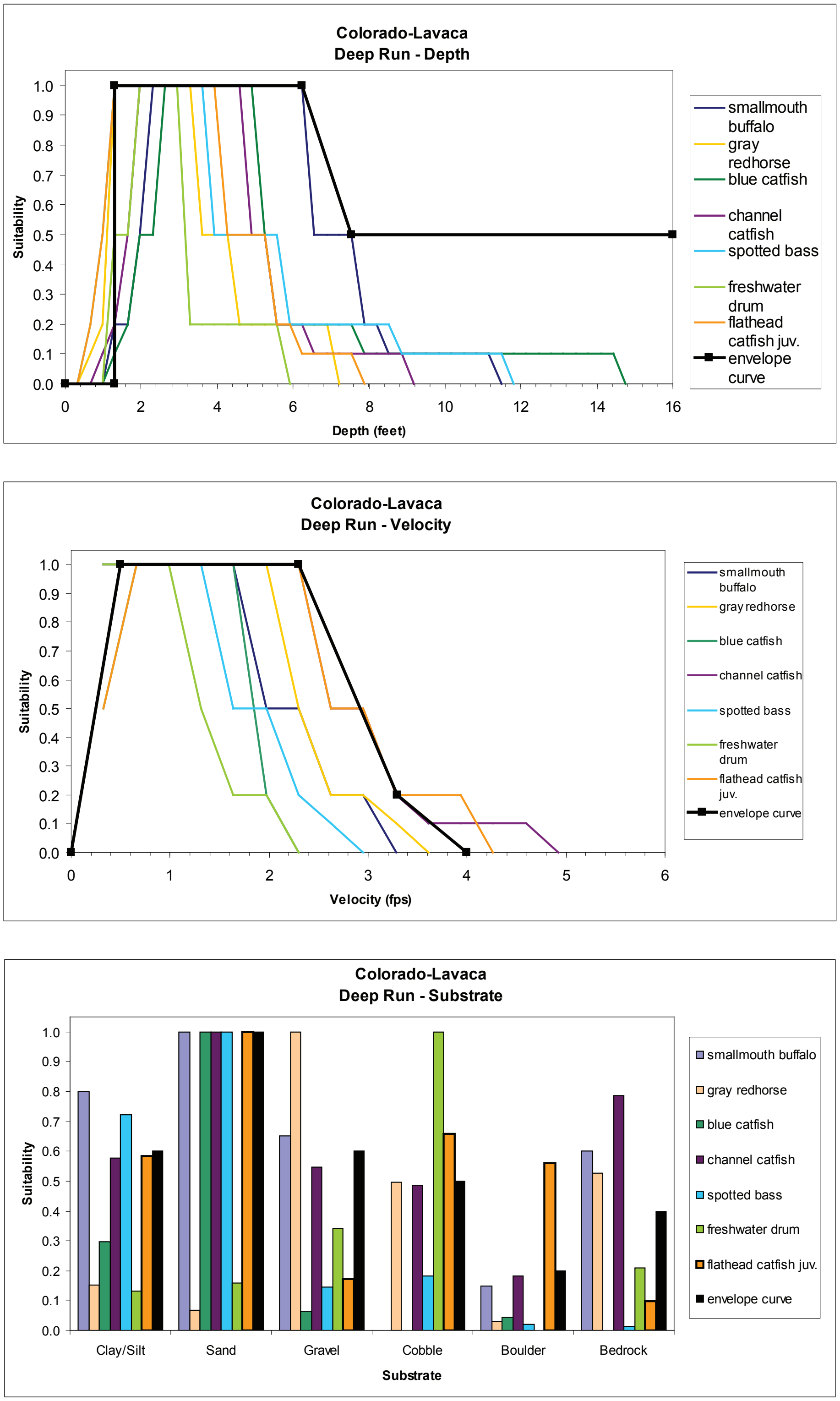
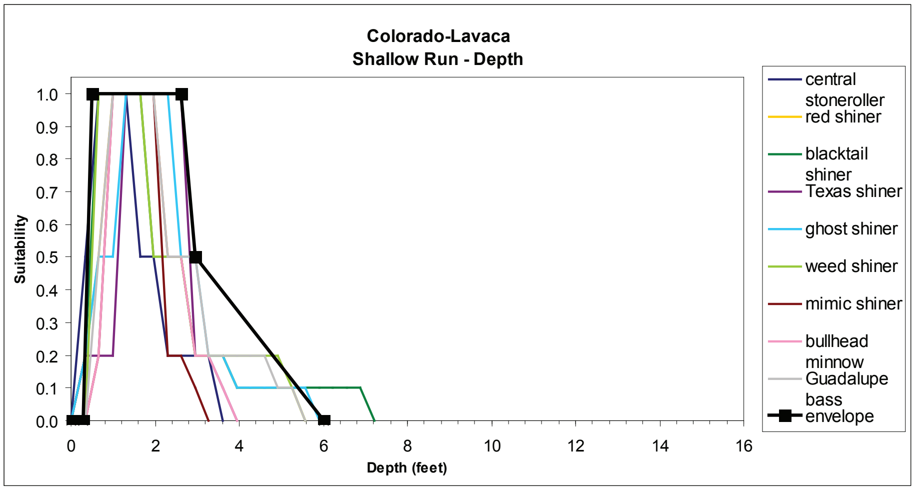
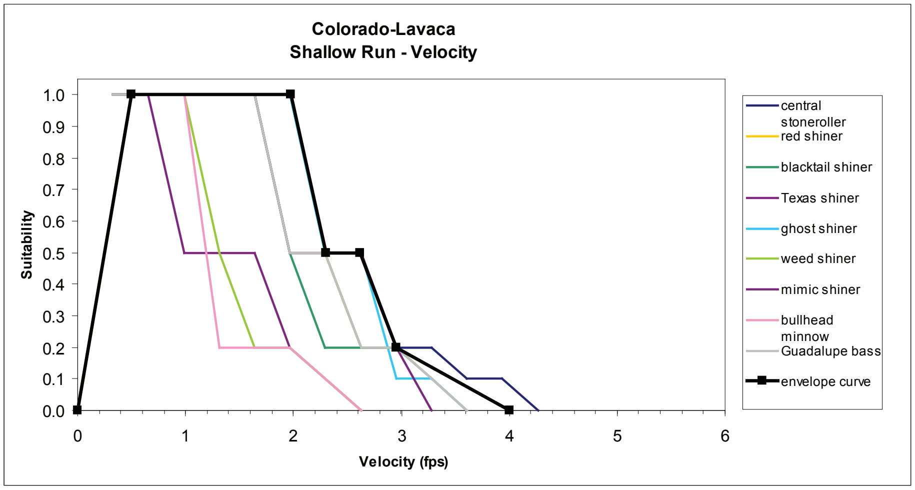


Figure 3.7.5 Envelope and species-specific habitat suitability curves for Colorado-Lavaca fish in the Deep Run habitat guild.





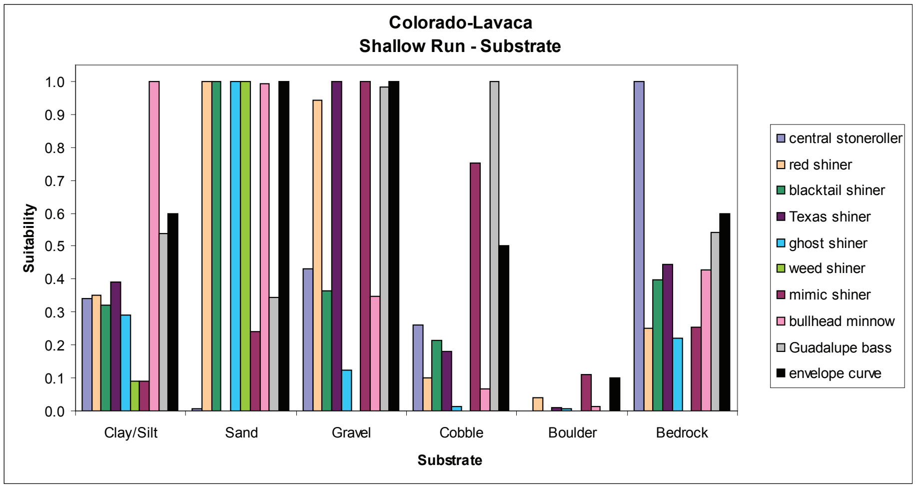


Figure 3.7.6 Envelope and species-specific habitat suitability curves for Colorado-Lavaca fish in the Shallow Run habitat guild.

Table 3.7.3 Colorado-Lavaca habitat suitability envelope curve values for depth (feet), velocity (f/s) and substrate. See Table 3.7.4 for substrate code definitions. Substrate codes 1, 5 and 9 are not used for this application and are set to zero.

Deep Pool		Shallow Run		Deep Run		Riffle	
Velocity (f/s)	Suitability	Velocity (f/s)	Suitability	Velocity (f/s)	Suitability	Velocity (f/s)	Suitability
0.00	1.00	0.00	1.00	0.00	0.00	0.00	0.00
1.31	1.00	1.00	1.00	0.50	1.00	0.50	0.20
1.50	0.50	1.31	0.50	2.30	1.00	0.98	1.00
1.64	0.20	2.50	0.00	3.30	0.20	2.95	1.00
2.00	0.00			4.00	0.00	3.28	0.50
						3.94	0.20
						5.00	0.00
Depth (ft)	Suitability	Depth (ft)	Suitability	Depth (ft)	Suitability	Depth (ft)	Suitability
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.49	0.00	0.50	0.00	1.29	0.00	0.09	0.00
1.50	1.00	0.80	0.50	1.31	1.00	0.33	0.50
7.00	1.00	1.00	1.00	6.23	1.00	0.50	1.00
7.50	0.50	3.00	1.00	7.54	0.50	2.00	1.00
25.00	0.50	3.50	0.50			2.50	0.50
		6.00	0.50			5.00	0.00
		6.50	0.20				
Substrate	Suitability	Substrate	Suitability	Substrate	Suitability	Substrate	Suitability
1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
2.00	1.00	2.00	1.00	2.00	0.60	2.00	0.10
3.00	1.00	3.00	0.90	3.00	1.00	3.00	0.50
4.00	0.50	4.00	0.50	4.00	0.60	4.00	1.00
5.00	0.00	5.00	0.00	5.00	0.00	5.00	0.00
6.00	0.10	6.00	0.40	6.00	0.50	6.00	0.80
7.00	0.10	7.00	0.10	7.00	0.20	7.00	0.10
8.00	0.30	8.00	0.50	8.00	0.40	8.00	0.60
9.00	0.00	9.00	0.00	9.00	0.00	9.00	0.00

Table 3.7.4 Colorado-Lavaca habitat suitability envelope curve substrate code definitions. Note that substrate codes 1, 5 and 9 are not used for this application and set to zero.

Substrate	Code
Organics/Grass	1
Silt	2
Sand	3
Fine Gravel	4
Coarse Gravel	5
Cobble/Rubble	6
Boulder	7
Bedrock	8
Aquatic Vegetation	9

3.7.7 Other Important Species

Although the development of the habitat guilds and corresponding habitat suitability relationships were derived from fisheries data, these relationships are expected to provide protection for other components of the aquatic resources such as macroinvertebrates, mussels, turtles, etc. The BBEST members believe this is justified based on the breadth of the habitat guilds that reflect the primary physical habitat features within river systems and the basic assumption that other aquatic resources partition within the defined gradients of depth, velocity, and substrates (Williams et al. 2005, Pendergrass 2006, Shattuck 2010).

3.7.8 Estimating Habitat Guild Availability as a Function of Discharge Ranges

An important component of establishing environmental flow regimes to ensure a sound ecological environment is the integration or overlay of biological information with the HEFR-based flow regimes (SAC 2009). Fundamentally, this step in the process evaluates the flow magnitudes on a monthly basis within the Base-Low, Base-Medium, and Base-High flow tiers in terms of providing adequate habitat availability across all habitat guilds. That is not to imply, for example, that at a specific flow magnitude associated with a Base-Low flow regime that the specific flow will necessarily provide optimal habitat conditions for all guilds simultaneously but it does imply that over the range of flow conditions (low, medium and high) that adequate habitat availability for all guilds is achieved. As noted previously, it is the variability of flow conditions seasonally (e.g., monthly) and the inter-annual variation in the overall flow regime (dry, normal and wet conditions) that are important to ensure that habitat is available for all habitat guilds at one time or another within the river.

3.7.9 Physical Habitat Modeling

Use of physical habitat modeling is perhaps the most commonly applied approach in instream flow assessments at the national and international levels (COST 626 2005, Locke et al. 2008; Annear et al. 2004). The general theory behind physical habitat modeling is based on the assumption that aquatic species will react to changes in the hydraulic environment (i.e., changes in depth and velocity as a function of flow rate). Estimation of available depths and velocities over a range of discharges is typically achieved through the calibration and simulation of 1-dimensional or 2-dimensional hydrodynamic models based on field measured topographies and hydraulic properties. In essence the stream reach at a particular flow is represented by a series of computational cells having different combinations of hydraulic parameters (i.e., depth, velocity, and substrate) as illustrated in Figure 3.7.7.

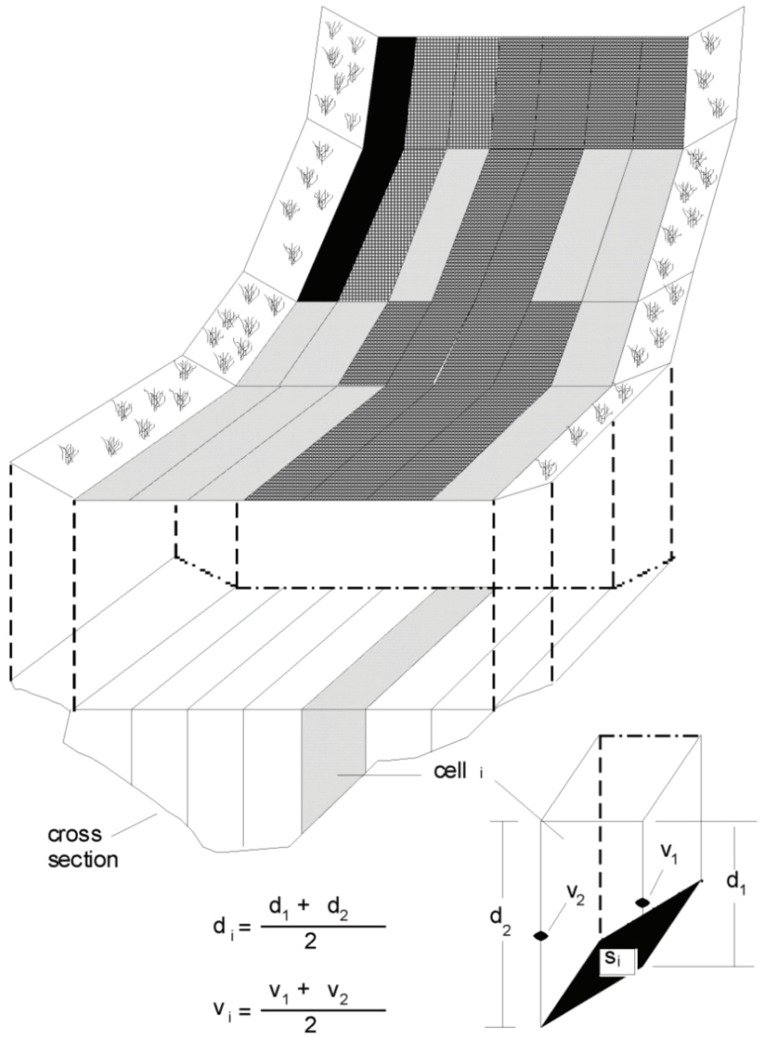


Figure 3.7.7 Conceptual example of a stream used in physical habitat modeling.

Depth and velocity attributes vary on a computational cell-by-cell basis with simulated changes in discharge resulting in changes in the amount and quality of available habitat. Physical habitat modeling uses the habitat suitability curves for depth, velocity, and substrate to estimate the cell-by-cell suitability given the various combinations of depth, velocity, and substrate to produce an estimate of the quantity and or quality of habitat. In the application to the Colorado-Lavaca systems these habitats represent the defined habitat guilds. This measure of available physical habitat is referred to as weighted usable area (WUA). Analytically, WUA is computed at a specific discharge from the sum of all cell habitat areas that are suitable as:

$$WUA = \sum_{i=1}^{n} A_i * C_i$$

where:

WUA = Total Weighted Usable Area in the stream at a specified discharge.

C_i = Composite suitability for computational cell $_i$.

A_i = Area of computational cell $_i$.

And the composite suitability for a computational cell is derived from the component suitability for depth, velocity and substrate based on the habitat suitability criteria:

$$C_i = (V_i * D_i * S_i)^{1/3}$$

where:

C_i = Composite suitability for computational cell $_i$.

V_i = Velocity suitability for computational cell $_i$.

D_i = Depth suitability for computational cell $_i$.

S_i = Substrate suitability for computational cell $_i$.

This process is then repeated for all simulated discharges, which produces the functional relationship between available physical habitat (WUA) for each target habitat guild and discharge. In many applications (as here) the habitat versus flow relationships are presented as a percent of maximum available habitat as illustrated in Figure 3.7.8.

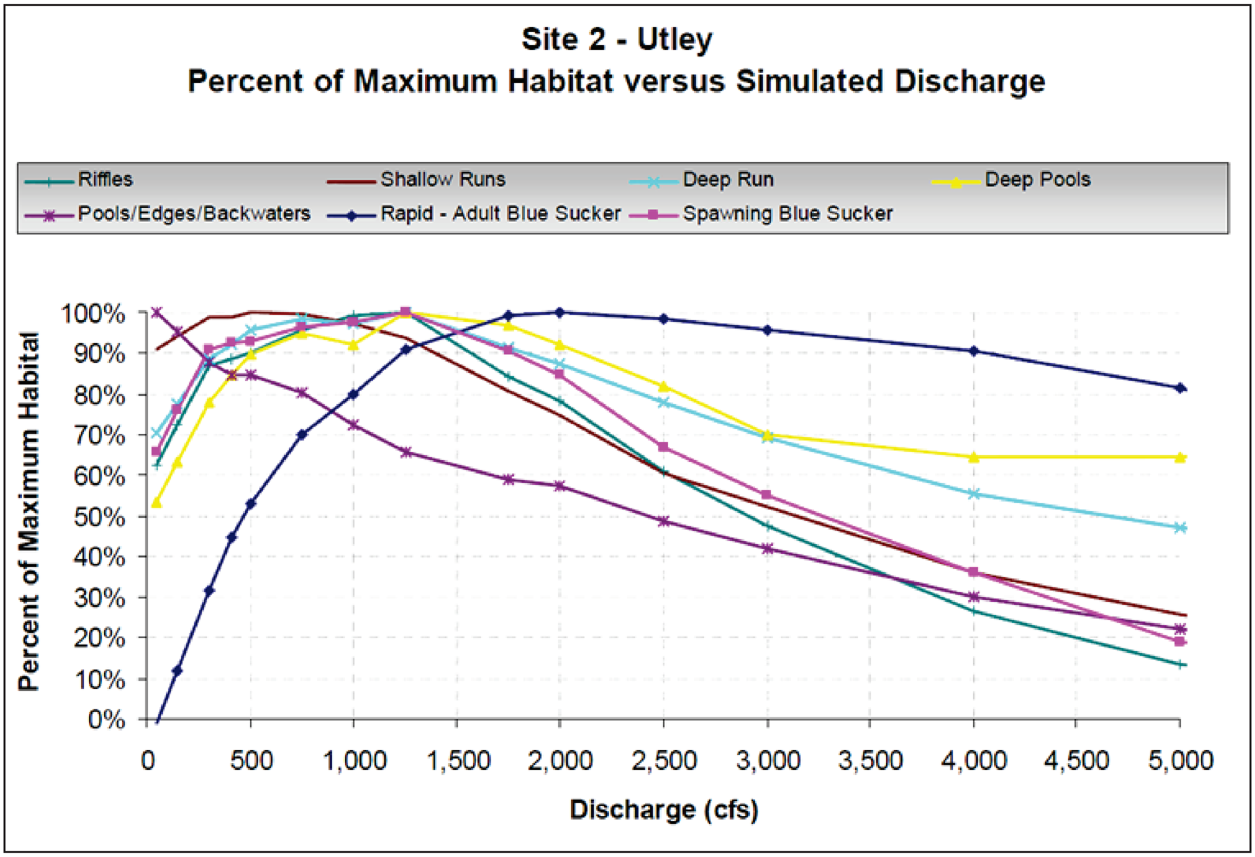


Figure 3.7.8 Example of the functional relationship between the percent of maximum habitat versus discharge (adapted from BIO-WEST, Inc. 2008a).

These relationships are then used in conjunction with the HEFR hydrologic results to provide one aspect of the biological overlay process in defining the environmental flow regime at sites.

3.7.10 Use of Existing Site-specific Habitat Modeling Results

An instream flow assessment to develop subsistence flow guidelines for the Colorado River near Lometa, Texas specific to the Lometa Reservoir Water Systems permit (Permit No. 5715) was available. This location is representative of the Colorado River at San Saba site. The study was based on habitat mapping, fish habitat modeling, and water quality information for a 20+ mile stretch of the Colorado River in the project area. The habitat modeling approach relied on an empirical-based mapping of suitable guild habitats following one of the recognized methodologies of the TIFP (Parasiewicz 2001, 2007). The BBEST critically reviewed the study and came to consensus that this information provided the best available science and agreed to adopt the recommended subsistence flows outlined in the report (BIO-WEST, Inc. 2009). The empirically derived habitat versus flow relationships for target habitat guilds was also adopted for use in the biological overlays with HEFR results. The summary habitat versus flow relationships for the defined guilds is provided in Figure 3.7.9 and was used in the HEFR biological overlays.

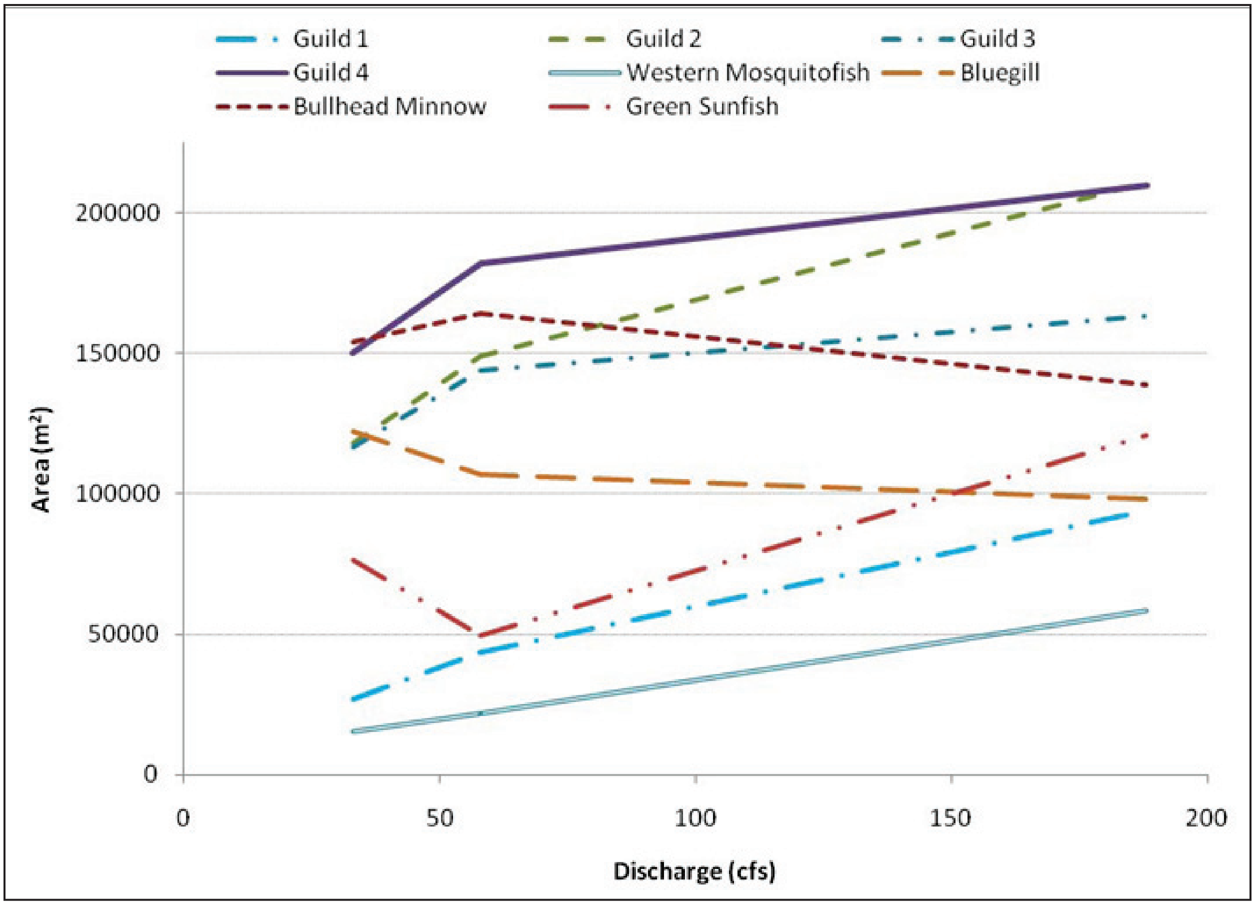


Figure 3.7.9 Percent of total area suitable for each of the habitat guilds at three flow rates for a reach of the Colorado River near San Saba (BIO-WEST, Inc. 2009).

Habitat versus flow relationships for habitat guilds and the state-threatened blue sucker (*Cycleptus elongatus*) were developed for the LSWP studies and used to formulate environmental flow regimes at several locations (BIO-WEST, Inc. 2008a). The studies relied upon two-dimensional hydrodynamic models for the hydraulic simulations, incorporated detailed sediment transport modeling, as well as detailed modeling of the diel temperature, and dissolved oxygen dynamics. These studies were conducted consistent with the goals and objectives of the TIFP and provide a strong scientific justification for the recommended instream flow regimes. The BBEST reached a consensus that the body of work represented the best available science and elected to use the developed instream flow regimes for those specific sites on the Colorado River.

3.7.11 Comparative Cross Section Methodology

Site specific instream flow assessments were not available at several sites for use in the biological overlays to the HEFR matrices. In these cases, a CCM was used to estimate the habitat versus flow relationships for the habitat guilds (Kennard 2000). The CCM relies on previously collected instream flow hydraulic models as the basis for predicting the distribution of depths and velocities given a target river's channel cross section morphology, flow estimate, habitat type, wetted width, substrate and slope. The underlying assumption to this methodology is based on physics of open channel flow where two cross sections having the same basic channel shape, slope, discharge, wetted width, and substrates will have the same basic hydraulic properties over simulated ranges of discharge.

The current analysis used two reference databases developed at the Utah Water Research Laboratory representing study results from the western United States and the United Kingdom. The US reference database contains 629 cross sections from 139 river locations with modeled flows between 25,000 and 0.1 cfs and includes rivers and streams with wetted widths that range from 440 feet to 0.1 feet. The UK reference database contains 460 cross sections from 54 river locations across the United Kingdom (UK) including data from Scotland, Northern Ireland, England, and Wales. Flows range from 3,128 cfs to 0.4 cfs, and wetted widths vary between 188 feet and 0.3 feet. Inclusion of cross section data in the reference databases required, at a minimum, three sets of calibration discharge and water surface elevation pairs and at least one set of calibration velocities. The calibration and simulation of the hydraulic properties at each cross section followed established guidelines, and only simulation results over valid ranges of discharges for each cross section were included (Hardy 2002).

The limitations of this approach are primarily based on finding a representative cross section within the reference database and having adequate cross section samples of the target streams' variability in mesohabitat features. In cases where no suitable reference cross section is found in the reference database, Manning's equation is calibrated to the field measured values and used to simulate hydraulic properties over the required range of discharges. Manning's equation is frequently used in engineering applications for channel design and can be used to solve water surface elevations, velocities, slopes, etc., given appropriate input data. In some instances, field measured channel topographies were extended based on use of Google Earth images of the site and cross section locations and review of ground-based photography obtained during field data collections.

The TWDB and TPWD provided cross section geometry, slope, substrates, wetted width, velocities, and discharge estimates at a single flow rate for representative mesohabitats at nine sites indicated in Table 3.7.5. The number of mesohabitat types sampled varied between sites due to site access and logistical constraints. For the Llano River and Pedernales River sites, cross sections were extracted from three-dimensional channel topographies collected by Texas State University and associated water surface elevations and velocities derived from a calibrated hydrodynamic model (MDSWS – McDonald et al. 2009) at a single discharge.

Table 3.7.5 Comparative cross section study sites.

Colorado River at Ballinger
Colorado River at San Saba
Concho River at Paint Rock
Garcitas Creek near Inez
Lavaca River near Edna
Llano River near Llano
Navidad River near Edna
Onion Creek near Driftwood
Pedernales River near Johnson City
San Saba River at San Saba
Tres Palacios Creek near Midfield

3.7.12 Habitat versus Flow Relationships for Habitat Guilds

The field derived cross section data were used in conjunction with the Colorado Habitat Guild suitability criteria to estimate the relationship between the amounts of habitat for various discharge ranges at each of the sites listed in Table 3.7.5. The ranges of discharge were simulated to encompass the low, medium, and high base flow discharge ranges estimated by the HEFR analysis at each site. Figures 3.7.10 to 3.7.20 provide the relationships between the percent of maximum habitat versus discharge at each site used in the fisheries component of the biological overlays to the HEFR matrices. The vertical lines in each plot represent the average discharge of the four seasonal values for the Low-Base, Medium-Base and High-Base discharges from the HEFR analyses. Tables 3.7.6 through 3.7.16 provide the associated numerical values for each companion figure at each site.

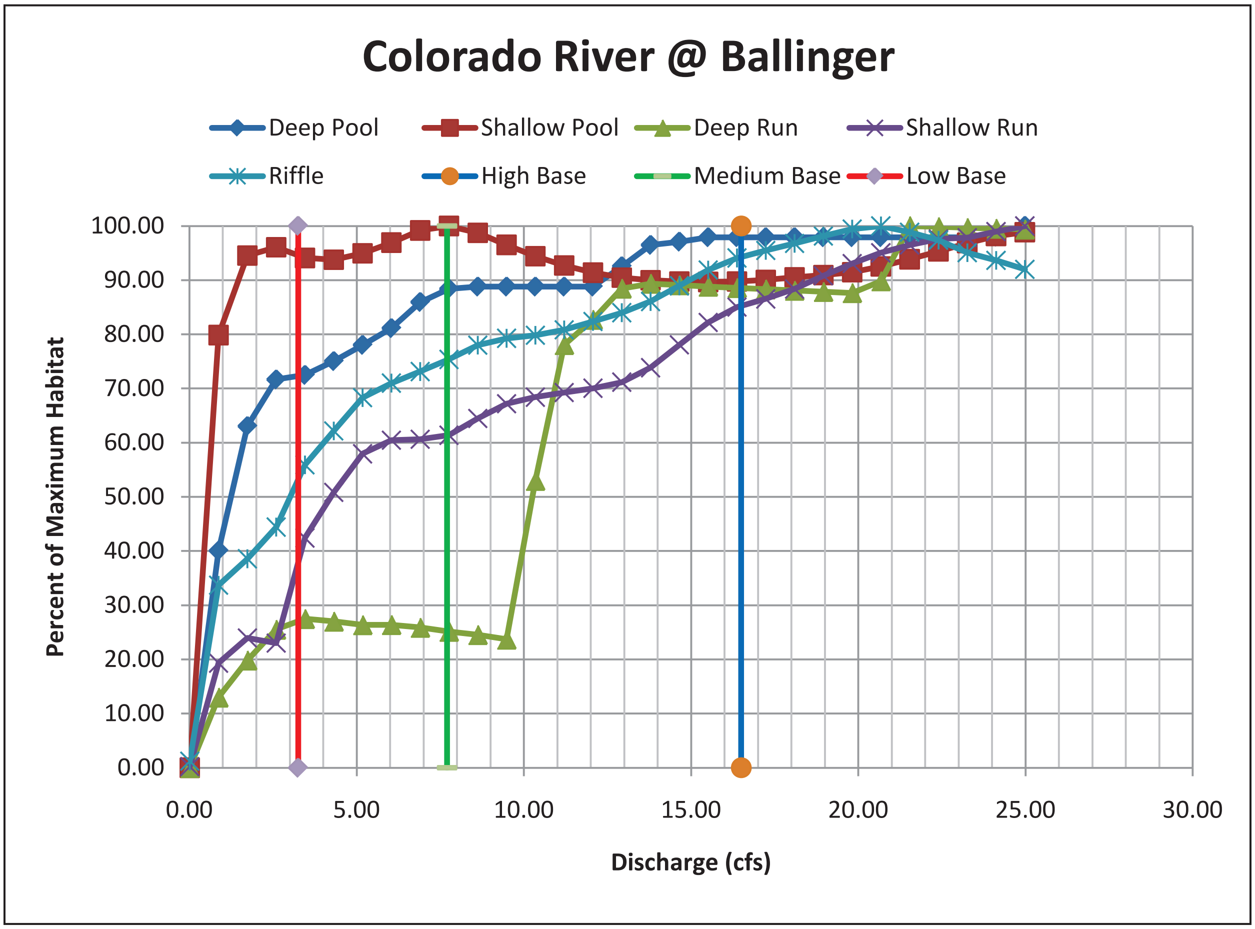


Figure 3.7.10 Relationship between the percent of maximum habitat and discharge at the Colorado River at Ballinger site.

Table 3.7.6 Percent of maximum habitat and discharge at the Colorado River at Ballinger site.

Discharge (cfs)	Deep Pool	Shallow Pool	Deep Run	Shallow Run	Riffle	Average	Minimum
0.01	0.00	0.00	0.00	0.20	1.22	0.28	0.00
0.87	40.06	79.87	13.01	19.32	33.70	37.19	13.01
1.73	63.04	94.54	19.85	23.95	38.57	47.99	19.85
2.59	71.65	96.06	25.52	23.01	44.41	52.13	23.01
3.45	72.48	94.10	27.50	42.42	55.93	58.49	27.50
4.32	75.04	93.78	27.02	50.82	62.15	61.76	27.02
5.18	78.03	94.95	26.37	57.95	68.31	65.12	26.37
6.04	81.12	96.93	26.40	60.46	70.99	67.18	26.40
6.90	85.94	99.18	25.89	60.62	73.13	68.95	25.89
7.76	88.38	100.00	25.15	61.38	75.38	70.06	25.15
8.62	88.78	98.75	24.55	64.47	77.98	70.91	24.55
9.48	88.78	96.51	23.70	67.17	79.27	71.09	23.70
10.34	88.78	94.40	53.00	68.41	79.82	76.88	53.00
11.20	88.78	92.70	78.07	69.26	80.85	81.93	69.26
12.06	88.78	91.38	82.71	70.05	82.37	83.06	70.05
12.93	92.54	90.48	88.46	71.18	83.99	85.33	71.18
13.79	96.48	89.97	89.37	73.84	86.07	87.15	73.84
14.65	97.08	89.74	89.10	78.06	88.96	88.59	78.06
15.51	97.90	89.67	88.82	82.20	91.88	90.10	82.20
16.37	97.90	89.76	88.58	85.02	94.09	91.07	85.02
17.23	97.90	90.02	88.32	86.54	95.47	91.65	86.54
18.09	97.90	90.52	88.08	88.37	96.78	92.33	88.08
18.95	97.90	90.95	87.86	90.81	98.15	93.13	87.86
19.81	97.90	91.49	87.65	93.07	99.44	93.91	87.65
20.67	97.90	92.54	89.83	95.05	100.00	95.06	89.83
21.54	97.90	93.86	100.00	96.51	98.84	97.42	93.86
22.40	97.90	95.33	99.83	97.61	97.38	97.61	95.33
23.26	97.90	96.87	99.66	97.84	95.09	97.47	95.09
24.12	98.01	98.14	99.52	98.97	93.67	97.66	93.67
24.98	100.00	98.86	99.37	100.00	92.00	98.05	92.00

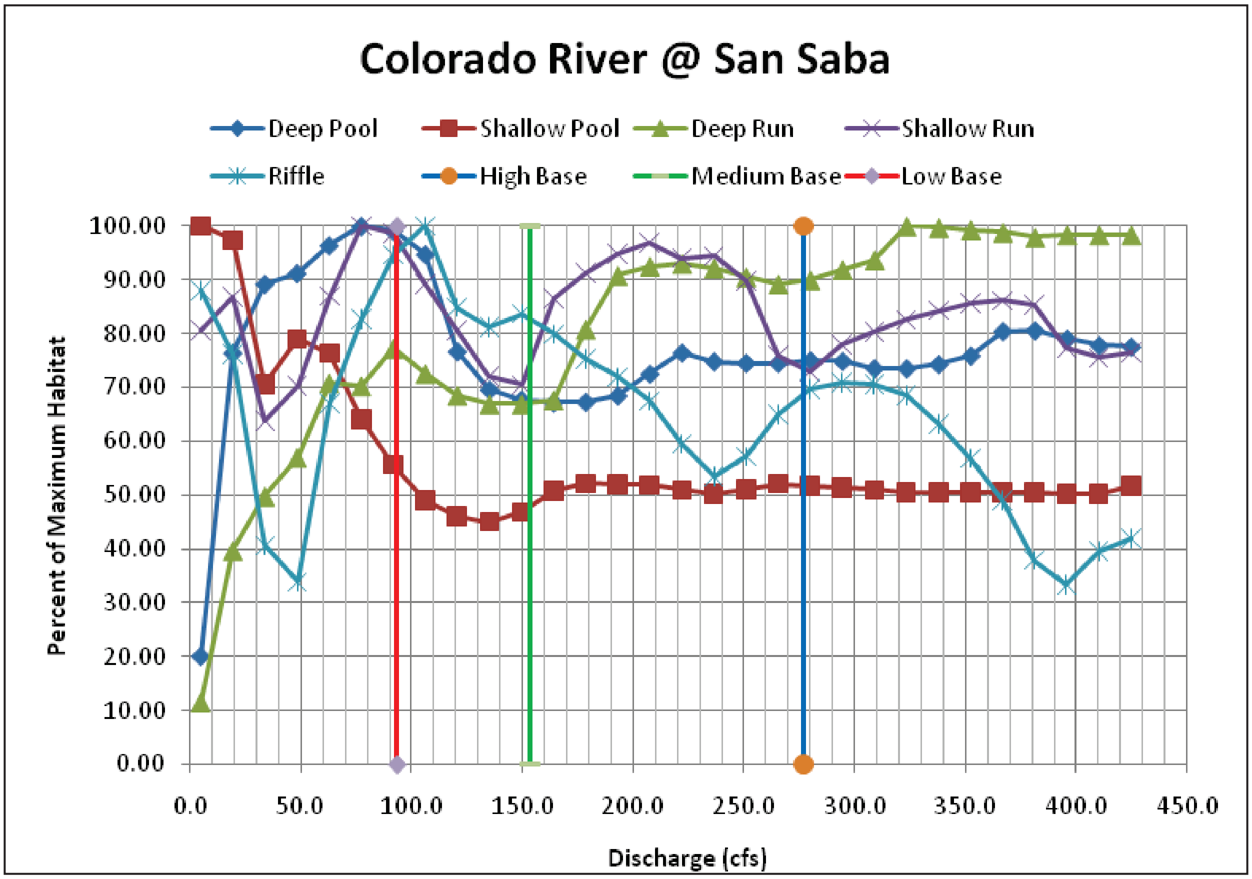


Figure 3.7.11 Relationship between the percent of maximum habitat and discharge at the Colorado River at San Saba site.

Table 3.7.7 Percent of maximum habitat and discharge at the Colorado River at the San Saba site.

Discharge (cfs)	Deep Pool	Shallow Pool	Deep Run	Shallow Run	Riffle	Average	Minimum
5.0	20.02	100.00	11.59	80.63	87.96	60.04	11.59
19.4	76.44	97.31	39.74	86.75	76.21	75.29	39.74
33.9	89.26	70.50	49.82	63.75	40.65	62.80	40.65
48.4	91.25	79.01	57.05	70.30	33.83	66.29	33.83
62.8	96.43	76.31	70.90	86.97	67.04	79.53	67.04
77.3	100.00	64.06	70.33	100.00	82.77	83.43	64.06
91.8	99.15	55.63	77.30	98.56	94.64	85.06	55.63
106.3	94.78	49.07	72.64	89.27	100.00	81.15	49.07
120.7	76.70	46.12	68.59	80.65	84.91	71.39	46.12
135.2	69.59	45.01	66.96	72.16	81.23	66.99	45.01
149.7	67.73	46.82	66.91	70.47	83.69	67.12	46.82
164.1	67.21	50.71	67.71	86.51	79.92	70.41	50.71
178.6	67.31	52.14	80.90	91.29	75.28	73.38	52.14
193.1	68.48	51.96	90.84	94.74	71.94	75.59	51.96
207.6	72.54	51.85	92.56	96.92	67.51	76.28	51.85
222.0	76.47	50.99	93.06	94.02	59.56	74.82	50.99
236.5	74.84	50.11	92.24	94.40	53.53	73.03	50.11
251.0	74.56	51.01	90.57	89.70	57.15	72.60	51.01
265.4	74.56	52.09	89.27	75.89	65.01	71.36	52.09
279.9	75.04	51.69	89.98	72.96	69.66	71.87	51.69
294.4	74.90	51.43	91.95	77.97	70.90	73.43	51.43
308.9	73.57	50.97	93.76	80.39	70.63	73.87	50.97
323.3	73.53	50.60	100.00	82.57	68.57	75.05	50.60
337.8	74.33	50.55	99.75	84.30	63.29	74.44	50.55
352.3	75.91	50.50	99.35	85.57	56.85	73.64	50.50
366.7	80.48	50.46	98.86	86.10	49.00	72.98	49.00
381.2	80.60	50.47	97.93	85.41	37.92	70.46	37.92
395.7	79.02	50.19	98.39	77.30	33.29	67.64	33.29
410.2	77.83	50.15	98.38	75.50	39.53	68.28	39.53
424.6	77.58	51.61	98.39	76.46	41.95	69.20	41.95

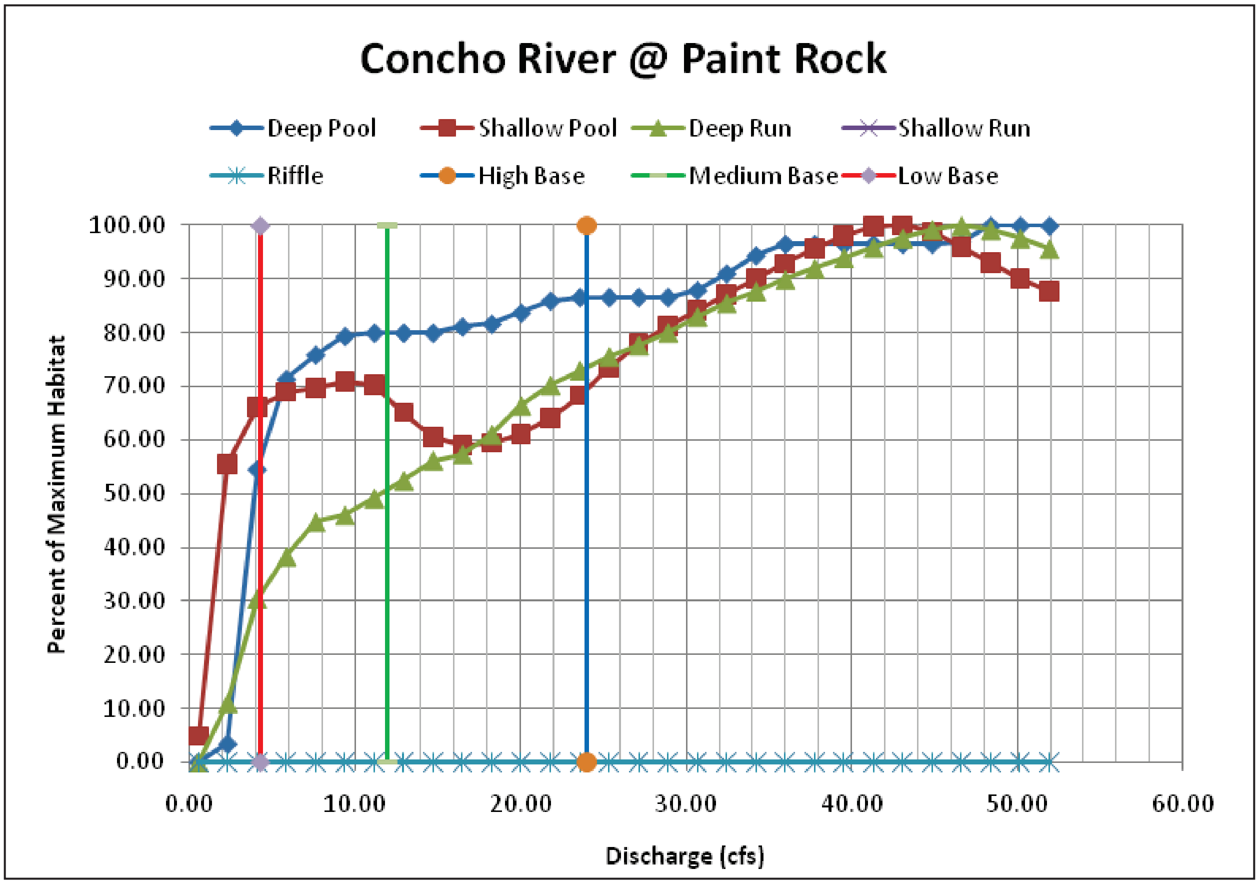


Figure 3.7.12 Relationship between the percent of maximum habitat and discharge at the Concho River at Paint Rock site.

Table 3.7.8 Percent of maximum habitat and discharge at the Concho River at Paint Rock site.

Discharge (cfs)	Deep Pool	Shallow Pool	Deep Run	Shallow Run	Riffle	Average	Minimum
0.54	0.02	4.86	0.00	0.00	0.00	1.63	0.00
2.31	3.42	55.50	11.04	0.00	0.00	23.32	3.42
4.08	54.59	66.17	30.49	0.00	0.00	50.41	30.49
5.86	71.37	68.96	38.34	0.00	0.00	59.56	38.34
7.63	75.94	69.75	44.79	0.00	0.00	63.49	44.79
9.40	79.38	70.92	46.07	0.00	0.00	65.46	46.07
11.17	80.02	70.34	49.20	0.00	0.00	66.52	49.20
12.95	80.02	65.11	52.50	0.00	0.00	65.88	52.50
14.72	80.02	60.49	56.26	0.00	0.00	65.59	56.26
16.49	81.17	59.06	57.41	0.00	0.00	65.88	57.41
18.26	81.68	59.51	61.09	0.00	0.00	67.42	59.51
20.04	83.76	61.10	66.47	0.00	0.00	70.44	61.10
21.81	85.99	64.03	70.29	0.00	0.00	73.44	64.03
23.58	86.66	68.36	73.04	0.00	0.00	76.02	68.36
25.35	86.66	73.40	75.62	0.00	0.00	78.56	73.40
27.13	86.66	77.87	77.70	0.00	0.00	80.75	77.70
28.90	86.66	81.23	80.08	0.00	0.00	82.66	80.08
30.67	87.94	84.14	83.04	0.00	0.00	85.04	83.04
32.44	91.08	87.15	85.59	0.00	0.00	87.94	85.59
34.21	94.46	90.03	87.83	0.00	0.00	90.77	87.83
35.99	96.57	92.89	89.95	0.00	0.00	93.13	89.95
37.76	96.57	95.60	92.02	0.00	0.00	94.73	92.02
39.53	96.57	98.11	94.03	0.00	0.00	96.24	94.03
41.30	96.57	99.89	95.91	0.00	0.00	97.46	95.91
43.08	96.57	100.00	97.68	0.00	0.00	98.08	96.57
44.85	96.57	98.84	99.27	0.00	0.00	98.23	96.57
46.62	97.02	96.07	100.00	0.00	0.00	97.70	96.07
48.39	100.00	92.98	99.21	0.00	0.00	97.40	92.98
50.17	100.00	90.06	97.65	0.00	0.00	95.90	90.06
51.94	100.00	87.80	95.69	0.00	0.00	94.50	87.80

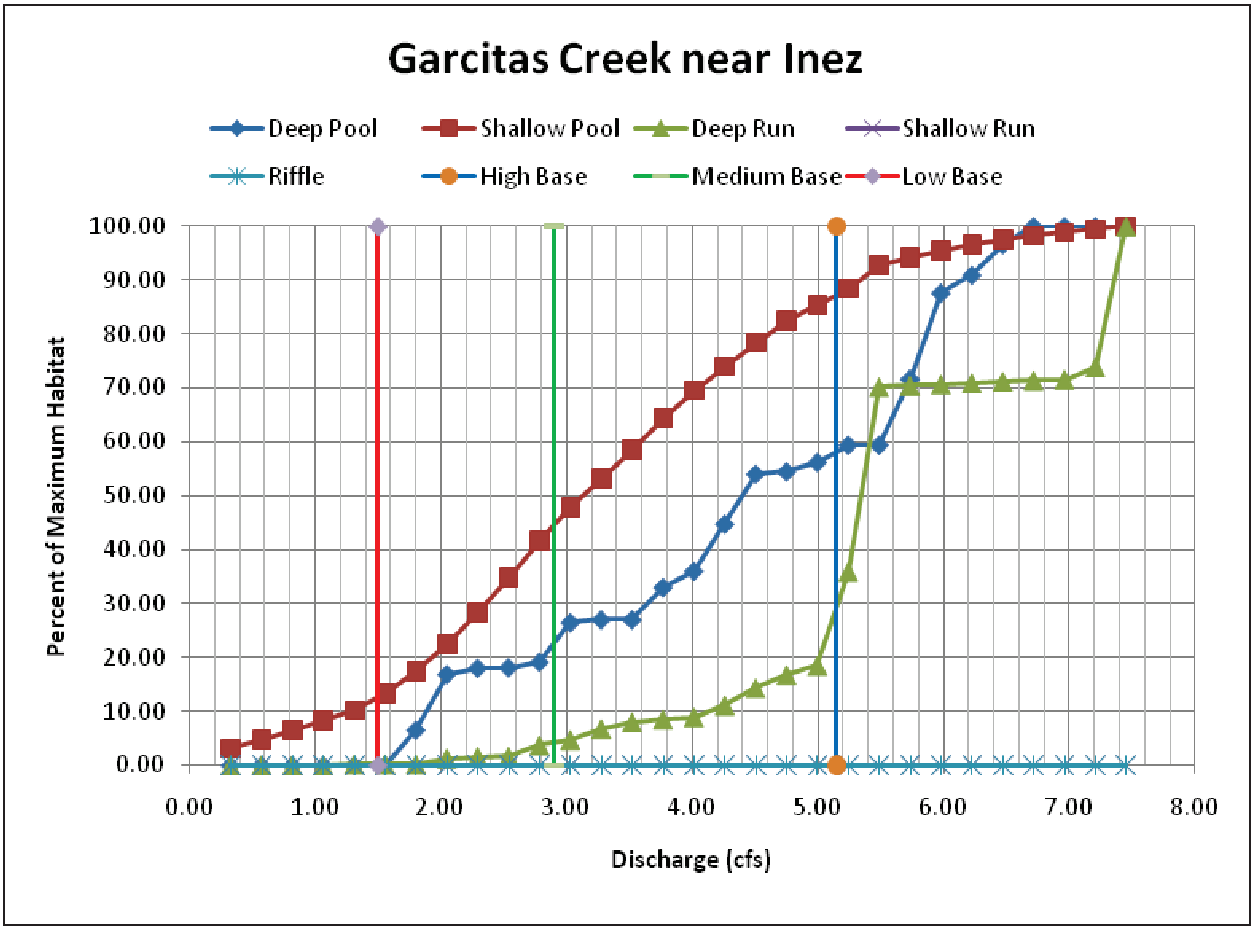


Figure 3.7.13 Relationship between the percent of maximum habitat and discharge at the Garcitas Creek near Inez site.

Table 3.7.9 Percent of maximum habitat and discharge at the Garcitas Creek near Inez site.

Discharge (cfs)	Deep Pool	Shallow Pool	Deep Run	Shallow Run	Riffle	Average	Minimum
0.33	0.00	3.14	0.00	0.00	0.00	1.57	0.00
0.58	0.00	4.63	0.00	0.00	0.00	2.32	0.00
0.82	0.00	6.43	0.00	0.00	0.00	3.21	0.00
1.07	0.00	8.24	0.02	0.00	0.00	4.12	0.00
1.31	0.00	10.20	0.18	0.00	0.00	5.10	0.00
1.56	0.00	13.22	0.21	0.00	0.00	6.61	0.00
1.80	6.54	17.41	0.21	0.00	0.00	11.97	6.54
2.05	16.89	22.42	1.32	0.00	0.00	19.66	16.89
2.30	18.03	28.28	1.62	0.00	0.00	23.16	18.03
2.54	18.14	34.90	1.66	0.00	0.00	26.52	18.14
2.79	19.16	41.70	3.73	0.00	0.00	30.43	19.16
3.03	26.50	47.77	4.72	0.00	0.00	37.14	26.50
3.28	27.03	53.25	6.74	0.00	0.00	40.14	27.03
3.52	27.03	58.49	8.01	0.00	0.00	42.76	27.03
3.77	33.02	64.40	8.54	0.00	0.00	48.71	33.02
4.02	36.05	69.55	8.98	0.00	0.00	52.80	36.05
4.26	44.77	73.97	11.13	0.00	0.00	59.37	44.77
4.51	54.08	78.37	14.35	0.00	0.00	66.23	54.08
4.75	54.51	82.35	16.80	0.00	0.00	68.43	54.51
5.00	56.25	85.41	18.48	0.00	0.00	70.83	56.25
5.24	59.44	88.44	35.96	0.00	0.00	73.94	59.44
5.49	59.44	92.75	70.20	0.00	0.00	76.09	59.44
5.73	71.69	94.13	70.47	0.00	0.00	82.91	71.69
5.98	87.67	95.48	70.73	0.00	0.00	91.57	87.67
6.23	90.99	96.59	70.98	0.00	0.00	93.79	90.99
6.47	96.72	97.48	71.23	0.00	0.00	97.10	96.72
6.72	100.00	98.21	71.43	0.00	0.00	99.11	98.21
6.96	100.00	98.83	71.62	0.00	0.00	99.41	98.83
7.21	100.00	99.40	73.93	0.00	0.00	99.70	99.40
7.45	100.00	100.00	100.00	0.00	0.00	100.00	100.00

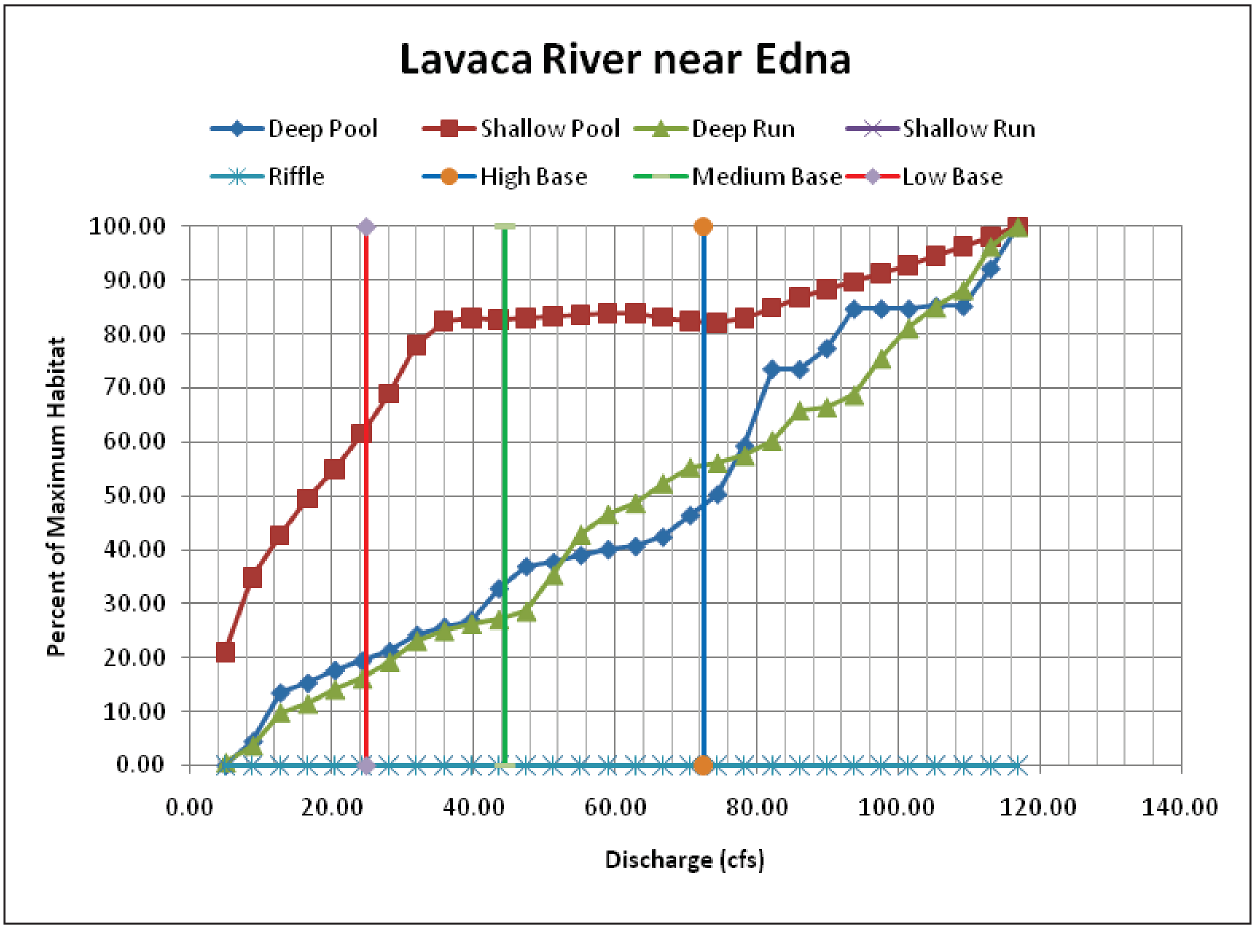


Figure 3.7.14 Relationship between the percent of maximum habitat and discharge at the Lavaca River near Edna site.

Table 3.7.10 Percent of maximum habitat and discharge at the Lavaca River near Edna site.

Discharge (cfs)	Deep Pool	Shallow Pool	Deep Run	Shallow Run	Riffle	Average	Minimum
0.33	0.00	3.14	0.00	0.00	0.00	1.57	0.00
0.58	0.00	4.63	0.00	0.00	0.00	2.32	0.00
0.82	0.00	6.43	0.00	0.00	0.00	3.21	0.00
1.07	0.00	8.24	0.02	0.00	0.00	4.12	0.00
1.31	0.00	10.20	0.18	0.00	0.00	5.10	0.00
1.56	0.00	13.22	0.21	0.00	0.00	6.61	0.00
1.80	6.54	17.41	0.21	0.00	0.00	11.97	6.54
2.05	16.89	22.42	1.32	0.00	0.00	19.66	16.89
2.30	18.03	28.28	1.62	0.00	0.00	23.16	18.03
2.54	18.14	34.90	1.66	0.00	0.00	26.52	18.14
2.79	19.16	41.70	3.73	0.00	0.00	30.43	19.16
3.03	26.50	47.77	4.72	0.00	0.00	37.14	26.50
3.28	27.03	53.25	6.74	0.00	0.00	40.14	27.03
3.52	27.03	58.49	8.01	0.00	0.00	42.76	27.03
3.77	33.02	64.40	8.54	0.00	0.00	48.71	33.02
4.02	36.05	69.55	8.98	0.00	0.00	52.80	36.05
4.26	44.77	73.97	11.13	0.00	0.00	59.37	44.77
4.51	54.08	78.37	14.35	0.00	0.00	66.23	54.08
4.75	54.51	82.35	16.80	0.00	0.00	68.43	54.51
5.00	56.25	85.41	18.48	0.00	0.00	70.83	56.25
5.24	59.44	88.44	35.96	0.00	0.00	73.94	59.44
5.49	59.44	92.75	70.20	0.00	0.00	76.09	59.44
5.73	71.69	94.13	70.47	0.00	0.00	82.91	71.69
5.98	87.67	95.48	70.73	0.00	0.00	91.57	87.67
6.23	90.99	96.59	70.98	0.00	0.00	93.79	90.99
6.47	96.72	97.48	71.23	0.00	0.00	97.10	96.72
6.72	100.00	98.21	71.43	0.00	0.00	99.11	98.21
6.96	100.00	98.83	71.62	0.00	0.00	99.41	98.83
7.21	100.00	99.40	73.93	0.00	0.00	99.70	99.40
7.45	100.00	100.00	100.00	0.00	0.00	100.00	100.00

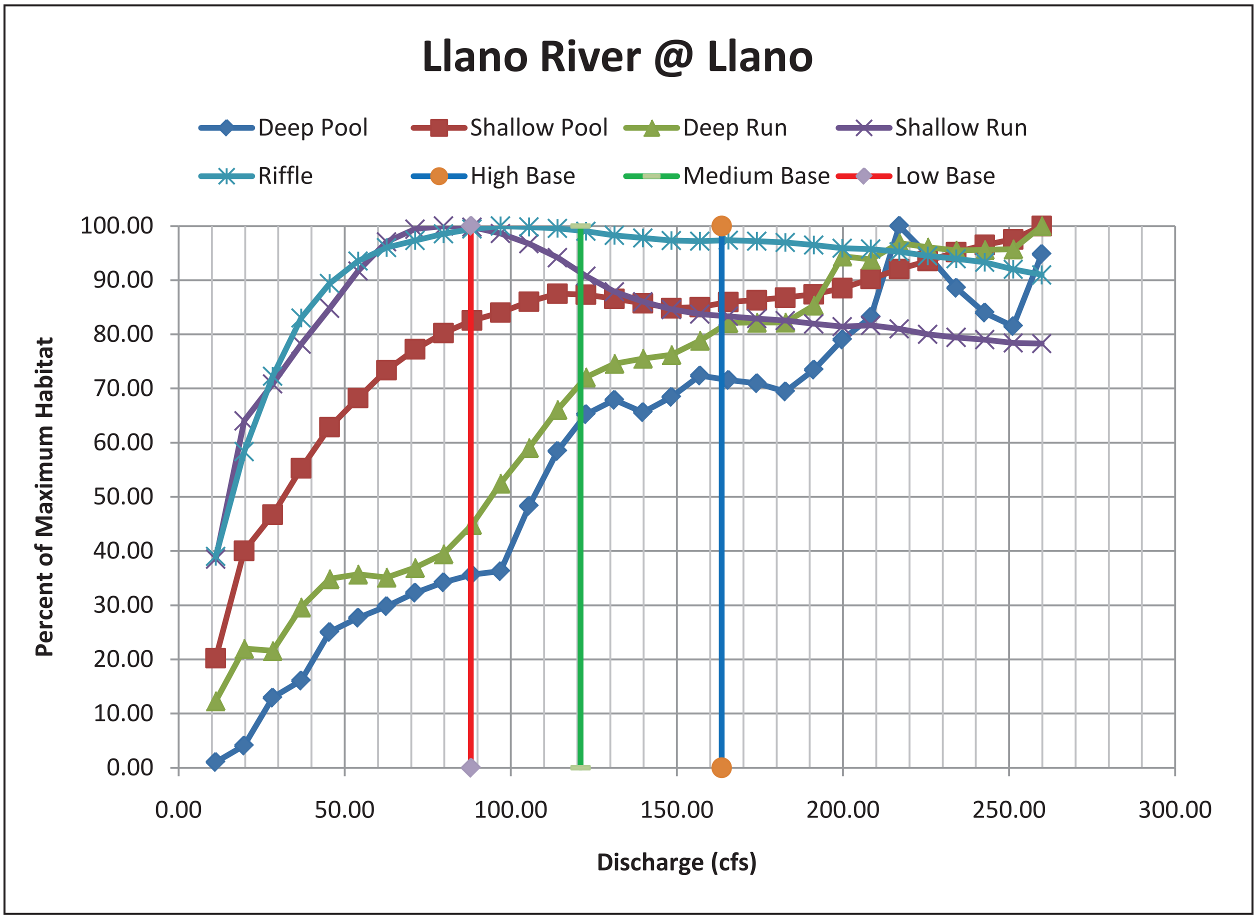


Figure 3.7.15 Relationship between the percent of maximum habitat and discharge at the Llano River near Llano site.

Table 3.7.11 Percent of maximum habitat and discharge at the Llano River near Llano site.

Discharge (cfs)	Deep Pool	Shallow Pool	Deep Run	Shallow Run	Riffle	Average	Minimum
11.14	1.07	20.23	12.34	38.51	39.00	22.23	1.07
19.71	4.10	40.05	22.00	64.03	58.37	25.38	4.10
28.29	12.94	46.72	21.61	70.86	72.28	29.41	12.94
36.86	16.09	55.29	29.63	78.17	83.04	31.08	16.09
45.43	25.06	62.87	34.86	84.81	89.39	33.98	25.06
54.01	27.69	68.26	35.71	91.71	93.55	37.11	27.69
62.58	29.82	73.38	35.15	97.07	96.02	38.56	29.82
71.16	32.31	77.25	36.92	99.42	97.34	40.08	32.31
79.73	34.22	80.23	39.46	100.00	98.57	41.67	34.22
88.30	35.62	82.58	44.86	99.81	99.45	43.25	35.62
96.88	36.28	84.01	52.49	98.60	100.00	44.41	36.28
105.45	48.32	86.03	59.06	96.74	99.82	46.96	48.32
114.02	58.45	87.50	66.09	94.16	99.57	50.84	58.45
122.60	65.24	87.33	72.08	90.76	99.02	55.15	65.24
131.17	67.88	86.58	74.60	87.87	98.28	58.91	67.88
139.74	65.61	85.75	75.54	86.01	97.78	60.94	65.61
148.32	68.43	84.83	76.22	84.59	97.33	61.38	68.43
156.89	72.37	85.01	78.85	83.74	97.21	62.12	72.37
165.47	71.56	85.98	82.11	83.34	97.37	63.54	71.56
174.04	70.95	86.31	82.17	82.89	97.21	65.53	70.95
182.61	69.44	86.77	82.21	82.53	96.97	69.64	69.44
191.19	73.46	87.40	85.34	81.94	96.49	75.01	73.46
199.76	79.02	88.54	94.40	81.41	95.90	81.27	79.02
208.33	83.22	90.24	93.82	81.66	95.75	86.62	81.66
216.91	100.00	92.07	96.84	81.00	95.25	90.16	81.00
225.48	94.66	93.54	96.05	80.01	94.46	92.95	80.01
234.06	88.56	95.19	95.48	79.44	93.93	93.44	79.44
242.63	83.99	96.51	95.60	79.03	93.28	95.94	79.03
251.20	81.50	97.53	95.72	78.40	91.98	97.69	78.40
259.78	94.79	100.00	100.00	78.29	90.97	100.00	78.29

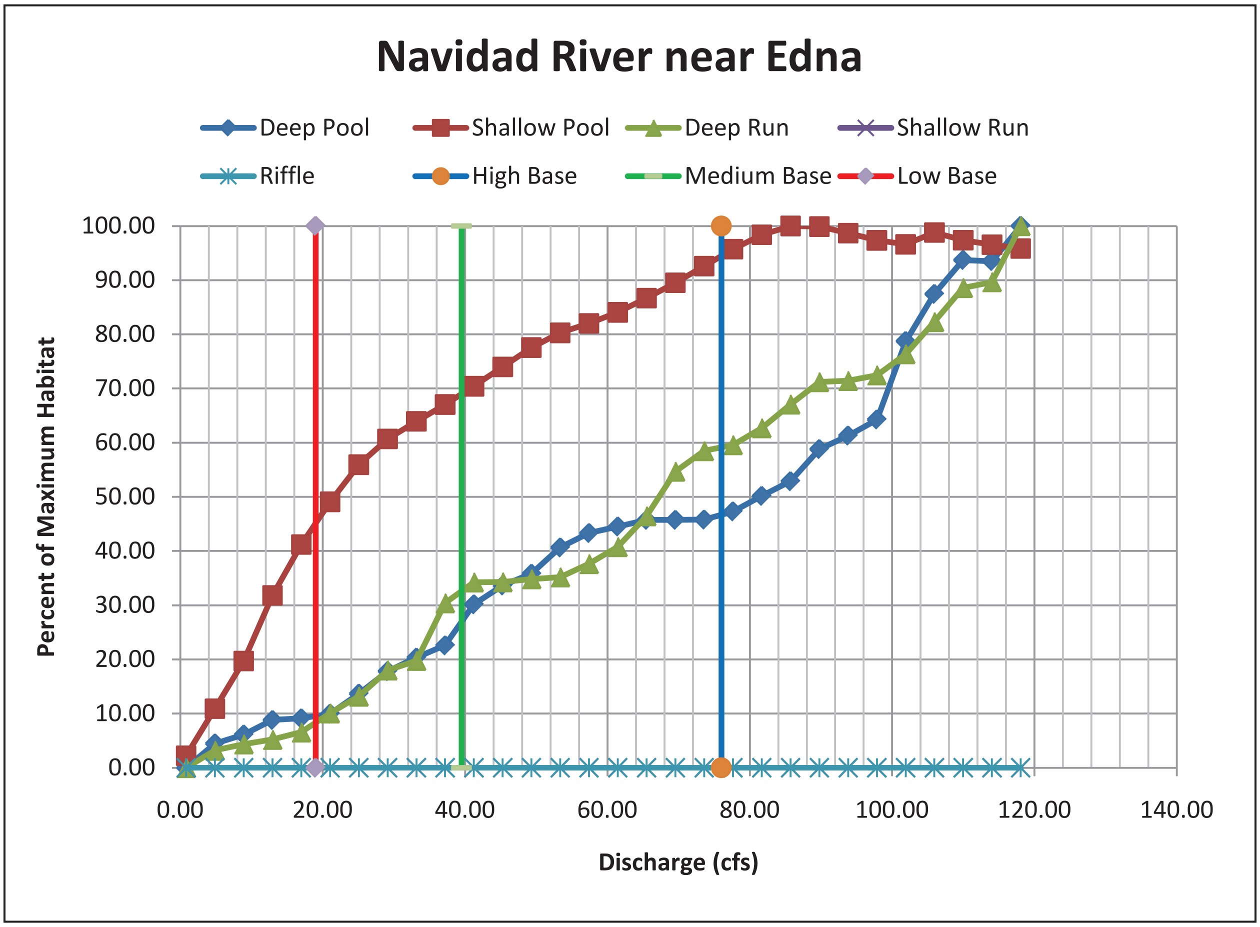


Figure 3.7.16 Relationship between the percent of maximum habitat and discharge at the Navidad River near Edna site.

Table 3.7.12 Percent of maximum habitat and discharge at the Navidad River near Edna site.

Discharge (cfs)	Deep Pool	Shallow Pool	Deep Run	Shallow Run	Riffle	Average	Minimum
0.81	0.00	2.21	0.00	0.00	0.00	0.74	0.00
4.85	4.49	10.90	3.20	0.00	0.00	6.20	3.20
8.90	6.13	19.72	4.37	0.00	0.00	10.07	4.37
12.94	8.81	31.80	5.21	0.00	0.00	15.27	5.21
16.98	9.11	41.22	6.57	0.00	0.00	18.97	6.57
21.03	9.98	49.08	10.08	0.00	0.00	23.04	9.98
25.07	13.68	55.95	13.18	0.00	0.00	27.60	13.18
29.11	17.83	60.70	18.02	0.00	0.00	32.18	17.83
33.16	20.33	63.94	19.78	0.00	0.00	34.68	19.78
37.20	22.58	67.04	30.41	0.00	0.00	40.01	22.58
41.24	30.16	70.41	34.26	0.00	0.00	44.94	30.16
45.29	33.64	73.98	34.28	0.00	0.00	47.30	33.64
49.33	35.81	77.56	34.85	0.00	0.00	49.40	34.85
53.37	40.65	80.28	35.20	0.00	0.00	52.04	35.20
57.42	43.31	82.03	37.64	0.00	0.00	54.33	37.64
61.46	44.52	84.06	40.78	0.00	0.00	56.45	40.78
65.50	45.74	86.68	46.46	0.00	0.00	59.63	45.74
69.55	45.74	89.50	54.69	0.00	0.00	63.31	45.74
73.59	45.79	92.59	58.48	0.00	0.00	65.62	45.79
77.63	47.30	95.72	59.58	0.00	0.00	67.54	47.30
81.68	50.16	98.39	62.70	0.00	0.00	70.42	50.16
85.72	52.87	100.00	67.08	0.00	0.00	73.32	52.87
89.76	58.80	99.89	71.21	0.00	0.00	76.64	58.80
93.81	61.29	98.68	71.43	0.00	0.00	77.13	61.29
97.85	64.26	97.35	72.47	0.00	0.00	78.03	64.26
101.89	78.74	96.60	76.37	0.00	0.00	83.90	76.37
105.94	87.43	98.81	82.29	0.00	0.00	89.51	82.29
109.98	93.69	97.37	88.57	0.00	0.00	93.21	88.57
114.02	93.49	96.55	89.66	0.00	0.00	93.23	89.66
118.07	100.00	95.83	100.00	0.00	0.00	98.61	95.83

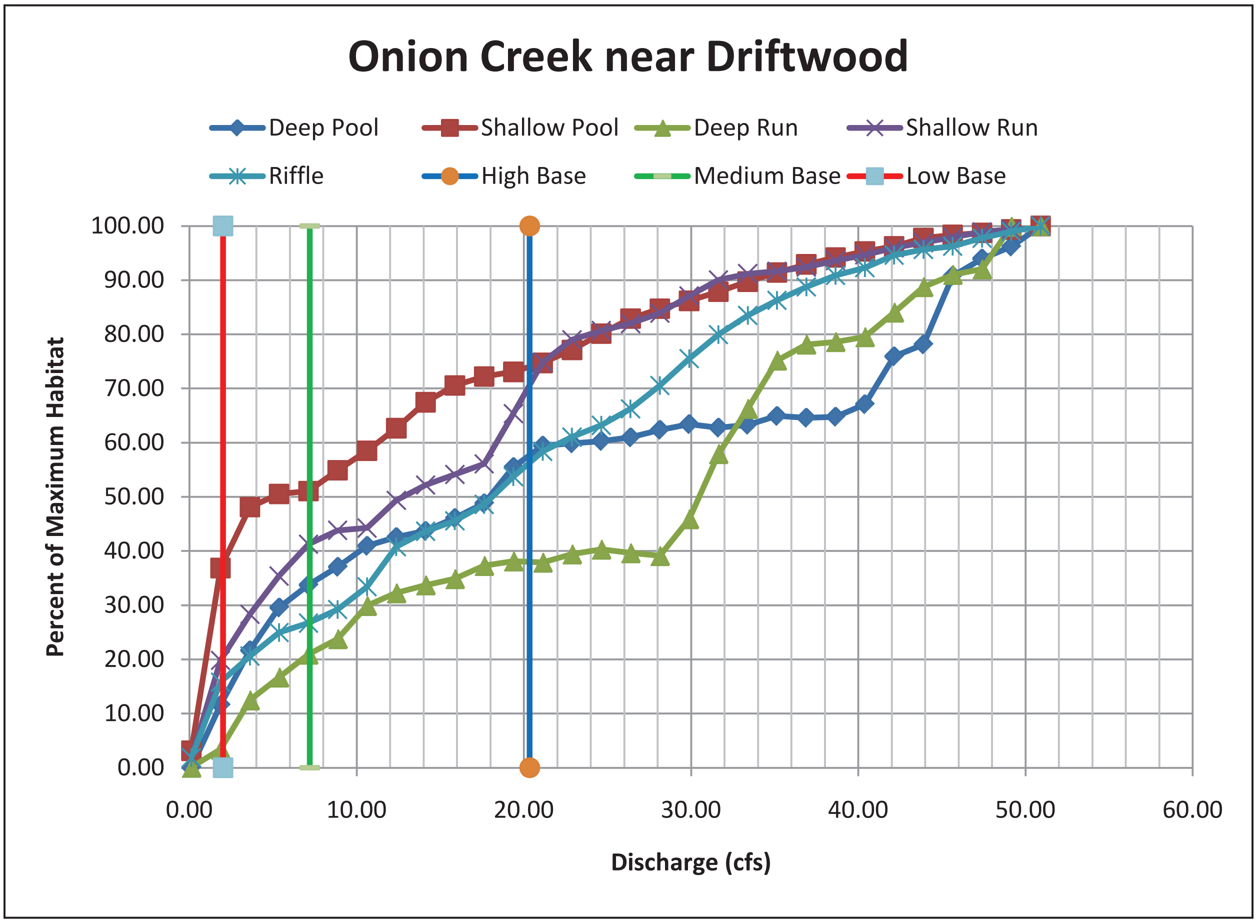


Figure 3.7.17 Relationship between the percent of maximum habitat and discharge at the Onion Creek near Driftwood site.

Table 3.7.13 Percent of maximum habitat and discharge at Onion Creek near Driftwood site.

Discharge (cfs)	Deep Pool	Shallow Pool	Deep Run	Shallow Run	Riffle	Average	Minimum
0.11	0.07	3.14	0.07	1.75	1.87	1.38	0.07
1.86	11.60	36.86	3.40	19.80	15.82	25.38	3.40
3.61	21.69	48.11	12.50	28.32	20.61	29.41	12.50
5.36	29.59	50.52	16.72	35.39	24.96	31.08	16.72
7.12	33.76	51.08	20.94	41.28	26.71	33.98	20.94
8.87	37.09	54.90	23.80	43.83	29.20	37.11	23.80
10.62	40.97	58.50	29.92	44.26	33.42	38.56	29.92
12.37	42.58	62.67	32.27	49.34	40.77	40.08	32.27
14.12	43.72	67.47	33.73	52.18	43.65	41.67	33.73
15.87	46.10	70.57	34.88	54.15	45.57	43.25	34.88
17.62	48.81	72.20	37.30	56.08	48.61	44.41	37.30
19.37	55.51	73.07	38.14	65.36	53.72	46.96	38.14
21.13	59.46	74.72	37.91	74.88	58.39	50.84	37.91
22.88	59.86	77.12	39.44	79.01	61.03	55.15	39.44
24.63	60.30	80.11	40.31	80.68	63.21	58.91	40.31
26.38	60.97	82.91	39.65	81.99	66.26	60.94	39.65
28.13	62.37	84.72	39.13	83.91	70.55	61.38	39.13
29.88	63.42	86.19	45.93	87.11	75.52	62.12	45.93
31.63	62.77	87.85	57.95	90.04	79.95	63.54	57.95
33.39	63.30	89.73	66.28	91.20	83.51	65.53	63.30
35.14	64.92	91.42	75.19	91.65	86.26	69.64	64.92
36.89	64.60	92.91	78.15	92.41	88.74	75.01	64.60
38.64	64.78	94.19	78.61	93.58	90.87	81.27	64.78
40.39	67.09	95.30	79.51	94.68	92.32	86.62	67.09
42.14	75.93	96.22	84.05	95.94	94.62	90.16	75.93
43.89	78.13	97.78	88.75	96.93	95.67	92.95	78.13
45.64	90.78	98.34	91.01	97.90	96.23	93.44	90.78
47.40	93.97	98.73	92.03	98.88	97.76	95.94	92.03
49.15	96.18	99.35	99.89	99.40	98.95	97.69	96.18
50.90	100.00	100.00	100.00	100.00	100.00	100.00	100.00

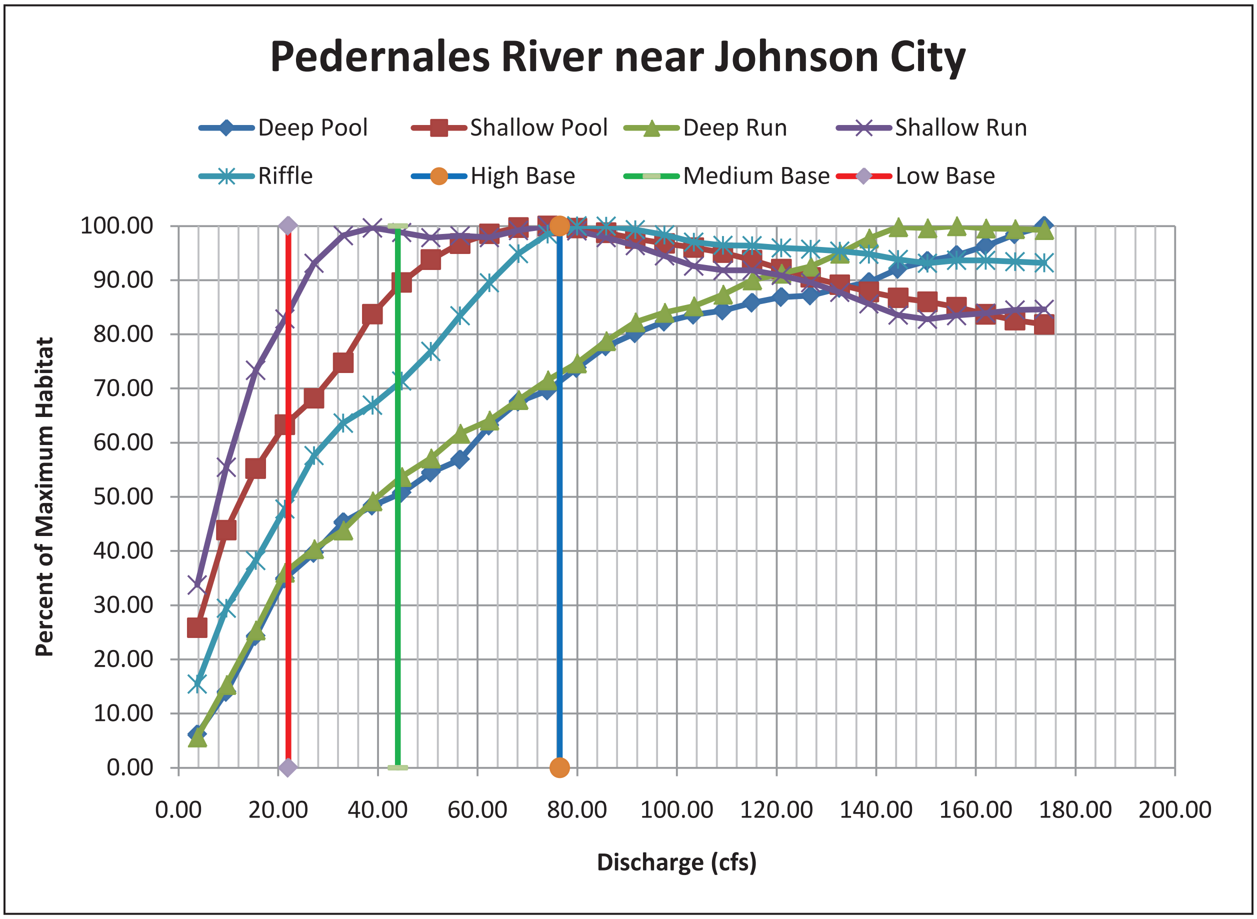


Figure 3.7.18 Relationship between the percent of maximum habitat and discharge at the Pedernales River near Johnson City site.

Table 3.7.14 Percent of maximum habitat and discharge at the Pedernales River near Johnson City site.

Discharge (cfs)	Deep Pool	Shallow Pool	Deep Run	Shallow Run	Riffle	Average	Minimum
3.73	6.15	25.84	5.65	33.74	15.44	17.37	5.65
9.59	14.00	43.88	15.34	55.47	29.45	25.38	14.00
15.45	24.29	55.23	25.40	73.36	38.27	29.41	24.29
21.31	34.91	63.32	36.05	82.84	47.75	31.08	34.91
27.18	39.64	68.19	40.39	93.14	57.61	33.98	39.64
33.04	45.32	74.73	43.85	98.24	63.62	37.11	43.85
38.90	48.37	83.73	49.22	99.65	66.93	38.56	48.37
44.76	50.72	89.58	53.71	98.77	71.39	40.08	50.72
50.62	54.48	93.79	57.14	97.83	76.85	41.67	54.48
56.48	56.87	96.75	61.71	98.21	83.42	43.25	56.87
62.34	63.13	98.54	64.14	97.88	89.53	44.41	63.13
68.20	67.58	99.71	67.91	99.18	94.90	46.96	67.58
74.07	69.62	100.00	71.56	100.00	98.48	50.84	69.62
79.93	73.77	99.64	74.68	99.11	100.00	55.15	73.77
85.79	77.76	98.76	78.78	97.85	99.95	58.91	77.76
91.65	80.18	97.67	82.25	96.37	99.33	60.94	80.18
97.51	82.31	96.79	84.01	94.49	98.35	61.38	82.31
103.37	83.59	96.01	85.22	92.60	97.01	62.12	83.59
109.23	84.37	95.05	87.36	91.80	96.41	63.54	84.37
115.10	85.81	93.70	90.00	91.84	96.35	65.53	85.81
120.96	86.85	92.04	91.23	90.89	95.95	69.64	86.85
126.82	87.14	90.51	92.53	89.55	95.72	75.01	87.14
132.68	88.53	89.15	94.93	87.73	95.37	81.27	87.73
138.54	89.63	87.84	97.73	85.62	94.81	86.62	85.62
144.40	92.04	86.73	99.82	83.57	93.84	90.16	83.57
150.26	93.52	86.01	99.61	82.80	93.13	92.95	82.80
156.12	94.60	85.02	100.00	83.47	93.67	93.44	83.47
161.99	96.33	83.70	99.57	83.92	93.64	95.94	83.70
167.85	98.44	82.64	99.45	84.49	93.42	97.69	82.64
173.71	100.00	81.85	99.29	84.62	93.21	100.00	81.85

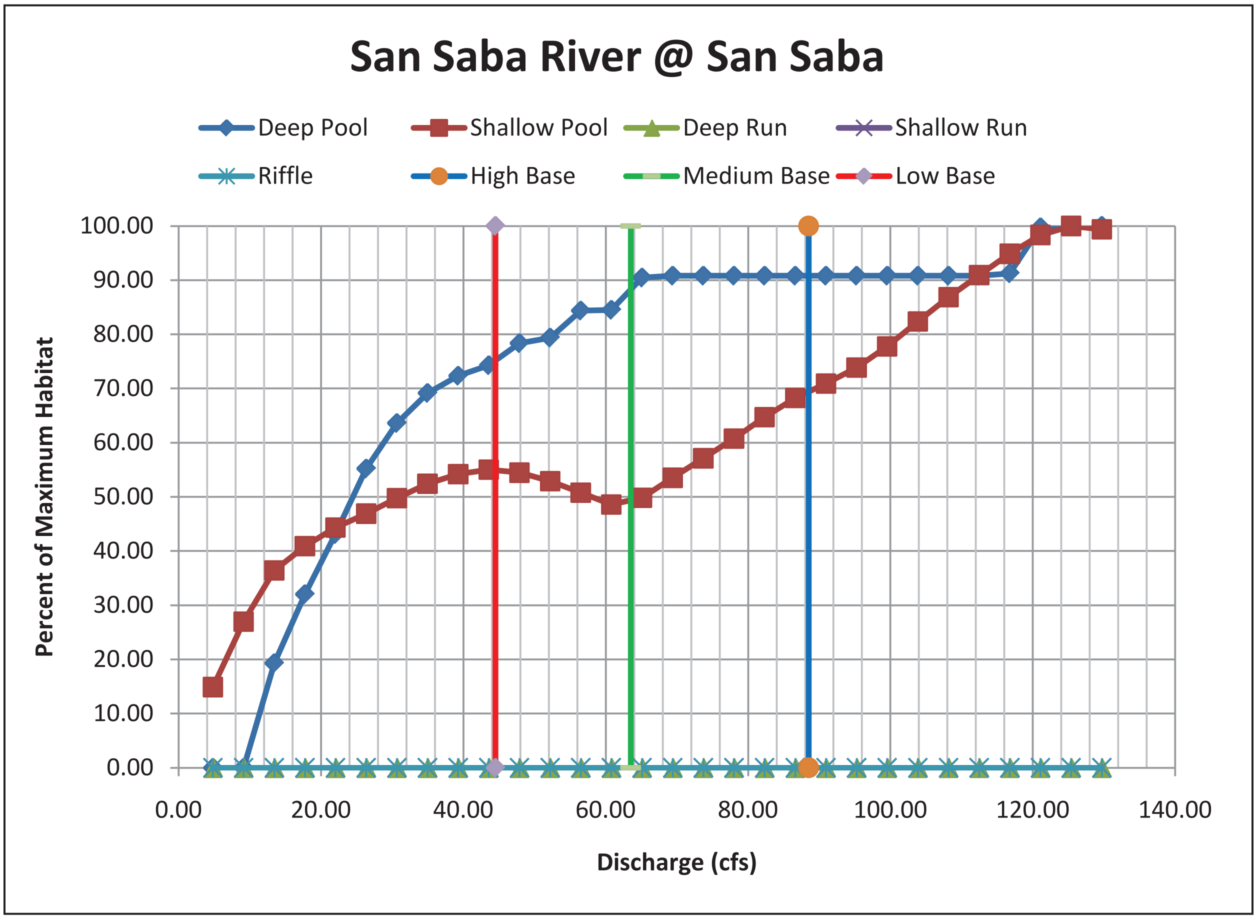


Figure 3.7.19 Relationship between the percent of maximum habitat and discharge at the San Saba River at San Saba site.

Table 3.7.15 Percent of maximum habitat and discharge at the San Saba River at San Saba site.

Discharge (cfs)	Deep Pool	Shallow Pool	Deep Run	Shallow Run	Riffle	Average	Minimum
4.82	0.00	14.89	0.00	0.00	0.00	7.45	0.00
9.13	0.00	26.97	0.00	0.00	0.00	13.48	0.00
13.43	19.31	36.44	0.00	0.00	0.00	27.87	19.31
17.74	32.03	40.90	0.00	0.00	0.00	36.47	32.03
22.04	43.13	44.33	0.00	0.00	0.00	43.73	43.13
26.35	55.21	46.90	0.00	0.00	0.00	51.06	46.90
30.65	63.61	49.78	0.00	0.00	0.00	56.69	49.78
34.96	69.16	52.41	0.00	0.00	0.00	60.78	52.41
39.27	72.34	54.21	0.00	0.00	0.00	63.27	54.21
43.57	74.28	55.02	0.00	0.00	0.00	64.65	55.02
47.88	78.35	54.47	0.00	0.00	0.00	66.41	54.47
52.18	79.37	52.90	0.00	0.00	0.00	66.13	52.90
56.49	84.36	50.76	0.00	0.00	0.00	67.56	50.76
60.79	84.50	48.60	0.00	0.00	0.00	66.55	48.60
65.10	90.45	49.85	0.00	0.00	0.00	70.15	49.85
69.40	90.80	53.52	0.00	0.00	0.00	72.16	53.52
73.71	90.80	57.13	0.00	0.00	0.00	73.96	57.13
78.02	90.80	60.77	0.00	0.00	0.00	75.78	60.77
82.32	90.80	64.72	0.00	0.00	0.00	77.76	64.72
86.63	90.80	68.24	0.00	0.00	0.00	79.52	68.24
90.93	90.80	70.92	0.00	0.00	0.00	80.86	70.92
95.24	90.80	73.85	0.00	0.00	0.00	82.33	73.85
99.54	90.80	77.75	0.00	0.00	0.00	84.27	77.75
103.85	90.80	82.36	0.00	0.00	0.00	86.58	82.36
108.16	90.80	86.86	0.00	0.00	0.00	88.83	86.86
112.46	90.80	90.94	0.00	0.00	0.00	90.87	90.80
116.77	91.25	94.87	0.00	0.00	0.00	93.06	91.25
121.07	99.73	98.34	0.00	0.00	0.00	99.03	98.34
125.38	100.00	100.00	0.00	0.00	0.00	100.00	100.00
129.68	100.00	99.38	0.00	0.00	0.00	99.69	99.38

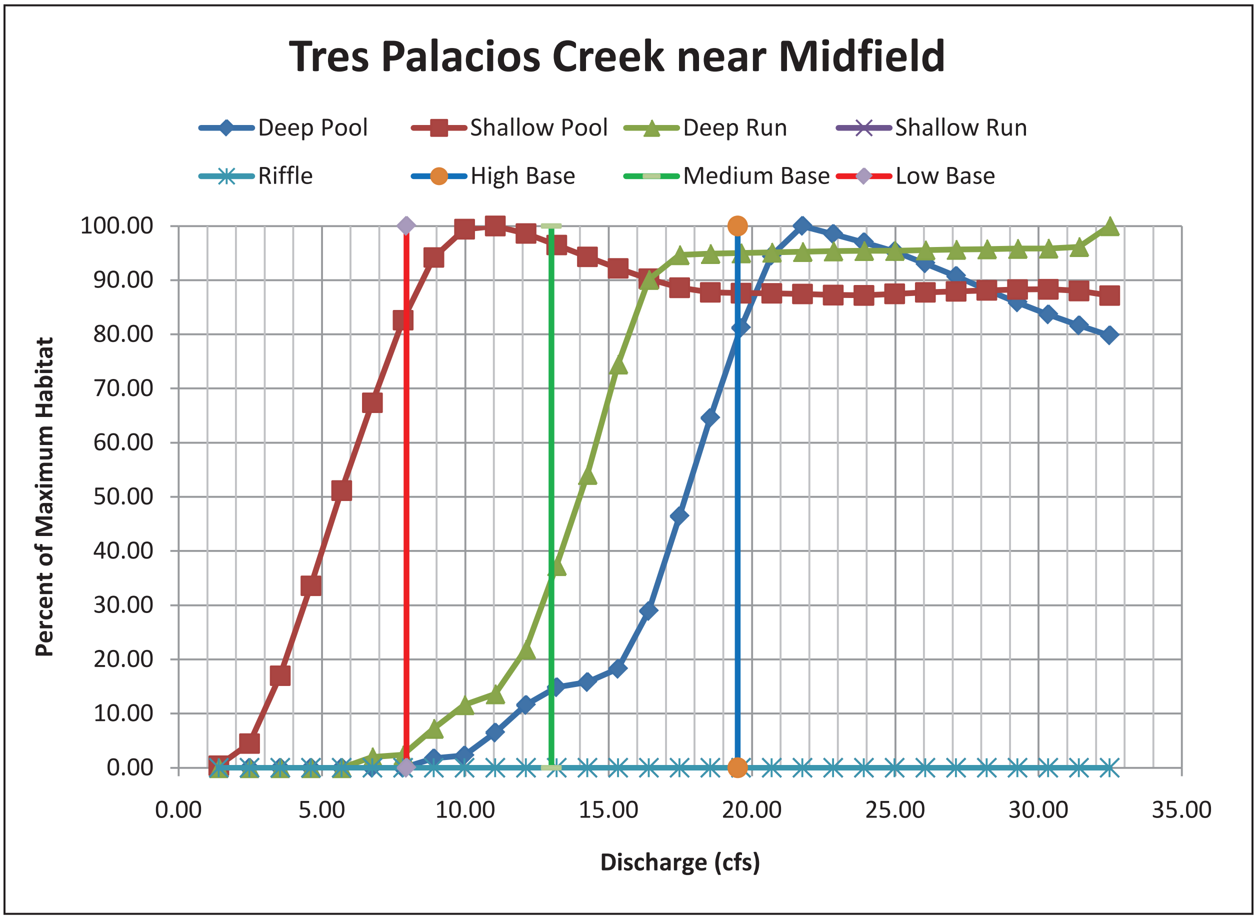


Figure 3.7.20 Relationship between the percent of maximum habitat and discharge at the Tres Palacios Creek near Midfield site.

Table 3.7.16 Percent of maximum habitat and discharge at the Tres Palacios Creek near Midfield site.

Discharge (cfs)	Deep Pool	Shallow Pool	Deep Run	Shallow Run	Riffle	Average	Minimum
1.40	0.00	0.40	0.00	0.00	0.00	0.13	0.00
2.47	0.00	4.46	0.00	0.00	0.00	1.49	0.00
3.54	0.00	16.98	0.00	0.00	0.00	5.66	0.00
4.62	0.00	33.60	0.00	0.00	0.00	11.20	0.00
5.69	0.00	51.16	0.00	0.00	0.00	17.05	0.00
6.76	0.00	67.39	2.00	0.00	0.00	23.13	0.00
7.83	0.00	82.59	2.37	0.00	0.00	28.32	0.00
8.90	1.73	94.17	7.25	0.00	0.00	34.38	1.73
9.97	2.26	99.40	11.62	0.00	0.00	37.76	2.26
11.05	6.49	100.00	13.63	0.00	0.00	40.04	6.49
12.12	11.59	98.62	21.88	0.00	0.00	44.03	11.59
13.19	14.86	96.50	37.29	0.00	0.00	49.55	14.86
14.26	15.82	94.29	54.10	0.00	0.00	54.74	15.82
15.33	18.26	92.19	74.48	0.00	0.00	61.64	18.26
16.40	28.93	90.25	90.08	0.00	0.00	69.75	28.93
17.48	46.43	88.60	94.65	0.00	0.00	76.56	46.43
18.55	64.55	87.74	94.87	0.00	0.00	82.39	64.55
19.62	81.18	87.60	94.99	0.00	0.00	87.92	81.18
20.69	94.51	87.55	95.12	0.00	0.00	92.39	87.55
21.76	100.00	87.44	95.24	0.00	0.00	94.22	87.44
22.83	98.50	87.25	95.35	0.00	0.00	93.70	87.25
23.91	96.97	87.19	95.42	0.00	0.00	93.19	87.19
24.98	95.31	87.48	95.43	0.00	0.00	92.74	87.48
26.05	93.09	87.75	95.53	0.00	0.00	92.12	87.75
27.12	90.75	87.92	95.64	0.00	0.00	91.44	87.92
28.19	88.23	88.12	95.73	0.00	0.00	90.69	88.12
29.26	85.88	88.26	95.81	0.00	0.00	89.98	85.88
30.34	83.66	88.32	95.86	0.00	0.00	89.28	83.66
31.41	81.64	88.01	96.15	0.00	0.00	88.60	81.64
32.48	79.80	87.16	100.00	0.00	0.00	88.99	79.80

3.7.13 Sensitivity of Habitat Relationships to Habitat Suitability Curves

One important aspect in the use and interpretation of the modeling results for the habitat versus discharge relationships is understanding the relative sensitivity of the modeling results associated with both guild definitions and the associated selection and application of the underlying habitat suitability curves. To provide some insights, the site-specific habitat guild suitability criteria developed as part of the LSWP studies on the lower Colorado and basin-wide habitat guild suitability criteria developed by the Gualalupe-San Antonio BBEST were used to generate habitat versus flow relationships at two river sites in that basin where calibrated habitat models were available (BIO-WEST, Inc. 2008a). The results presented in Figures 3.7.21 and 3.7.22 clearly indicate that although the overall pattern in the functional relationships between available habitat and discharge remain fairly consistent there are shifts in the discharge that maximizes the habitat for comparable guild types. This variability or sensitivity in the habitat versus discharge relationships are within expected ranges of variation observed over a large number of instream flow studies conducted in a wide array of river types (Dr. Thomas Hardy, personal observations). This source and degree of uncertainty should be considered carefully when making flow recommendations.

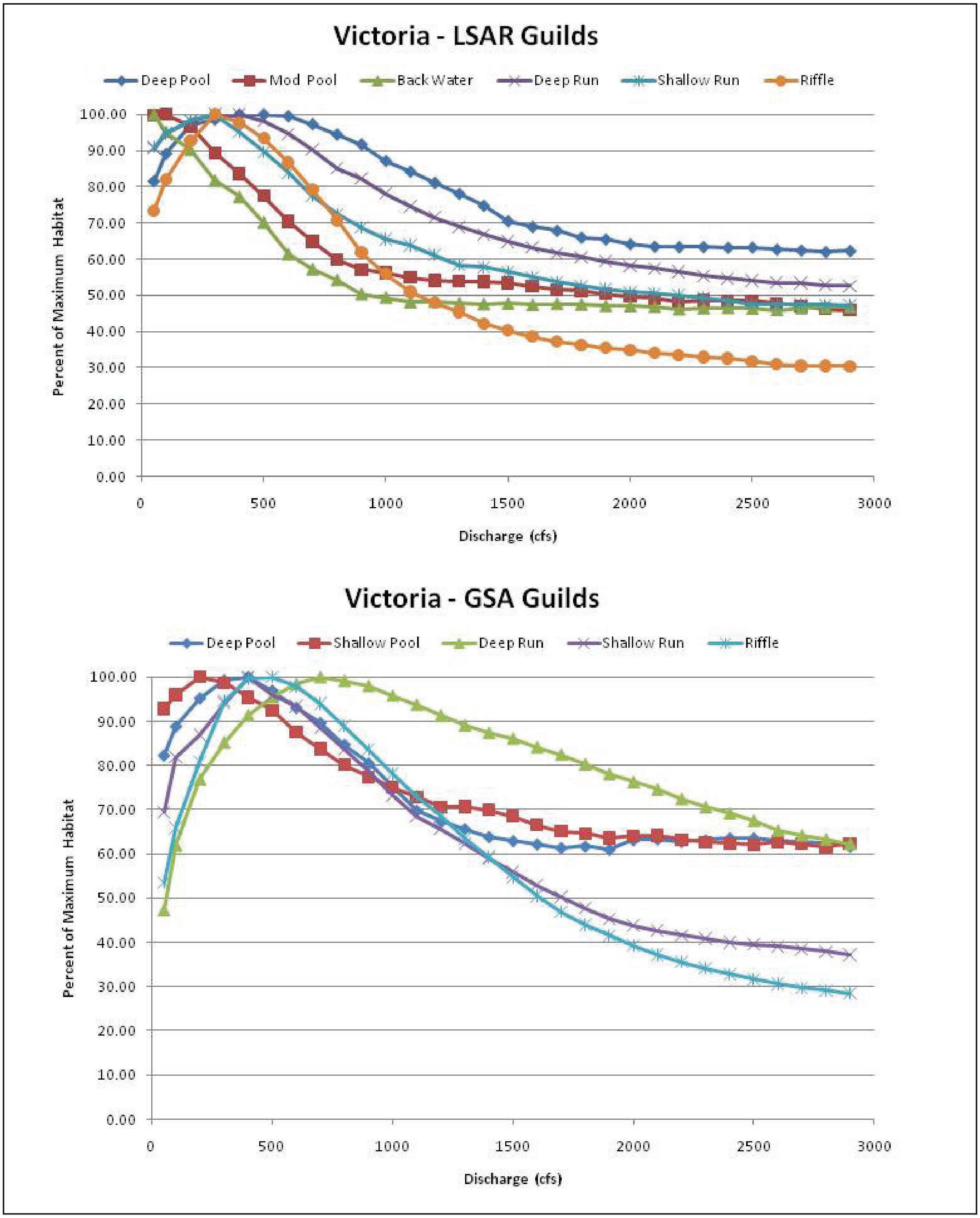


Figure 3.7.21 Simulated relationships between available habitat and discharge for LSAR and GSA BBEST based habitat guild suitability curves at Guadalupe River at Victoria. LSAR Guilds are the guilds from the LSWP studies.

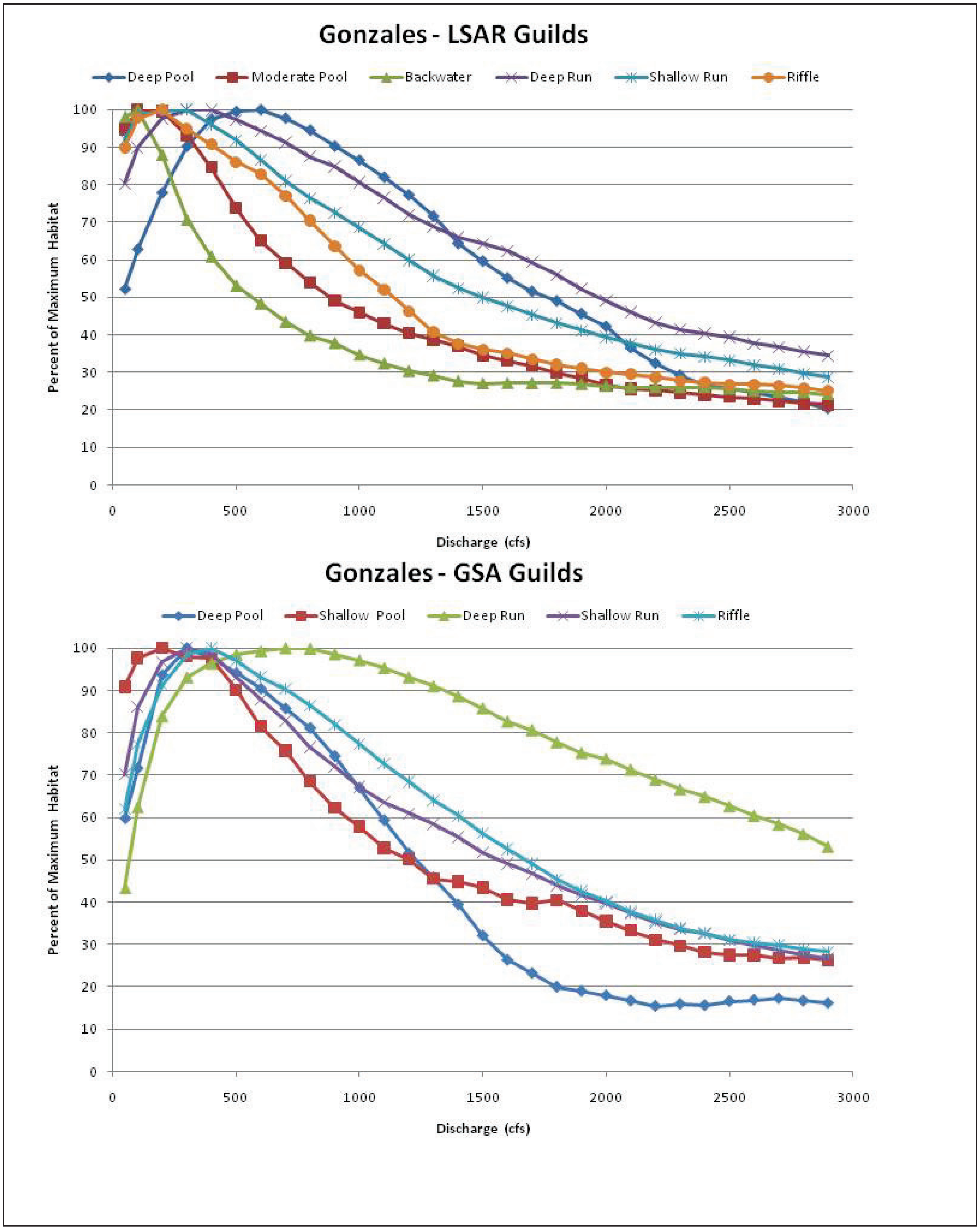


Figure 3.7.22 Simulated relationships between available habitat and discharge for LSAR and GSA BBEST based habitat guild suitability curves at Guadalupe River at Gonzales. LSAR Guilds are the guilds from the LSWP studies.

3.8 Riparian/Floodplain Vegetation Methodology

The term "riparian" refers to transitional areas between terrestrial and aquatic ecosystems that depend on the existence of surface or subsurface water flows (Naiman and Decamps 1997). Riparian communities are essentially biotic communities on the shores of streams and lakes. The riparian corridor along the Colorado and Lavaca-Navidad River systems is a band along the streams that encompasses low-flow channel sandbars, stream banks, and floodplains that are vegetated, in part, by phreatophytic plants that use ground water from the stream alluvium or interflow that is migrating from adjacent (or distant) uplands toward the stream channel.

Riparian vegetation is important for many functions in riverine systems. Black (2004) noted that hydrologic functions of vegetative cover include 1) buildup of organic matter in the soil, 2) organic material on the soil that protects against soil erosion, 3) slowing of the runoff process, 4) increasing infiltration, and 5) shading that causes reduced evaporation rates. Previous studies have shown the importance of stream flow volume to growth of riparian trees in an alluvial stream and the sensitivity of the tree species to reductions in stream flow (Reily and Johnson 1982, Stromberg and Patten 1990).

3.8.1 Riparian Biology Overlay Framework

The BBEST formed a riparian subgroup to identify important riparian communities and their relationships to instream flows in the Colorado and Lavaca-Navidad River systems. The riparian subgroup contacted biologists and scientists familiar with riparian communities in the region, conducted a literature review, and compiled data to support a riparian component analysis. The subgroup determined early in the process that site-specific information on riparian community responses to instream flows is currently not available and has not been addressed to the same level that instream habitat has been studied in this system. Therefore, an analysis of riparian communities to identify distinct vegetation communities at a reach-level scale near each of the gage locations was deemed appropriate with the available information and time constraints of the SB 3 process.

The information available regarding riparian communities in this region includes aerial photography, soils maps through the NRCS, wetland maps through USFWS, a statewide vegetation-mapping program by TPWD, and limited additional field-collected data on plant species composition in riparian areas. There is also literature pertaining to the life history of many of the riparian species found in this region.

The main questions addressed in this analysis were:

- What are the riparian vegetation communities that exist in the Colorado and Lavaca-Navidad River watersheds?
- How are these communities governed or maintained by instream flows?
- Are there indicator species that will enable a link between environmental flows and vegetation community responses?
- Does this method incorporate the current relevant scientific information available for riparian assessment?

- Will this method of assessment allow the BBEST to develop an environmental flow regime that will provide a sound ecological environment for riparian communities?
- Will this method be sufficient for use at all gage locations?

This riparian analysis was focused on describing the vegetation communities and their environmental flow needs at a reach-scale for gage locations where recommendations will be provided. However, there are riparian communities such as adjacent wetlands that may require a smaller-scale or more temporally sensitive analysis to inform environmental flow needs and detect changes in its plant community composition. Additionally, future studies that quantify more specific environmental flows necessary for seeding, germination, and recruitment would be beneficial in determining the ability of these vegetation communities to be self-sustaining.

3.8.2 Literature Review

Hydroperiod and light have been identified as the principal factors that influence population dynamics and species composition in bottomland hardwood forest communities (Streng et al. 1989, Hall and Harcombe 1998, Battaglia et al. 2000, Lin et al. 2004, Battaglia and Sharitz 2006). Life history strategies, especially the timing and modes of seed dispersal, germination requirements, and seedling growth rates are also important mechanisms maintaining riparian vegetation communities. While mature trees may be tolerant of varying degrees of inundation and drought, seedlings are very susceptible to desiccation under dry conditions, uprooting during flow pulses, and anoxic soil conditions for prolonged periods. Bottomland hardwood forest communities typically include species that are adapted to a high water table, periods of inundation, and a disturbance regime resulting from natural river processes.

A literature review was conducted to investigate the relationships between bottomland hardwood forests and instream flows, as well as the life history strategies of facultative and obligate wetland species that occur in these communities in the Colorado and Lavaca-Navidad basins. Based on USFWS (1988) data and definitions for wetland plant indicator categories:

- Obligate wetland (OBL) species occur almost always (estimated probability 99%) under natural conditions in wetlands
- Facultative wetland (FACW) species usually occurs in wetlands (estimated probability 67%–99%), but occasionally found in non-wetlands
- Facultative (FAC) species are equally likely to occur in wetlands or non-wetlands (estimated probability 34%–66%)

A summary of the life history information for several obligate wetland, facultative wetland, and facultative tree, shrub, and herbaceous plant species is provided below. This information was used to describe the importance of environmental flows to maintaining these species in communities where they currently exist.

Tree Layer

American sycamore, *Platanus occidentalis* (Burns and Honkala 1990)

- Classified as a facultative (FAC) species
- Can grow in river bottoms saturated for 2–4 months
- Seed production starts when trees are 25 years, with optimum production between 50–200 years and good seed crops every 1 or 2 years
- Seeds are dispersed primarily by wind and water from February–May
- Germination will not occur where litter layer is more than 2 inches deep
- Seedlings require direct light
- Can live more than 250 years

American elm, *Ulmus americana* (Burns and Honkala 1990)

- Classified as a facultative (FAC) species
- Can withstand flooding in the dormant season, but not if the flooding is prolonged in the growing season
- Intermediately tolerant to complete inundation
- Seed production starts when trees are at least 15 years of age, but seldom abundant before age 40
- Seeds fall occurs in early spring and is usually complete by mid-March in the south
- Seed dispersal is by wind and wildlife (birds)
- Germination occurs within 6-12 days, although some seeds may remain dormant until the spring
- Seedlings that develop in saturated soils are stunted

Bald cypress, *Taxodium distichum* (Langdon 1958)

- Classified as an obligate wetland (OBL) species
- Seeding occurs annually, with good seed crops approximately every 3 years
- Seeds fall from October to November
- Water is necessary for seed dispersal (few seeds are disseminated by animals)
- Germination occurs after 1–3 months in saturated or wet, organic, or peaty soils
- Can live to 1200 years

Black willow, *Salix nigra* (Burns and Honkala 1990)

- Classified as a facultative wetland (FACW) species
- Seed production starts when trees are approximately 10 years old, and occurs annually
- Seeds are distributed by water and wind, and must reach a seedbed within 12–24 hours, unless floating in water
- Very moist, almost flooded mineral soil is best for germination and development
- Seedlings grow best when there is abundant moisture available throughout the growing season

- Can survive more than 30 days of inundation
- Tends to be shallow rooted
- Not drought tolerant

Boxelder, *Acer negundo* (Friedman and Auble 1999)

- Classified as a facultative wetland (FACW) species
- Seed production starts when trees are 8–11 years of age, and occurs annually
- Seeds are wind distributed continuously from fall until spring on a variety of seedbeds
- Saplings can be killed if inundated for more than 85 days during the growing season
- Usually develops a shallow, fibrous root system
- Mature trees can survive being inundated for an entire growing season
- Tolerant to some extent of drought
- Can live 60–100 years

Cottonwood, *Populus deltoides* (Burns and Honkala 1990)

- Classified as a facultative (FAC) species
- Seed production starts when trees are 5–10 years of age, and occurs annually
- Seed dispersal occurs from May to mid-July in the southeast U.S.
- Unless floating or immersed, seeds must reach a suitable germination site within 1–2 weeks to avoid desiccation
- Late spring high flows generate bare, moist, mineral substrate and silt deposits where cottonwood normally become established
- Seedlings are delicate for the first few weeks when root growth is slow
- Cottonwood is a shade intolerant, pioneer species and relies on a disturbance regime to regenerate
- In addition to regeneration from seed, cottonwood sprouts readily from roots
- The best sites have water tables from 24 to 72 inches below ground
- May be stressed by wetter than normal summer soil conditions (Dudek et al. 1998)
- Can live 100–200 years

Green ash, *Fraxinus pennsylvanica* (Burns & Honkala 1990, NRCS 2002)

- Classified as a facultative wetland (FACW) species
- Grows best on moist, fertile, well drained soils
- Tolerant of seasonal flooding, up to 40% of the growing season
- Intolerant of shading from surrounding trees

Shrub Layer

Buttonbush, *Cephalanthus occidentalis* (NRCS 2004)

- Classified as an obligate wetland (OBL) species

- A tall shrub common along the borders of ponds and streams and in shrub-scrub wetlands
- Prefers medium to wet soils and is intolerant of dry soils
- Fruits in September–October
- Seeds germinate in moist soils

Deciduous holly, *Ilex decidua* (Sullivan 1993)

- Classified as a facultative wetland (FACW) species
- Usually found on moist soils of floodplains, low woodlands, wet thickets, and along streams
- Moderately tolerant of periodic flooding, with mature trees able to withstand flooding up to 35% of the growing season
- Produces seeds that are dispersed by animals from September to spring
- Seedlings grow slowly
- Tolerant of drought and shade tolerant

Herbaceous Layer

Bushy bluestem, *Andropogon glomeratus* (NRCS 2006)

- Classified as a facultative wetland (FACW) species
- A native, perennial, warm-season low-growing bunchgrass
- Grows in moist soils, irregularly to seasonally inundated or saturated
- Does not tolerate heavy shade

Inland sea oats, *Chasmanthium latifolium* (Davis 2010)

- Classified as a facultative (FAC) species
- Inhabits areas along streams and waterways, shaded slopes, and bottomland hardwoods
- Perennial colonial grass with rhizomatous clumps, with annual seed production
- Flowers from June-October
- Shade tolerant and salt tolerant

Virginia wildrye, *Elymus virginicus* (Lloyd-Reilley et al. 2002)

- Classified as a facultative (FAC) species
- Medium tolerance to anaerobic soil conditions
- Tolerates wet soils and seasonal flooding (Sanderson et al. 2010)
- Perennial, cool season, bunchgrass with annual seed production and tillering reproduction

Switchgrass, *Panicum virgatum* (Bransby 2010)

- Classified as a facultative wetland (FACW) species
- Native, perennial, warm season bunchgrass
- Most of its growth occurs from late spring through early fall, and becomes dormant in cold months

- Produces a large permanent root system that penetrates over 10 feet into the soil
- Tolerant of poor soils, flooding, and drought

Eastern gamagrass, *Tripsacum dactyloides* (NRCS 2008)

- Classified as a facultative (FAC) species
- A long-lived (up to 50 years), native, perennial, warm season sod-forming grass
- Grows well in moderately well drained to somewhat poorly drained soils
- Tolerant of extended periods of flooding
- Seeds produced from June to September
- Approximately 3–10 weeks of cold, moist weather conditions are necessary for germination

3.8.3 Riparian and Floodplain Vegetation Community Data

The TPWD is conducting an ecological mapping effort in Texas called the Texas Ecological Systems Classification Program (TESCP; TPWD 2011) that makes vegetation community information available to the public (German et al. 2009). To accomplish this effort, TPWD is coordinating with private, state, and federal partners to produce a new land classification map for Texas, based on the NatureServe Ecological System Classification System as described by Comer (2003). The data are being developed in phases covering different parts of the state, and over a period of several years. Phases 1, 2, and 3 of the project are complete and cover 80,168,327 acres or 47% of Texas land area. Phase 1 generally covers eastern Texas, Phase 2 covers central and parts of North Texas, and Phase 3 covers the middle Texas coast. There are 73 Ecological Systems mapped in Phases 1 thru 3 and 288 mapping subsystems. Improved thematic and spatial resolution provided by this data was achieved by using advanced remote sensing techniques and spatial analysis of existing digital data related to ecoregions, soils, elevation models, aerial and satellite imagery, and hydrology, among other ecosystem variables. ESRI products were used for spatial modeling, and Earth Resource Data Analysis System (ERDAS) Imagine software was used to perform remote sensing analysis and to produce the final ArcGIS compatible gridded data generated at 10-meter resolution. As new project phases are completed the land classification data and supporting documentation can be downloaded by the public through links provided on the TPWD project website (TPWD 2011). ERDAS Imagine is recommended for working with the data and interactive exploration is encouraged due to the level of detail available.

The Colorado-Lavaca BBEST vegetation community maps were generated using ArcGIS. USGS gage locations were overlayed onto the land classification data and a gage of interest was identified. After zooming to a suitable extent, raster clipping tools were used to create a subset of the data. Riparian and floodplain vegetation classes were then identified through information in the attribute table, and then displayed using layer symbology options. Finally, the spatial extent was adjusted to show approximately 1 mile upstream and 1 mile downstream from the gage as requested by the BBEST. Map legend contents were refined by removing vegetation classes not visible within the area of interest, and a color scheme was developed for each ecological system to improve contrast and aid with interpretation. World imagery from ESRI ArcGIS map services is shown in the background (ESRI et al. 2011).

3.8.4 Relating Vegetation Communities to Environmental Flow

Obligate and facultative wetland riparian vegetation species were identified in each dominant riparian and floodplain vegetation community mapped by TESCP. Characteristics typical of obligate riparian vegetation are dependence on a high water table, tolerance to inundation and soil anoxia, tolerance to physical damage from floods, tolerance to burial by sediment, ability to colonize flood-scoured surfaces or fresh alluvial deposits, and ability to colonize and grow in substrates with few soil nutrients (Kondolf et al. 1996).

Maintaining diversity of riparian habitat may require continued lateral migration of a meandering alluvial channel, which in turn requires adequate flows to erode banks and deposit point bars. Similarly, preventing invasion of xeric plants onto bottomlands may require periodic flooding and high river stages that maintain seasonally high water tables. A study in Arizona found that depth to groundwater was an important driver of riparian tree species presence, abundance, and health; and riparian tree species were more likely to occur in areas with shallow groundwater (<6.5 feet; Merritt et al. 2010).

The Colorado-Lavaca BBEST team assessed riparian and floodplain vegetation communities within reaches associated with each of the gage locations. The analysis focused on vegetation communities adjacent to the stream and river channels, where responses to stream flow may be more direct. This analysis involved reviewing the TESCP-listed species that make up the riparian and floodplain communities to determine if they were obligate or facultative wetland species. Streams in the more arid upper basin (from Pecan Bayou and upstream) typically had few of the wetland riparian species described here and relatively low densities of typical riparian species compared to downstream reaches.

Additionally, there is some information in the Colorado River Basin regarding the area of inundation from pulse flow events. The LCRA provided modeled water's edge data for a range of pulse flow events (2-year, 5-year, 10-year, 25-year, 50-year, 100-year, and 500-year events) to compare to the vegetation communities within the Colorado River at Bastrop, Colorado River at Columbus, and Colorado River at Wharton reaches. Periodic pulse flow analysis for the Colorado River was conducted using HECRAS modeling. The corresponding discharge (cfs) for each modeled flow event for these sites was developed previously by LCRA during an unrelated pulse flow analysis, and may reflect slightly different flows that those reported by the HEFR and BBEST analysis (Table 3.8.1).

HECRAS model results were also available for an approximately 10-mile reach at the Colorado River at Silver, Colorado River at Ballinger, and Colorado River at San Saba sites (Freese and Nichols, Inc. unpublished data). Since these upper Colorado River sites experience lower flows that the lower Colorado River sites, pulse flow events including the 1-year, 2-year and 5-year events were used in this analysis. The corresponding discharge (cfs) for each of these modeled flow events were based primarily on the HEFR and BBEST analysis, although this HECRAS analysis was conducted prior to final BBEST HEFR analysis (Table 3.8.2).

Table 3.8.1 HECRAS modeled flow events with corresponding discharge (cfs) on the lower Colorado River.

Floodplain contour	Bastrop		Columbus		Wharton	
	Discharge (cfs)	Elevation (ft)	Discharge (cfs)	Elevation (ft)	Discharge (cfs)	Elevation (ft)
2-year	26,800	328.6	27,406	174.3	25,816	84.0
5-year	49,100	335.3	48,350	181.6	45,715	91.5
10-year	72,000	340.7	67,141	186.2	60,366	95.7
25-year	103,400	346.5	96,266	189.5	77,262	99.8
50-year	121,000	349.3	114,378	191.1	94,056	101.2
100-year	142,000	352.2	135,246	192.3	114,112	102.1
500-year		366.5		198.3		103.6

Table 3.8.2 HECRAS modeled flow events with corresponding discharge (cfs) on the upper Colorado River.

Floodplain contour	Silver	Ballinger	San Saba
1-year	3,000	4,500	19,000
2-year	4,500	7,000	30,000
5-year	8,000	12,000	40,000

Example Riparian/Floodplain Vegetation Analysis: Onion Creek near Driftwood

Based on a field visit in October 2010, both banks of the Onion Creek near Driftwood reach were lined with baldcypress. American sycamore, American elm, and pecan trees were observed higher up on the banks. Trees, saplings, and seedlings of each of these species were observed. Live oaks were observed on the bluffs.

The main TESCP mapped riparian vegetation community in this reach is Edwards Plateau floodplain hardwood forest, with some floodplain herbaceous vegetation, and very small patches of floodplain ashe juniper forest and floodplain live oak forest. The hardwood forest community extends across the channel and narrow floodplain of Onion Creek. This floodplain hardwood forest community is described as commonly consisting of cedar elm, American elm, pecan, plateau live oak, bur oak, western soapberry, Arizona walnut, and green ash (German et al. 2009).

With the occurrence of mature bald cypress-lined banks in this reach of Onion Creek, and current recruitment of saplings and seedlings in the community, it is apparent that water is maintained in the channel perennially. Bald cypress seed germination is dependent on saturated soil conditions for 1–3 months, and the species is adapted to areas of frequent to permanent inundation. A base flow in this creek that maintains frequent inundation of bald cypress roots or perennial pools would allow this species to grow. High flow pulses in this region transport organic material, which is likely deposited on the bank side of the bald cypress trees, enriching the soil and maintaining the shoreline elevation. High flow pulses also transport seeds for sycamore, elm, and pecan trees. Moist soil conditions from pulse flows and a shallow water table, combined with periodic overland flow and direct precipitation, would allow germination and recruitment of these species.

3.9 Water Quality

3.9.1 Description of Methods and Assumptions

The primary objectives of the water quality component of the BBEST were to (1) characterize the baseline water quality at the study sites by reviewing existing data, (2) evaluate correlations between water quality parameters and flow at the sites, and (3) use the results of the water quality assessment to adjust proposed flow regimes at the study sites to minimize potential water quality issues and promote a sound ecological environment.

Baseline water quality was characterized based on a screening assessment of the following parameters: water temperature, dissolved oxygen (DO), specific conductance, chloride, pH, nitrate plus nitrite nitrogen (NO3+NO2–N), and total phosphorus (TP). Existing sampling data for each of these parameters were compiled from the TCEQ Clean Rivers Program (CRP) database for the available water quality period of record at each study site. No water quality sampling was conducted by the BBEST.

In addition, the baseline water quality characterization included a review of historical water quality concerns. The Texas Surface Water Quality Standards (Texas Administrative Code Title 30, Chapter 307) provide the basis to evaluate water quality and determine whether or not designated uses, including aquatic life, water supply, recreation, and aquifer protection, are impaired. The surface water quality criteria for the Colorado River Basin, Colorado-Lavaca Coastal Basin, and Lavaca River Basin are presented in Tables 3.9.1 through 3.9.3.

The BBEST reviewed TCEQ's 2008 and Draft 2010 Water Quality Inventory Basin Assessment Data by Segment to identify specific water quality concerns previously identified and documented by TCEQ. The TCEQ's list of impaired water bodies, i.e., the 303(d) List, also was reviewed to identify whether any designated uses were impaired by water quality constituents in the Colorado River or associated coastal basins. The integrated report covering TCEQ's Basin Assessments and 303(d) List is available online at http://www.tceq.state.tx.us/compliance/monitoring/water/quality/data/wqm/305_303.html.

Table 3.9.1 Texas Surface Water Quality Criteria for the Colorado River Basin

Colorado River Basin			Criteria						
Segment No.	Segment Name	Uses[9]	Cl^{-1} (mg/L)	SO_4^{-2} (mg/L)	TDS (mg/L)	Dissolved Oxygen (mg/L)	pH Range (SU)	Indicator Bacteria[1] #/100ml	Temperature (°F)
1401	Colorado River Tidal	PCR, H				4.0	6.5-9.0	35	95
1402	Colorado River Below La Grange	PCR, H, PS	100	100	500	5.0	6.5-9.0	126	95
1403	Lake Austin	PCR, H, PS	100	75	400	5.0	6.5-9.0	126	90
1404	Lake Travis	PCR, E, PS	100	75	400	6.0	6.5-9.0	126	90
1405	Marble Falls Lake	PCR, H, PS	125	75	500	5.0	6.5-9.0	126	94
1406	Lake Lyndon B. Johnson	PCR, H, PS	125	75	500	5.0	6.5-9.0	126	94
1407	Inks Lake	PCR, H, PS	150	100	600	5.0	6.5-9.0	126	90
1408	Lake Buchanan	PCR, H, PS	150	100	600	5.0	6.5-9.0	126	90
1409	Colorado River Above Lake Buchanan	PCR, H, PS	200	200	900	5.0	6.5-9.0	126	91
1410	Colorado River Below O. H. Ivie Reservoir	PCR, H, PS	500	455	1,475	5.0	6.5-9.0	126	91
1411	E. V. Spence Reservoir	PCR, H, PS	440	360	1,630	5.0	6.5-9.0	126	93
1412	Colorado River Below Lake J. B. Thomas	PCR, H	4,740	1,570	9,210	5.0	6.5-9.0	33	93
1413	Lake J. B. Thomas	PCR, H, PS	140	250	520	5.0	6.5-9.0	126	90
1414	Pedernales River	PCR, H, PS	125	75	525	5.0	6.5-9.0	126	91
1415	Llano River [2]	PCR, H, PS	50	50	350	5.0	6.5-9.0	126	91
1416	San Saba River	PCR, H, PS	50	50	425	5.0	6.5-9.0	126	90
1417	Lower Pecan Bayou	PCR, H	310	120	1,025	5.0	6.5-9.0	126	90
1418	Lake Brownwood	PCR, H, PS	150	100	500	5.0	6.5-9.0	126	90
1419	Lake Coleman	PCR, H, PS	150	100	500	5.0	6.5-9.0	126	93
1420	Pecan Bayou Above Lake Brownwood	PCR, H, PS	500	500	1,500	5.0	6.5-9.0	126	90
1421	Concho River	PCR, H, PS	610	420	1,730	5.0	6.5-9.0	126	90
1422	Lake Nasworthy	PCR, H, PS	450	400	1,500	5.0	6.5-9.0	126	93
1423	Twin Buttes Reservoir	PCR, H, PS	200	100	700	5.0	6.5-9.0	126	90
1424	Middle Concho/South Concho River [3]	PCR, H, PS	150	150	700	5.0	6.5-9.0	126	90
1425	O. C. Fisher Lake	PCR, H, PS	150	150	700	5.0	6.5-9.0	126	90
1426	Colorado River Below E. V. Spence Reservoir	PCR, H, PS	1,000	1,110	1,770	5.0	6.5-9.0	126	91
1427	Onion Creek	PCR, H, PS/ AP[4]	100[5]	100[5]	500[5]	5.0	6.5-9.0	126	90
1428	Colorado River Below Lady Bird Lake/Town Lake	PCR, E, PS	100	100	500	6.0[6]	6.5-9.0	126	95
1429	Lady Bird Lake/Town Lake[7]	PCR, H, PS	75	75	400	5.0	6.5-9.0	126	90
1430	Barton Creek [8]	PCR, H, AP[4]	50	50	500	5.0	6.5-9.0	126	90

Table 3.9.1 Texas Surface Water Quality Criteria for the Colorado River Basin (continued)

Colorado River Basin			Criteria						
Segment No.	Segment Name	Uses[9]	Cl^{-1} (mg/L)	SO_4^{-2} (mg/L)	TDS (mg/L)	Dissolved Oxygen (mg/L)	pH Range (SU)	Indicator Bacteria[1] #/100ml	Temperature (°F)
1431	Mid Pecan Bayou	PCR	410	120	1,100	2.0	6.5-9.0	126	90
1432	Upper Pecan Bayou	PCR, H, PS	200	150	800	5.0	6.5-9.0	126	90
1433	O. H. Ivie Reservoir	PCR, H, PS	430	330	1,520	5.0	6.5-9.0	126	93
1434	Colorado River Above La Grange	PCR, E, PS	100	100	500	6.0	6.5-9.0	126	95

Notes:

1. The indicator bacteria for freshwater is *E. coli* and *Enterococci* for saltwater. The indicator bacteria and alternate indicator for Segment 1412 is *Enterococci* and fecal coliform, respectively.
1. The critical low flow for the South Llano River portion of Segment 1415 is calculated according to §307.8(a)(2)(B) of this title.
1. The critical low flow for the South Concho River portion of Segment 1424 is calculated according to §307.8(a)(2)(B) of this title.
1. The aquifer protection use applies to the contributing, recharge, and transition zones of the Edwards Aquifer.
1. The aquifer protection reach of Onion Creek is assigned criteria of 50 mg/L for chloride (Cl^{-1}), 50 mg/L for sulfate (SO_4^{-2}), and 400 mg/L for total dissolved solids (TDS).
1. Dissolved oxygen criterion of 6.0 mg/L only applies at stream flows greater than or equal to 150 cfs as measured at USGS gage number 08158000 located in Travis County upstream from U.S. Highway 183. Dissolved oxygen criterion of 5.0 mg/L applies to stream flows less than 150 cfs and greater than or equal to the 7Q2 for the segment.
1. While Segment 1429 exhibits quality characteristics that would make it suitable for primary contact recreation, the use is prohibited by local regulation for reasons unrelated to water quality.
1. The critical low flow for Segment 1430 is calculated according to §307.8(a)(2)(A) of this title.
1. PCR=primary contact recreation, H=high aquatic life use, E=exceptional aquatic life use, PS=public supply, AP=aquifer protection

Table 3.9.2 Texas Surface Water Quality Criteria for the Colorado-Lavaca Coastal Basin

Colorado-Lavaca Coastal Basin			Criteria						
Segment No.	Segment Name	Uses[2]	Cl^{-1} (mg/L)	SO_4^{-2} (mg/L)	TDS (mg/L)	Dissolved Oxygen (mg/L)	pH Range (SU)	Indicator Bacteria[1] #/100ml	Temperature (°F)
1501	Tres Palacios	PCR, E				5.0	6.5-9.0	35	95
1502	Tres Palacios Above Tidal	PCR, H	250	100	800	5.0	6.5-9.0	126	90

Notes:

1. The indicator bacteria for freshwater is *E. coli* and *Enterococci* for saltwater.
1. PCR=primary contact recreation, H=high aquatic life use, E=exceptional aquatic life use, PS=public supply, AP=aquifer protection

Table 3.9.3 Texas Surface Water Quality Criteria for the Lavaca River Basin

Lavaca River Basin			Criteria						
Segment No.	Segment Name	Uses[2]	Cl^{-1} (mg/L)	SO_4^{-2} (mg/L)	TDS (mg/L)	Dissolved Oxygen (mg/L)	pH Range (SU)	Indicator Bacteria[1] #/100ml	Temperature (°F)
1601	Lavaca River Tidal	PCR, H				4.0	6.5-9.0	35	95
1602	Lavaca River Above Tidal	PCR, H, PS	200	100	700	5.0	6.5-9.0	126	91
1603	Navidad River Tidal	PCR, H				4.0	6.5-9.0	35	91
1604	Lake Texana	PCR, H, PS	100	50	500	5.0	6.5-9.0	126	93
1605	Navidad River Above Lake Texana	PCR, H, PS	100	50	550	5.0	6.5-9.0	126	91

Notes:

1. The indicator bacteria for freshwater is *E. coli* and *Enterococci* for saltwater.

1. PCR=primary contact recreation, H=high aquatic life use, E=exceptional aquatic life use, PS=public supply, AP=aquifer protection

The TCEQ's CRP water quality data for each site were evaluated using an Excel spreadsheet model developed by the LCRA's Water Quality Protection Division (LCRA 2010) to evaluate water quality in the middle, lower, and coastal portions of the Colorado River Basin. The model calculates summary statistics for user-specified water quality parameters at each study site, plots the constituent concentrations versus flow, and plots a summary chart indicating which parameters, if any, are significantly correlated ($p<0.05$) with flow and whether the relationship is positive or negative. A positive correlation with flow indicates that the historical water quality observations tended to increase as flow increased, while negative correlations indicate that the parameter tended to decrease as flow increased. Results of the correlation analyses are summarized in Table 3.9.1-4. An example of the water quality analysis output from the model for each station is presented in the Appendix.

Table 3.9.4 Summary of Correlation Analyses Results for Water Quality Parameters and Flow.

Gage Name	Parameters						
	Water Temperature (°C)	Specific Conductance (µs/cm)	Dissolved Oxygen (mg/L)	pH (SU)	NO2+NO3 - Nitrogen (mg/L)	Total Phosphorus (mg/L)	Chloride (mg/L)
Colorado River above Silver	ns	-	ns	+	+	+	-
Colorado River near Ballinger	ns	-	-	ns	ns	ns	-
Elm Creek at Ballinger	ns	-	ns	ns	ns	ns	-
South Concho River at Christoval	ns	-	+	ns	ns	ns	ns
Concho River at Paint Rock	ns	-	ns	ns	ns	ns	-
Pecan Bayou near Mullin	ns	-	ns	ns	ns	ns	-
San Saba River at San Saba	ns	-	ns	ns	+	+	-
Colorado River near San Saba	ns	-	-	+	ns	+	-
Llano River near Llano	ns	ns	ns	ns	+	+	-
Pedernales River near Johnson City	ns	-	ns	-	ns	ns	-
Onion Creek near Driftwood	ns	ns	ns	ns	ns	ns	ns
Colorado River at Austin	ns	ns	+	ns	ns	-	+
Colorado River at Bastrop	ns	-	ns	-	-	-	ns
Colorado River at Columbus	ns	-	ns	+	-	-	ns
Colorado River at Wharton	ns	ns	ns	ns	ns	ns	-
Colorado River nr Bay City	ns	-	ns	ns	ns	+	ns
West Mustang Creek nr Ganado	ns	-	ns	ns	ns	ns	-
East Mustang Creek near Louise	ns	-	ns	ns	ns	+	ns
Navidad near Edna	ns	-	ns	ns	ns	ns	ns
Sandy Creek near Ganado	ns	-	ns	+	ns	ns	ns
Lavaca nr Edna	ns	-	ns	ns	ns	ns	-
Garcitas Creek near Inez	-	-	-	ns	ns	ns	-
Tres Palacios Creek near Midfield	ns	-	ns	+	ns	ns	-

Notes:

1. '+' indicates that the water quality parameter tended to increase with increasing flow.
1. '–' indicates that the water quality parameter tended to decrease with increasing flow.
1. 'ns' indicates no significant correlation between the water quality parameter and flow.

Upon completing the review of basin water quality assessments, 303(d) lists, and calculating summary statistics and correlation coefficients for water quality parameters versus flow, the water quality assessment was completed by addressing the following items for each gage site:

- Identify the water quality period of record for this gage
- Identify relationships between flow and water quality parameters
- Review the Texas Water Quality Inventory Basin Assessment Data (TCEQ 305(b) Report) to

determine whether water quality in this segment fully supports designated uses
- Identify known water quality impairments, if any, based on the TCEQ 303(d) list
- Characterize the relationship between temperature and flow
- Characterize the relationship between dissolved oxygen and flow
- Compare observed water quality to Texas Surface Water Quality Standards criteria

As reflected in these evaluation points, the water quality parameters of primary interest in developing flow recommendations for the Colorado and Lavaca Rivers and coastal basins were temperature and dissolved oxygen, as these are the constituents most likely to cause limitations for aquatic life, particularly at subsistence and base flows. The results of the evaluation of these items are presented in the detailed summaries for each gage site elsewhere in this report.

3.10 Geomorphology

3.10.1 Summary

1. The computations described in this section show how reducing average annual flow could affect sediment transport in the Colorado River at San Saba, Colorado River at Columbus, and Lavaca River at Edna.

2. Stream channel shape (geometry or bathymetry) is determined by the movement of bed material (sediment) by flow. Substantial, long-term changes in flow will change stream channel shape and consequently change existing habitat conditions for aquatic life.

3. The existing channels at three study sites (Colorado River near San Saba, Colorado River at Columbus, and Lavaca River near Edna) appear to be stable.

4. If stream flows were limited to amounts equal to the HEFR regime flows from subsistence through the one per season pulse flows, the average annual flow would be reduced by approximately: 73% at the Colorado River near San Saba, 57% at the Colorado River at Columbus, and 86% at the Lavaca River near Edna. The channel at all three sites would be unstable and transition to a smaller channel under the HEFR-only regimes. At all 3 sites, more extensive analysis may show that a stable channel may be maintained at a lower annual average flow than has been examined in this study.

5. Before any major new diversion of water, analysis of sediment transport should be conducted to ensure the new diversion will not impact sediment transport to the extent channel morphology is negatively affected.

3.10.2 Introduction

The channel shape (geometry or bathymetry) of an alluvial river adjusts in response to the range of flows that mobilize the boundary sediments. It has been observed that in many rivers, a single representative flow from the range of flows that have occurred historically can be used to determine a stable channel shape. A stable channel shape is important because it maintains the existing habitat conditions within the channel. These habitat conditions, if they represent a sound ecological environment under existing conditions, meet the biological objectives of an environmental flow regime. The BBEST has determined that the current channels appear to be stable and support acceptably sound environments. If substantial changes in flow regime, destabilize the stream channel, habitat conditions and the relationship between habitat and flow will change. It is not known whether resulting changes in channel shape and flow-habitat relationships would have positive or negative environmental effects. Without knowing how a change in the flow regime would affect channel shape and habitats, it is appropriate to support the existing environmental impact sediment transport to the extent channel morphology flow regime.

Changes in the flow regime of a stable channel can cause unstable conditions due to changes in the rate of:

- Erosion,
- Sediment transport, and/or
- Sediment deposition.

While these processes are at work in any river and channel shape is always adjusting somewhat, a stable channel exhibits what river engineers call "dynamic equilibrium." Once dynamic equilibrium is disrupted, the channel will be unstable while these processes work to reestablish equilibrium by changing the channel geometry (width, depth), width-depth ratio, sinuosity, and slope (Schumm 1969).

There are some indications in the scientific literature regarding the flows required to maintain the physical characteristics/habitats of river systems. Biedenharn et al. (2000) report that channels should remain dynamically stable if the sediment transport capacity of a reach is within 10% of the sediment supplied to the reach. Acreman et al. (2010) report that environmental standards adopted in the United Kingdom were developed with consideration of biology (macroinvertebrates, fish, and macrophytes) and geomorphology. Those standards allow diversion of from 7.5 to 30 % of the natural daily flow, depending on geomorphology, flow conditions, and desired ecological status. In addition, at least some of the reported impacts on biologic communities due to flow alterations are probably due to changes in river geomorphology (and therefore habitat).

Poff and Zimmerman (2010) found that a 50% change or greater in flow magnitudes (including peak, total or mean, base or hourly discharge) had a negative impact on fish communities. They could not precisely identify the level of flow alteration when fish were likely to be impacted, however, because of limited data related to systems with flow alterations in the range of 0 to 50%. Carlisle et al. (2010) found that a decrease of 60% in the mean annual maximum flow was likely to lead to degraded fish communities. The mean annual maximum flow is the average over a number of years of the maximum daily flows that occurred in any year. In most systems, mean annual maximum flows significantly affect the channel's shape or morphology. The impact on fish communities related to changes in mean annual maximum flow may be directly related to changes in habitat, though disruptions to spawning cues, access to floodplain habitats, or other factors may also play a role.

When significant changes to a river's flow regime are proposed, a geomorphic analysis should be conducted to determine if the proposed regime can be expected to maintain the current channel shape. The need for performing such a geomorphic analysis is discussed in the SAC guidance document "Fluvial Sediment Transport as an Overlay to Instream Flow Recommendations for the Environmental Flows Allocation Process" (SAC 2009b). The foundation of the SAC guidance is the use of effective discharge as a means to estimate if a future hydrologic regime is capable of maintaining the existing channel shape. The effective discharge is the (relatively narrow) range of flows from the entire range of flows associated with some hydrologic condition that transport the most sediment over time. Effective discharge incorporates the principles prescribed by Wolman and Miller (1960) that channel-forming discharge is a function of both the magnitude of an event and its frequency of occurrence. The analysis performed for the BBEST was performed as outlined in the SAC document including the use of the program SAMWin.

3.10.3 Study Locations

Three locations were chosen for performing sediment transport analysis in support of the Geomorphic Overlay for the Colorado-Lavaca BBEST study. The locations chosen were the:

- Colorado River near San Saba – USGS Gage Number 08147000, Lampasas County.
- Colorado River at Columbus – USGS Gage Number 08161000, Colorado County.
- Lavaca River near Edna – USGS Gage Number 08164000, Jackson County.

These locations were chosen because they are representative of the Colorado-Lavaca basin's climatologic, hydrologic and geographic diversity. The Colorado River near San Saba is representative of the upper portion of the basin. The Colorado River at Columbus is representative of the larger, sand and sand/gravel channels found in the middle portion of the basin and is downstream of the major reservoirs on the Colorado River main stem. The Lavaca River near Edna is representative of the low gradient streams found on the coastal plains of the basin.

3.10.4 Frequency Curves

An understanding of the basic hydrology of a stream is necessary when performing geomorphic studies. The basic assumption of the effective discharge approach is that channel shape is a function of the flow in the channel. The stability of a channel in a study reach can also be judged by the frequency of occurrence of the effective discharge. The effective discharge of a stable alluvial channel is usually associated with peak flows that occur every 1 to 3 years (Biedenharn, Little, and Thorne 1999). In the western semi-arid areas of the Colorado River Basin and/or in locations where the channel bed is composed of material larger than sand (gravel, cobble, and/or bedrock), effective discharges are expected to occur less often. For the Llano River at Llano, Heitmuller (2009) found that floods with return periods ranging from about 10 to 40 years play an important role in shaping the channel. The Llano River at Llano is a bedrock channel with sands and gravels found in the overbank areas.

Frequency curves for this effort were developed using the U.S. Army Corps of Engineers Hydrologic Engineering Center Statistical Software Package (HEC-SSP). This software allows the user to perform a variety of statistical analyses of hydrologic data. The current version of HEC-SSP can perform flood flow frequency analysis based on "Bulletin 17B - Guidelines for Determining Flood Flow Frequency" (IACWD 1982), a generalized frequency analysis on not only flow data but other hydrologic data as well, and a volume-duration frequency analysis on high and low flows. HEC-SSP uses annual peak flows to develop the flood frequency curves. Langbein (1949) showed that the Annual Flood flow frequency analysis underestimates the return interval of flows by about 0.5 year, which is important on the lower end of the frequency analysis. For example, the annual series flood frequency event calculated to occur once every year can be expected to occur about every six months. Annual Discharge Frequency curves that show the likelihood that floods of certain volumes will occur for the study sites are shown in figures 3.10.1 – 3.10.3 below. For example, in Figure 3.10.1, there is a 50% chance (see the bottom axis) that a flood of 20,000 cfs (see the left hand axis), will occur in any year. Or, put another way, a flood of 20,000 cfs is expected to occur, on average, about once every 2 years (see the top axis). Table 3.10.1 shows both annual flood frequency calculations and the frequency when adjusted as recommended by Langbein (1949).

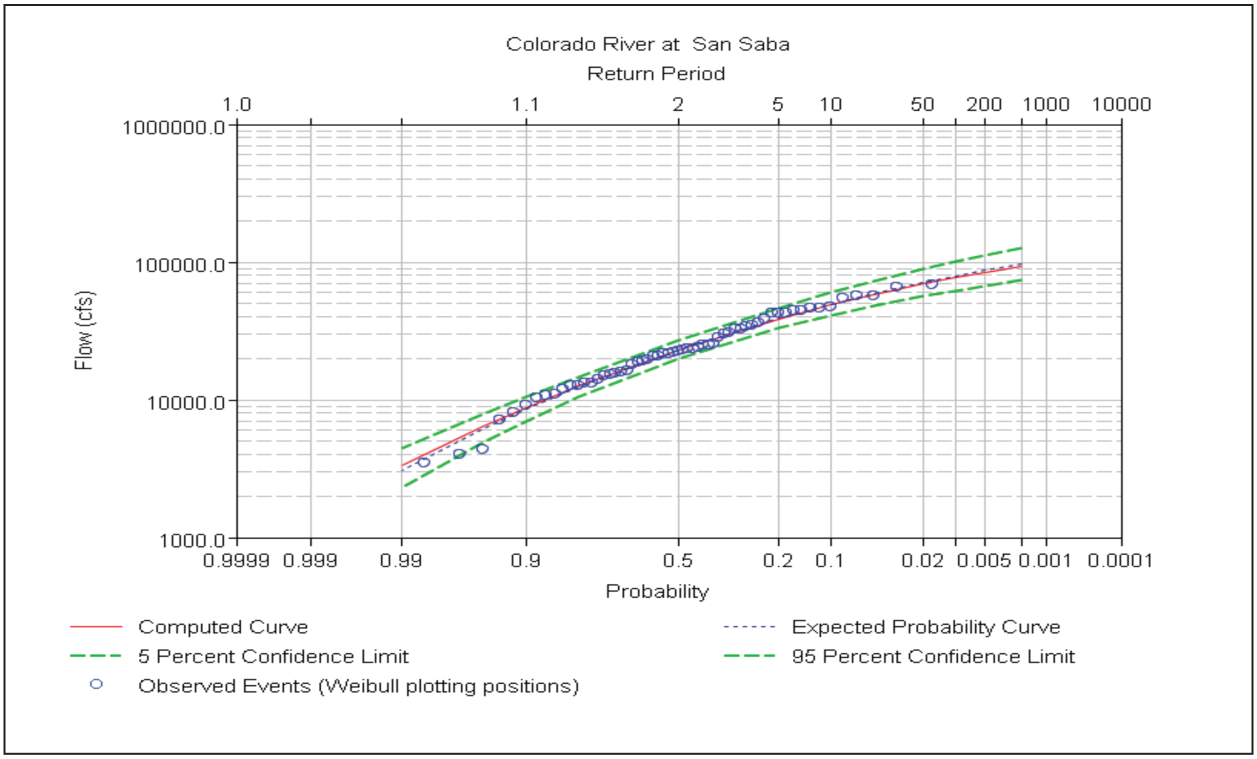


Figure 3.10.1 Annual Discharge Frequency Curve for Colorado River near San Saba

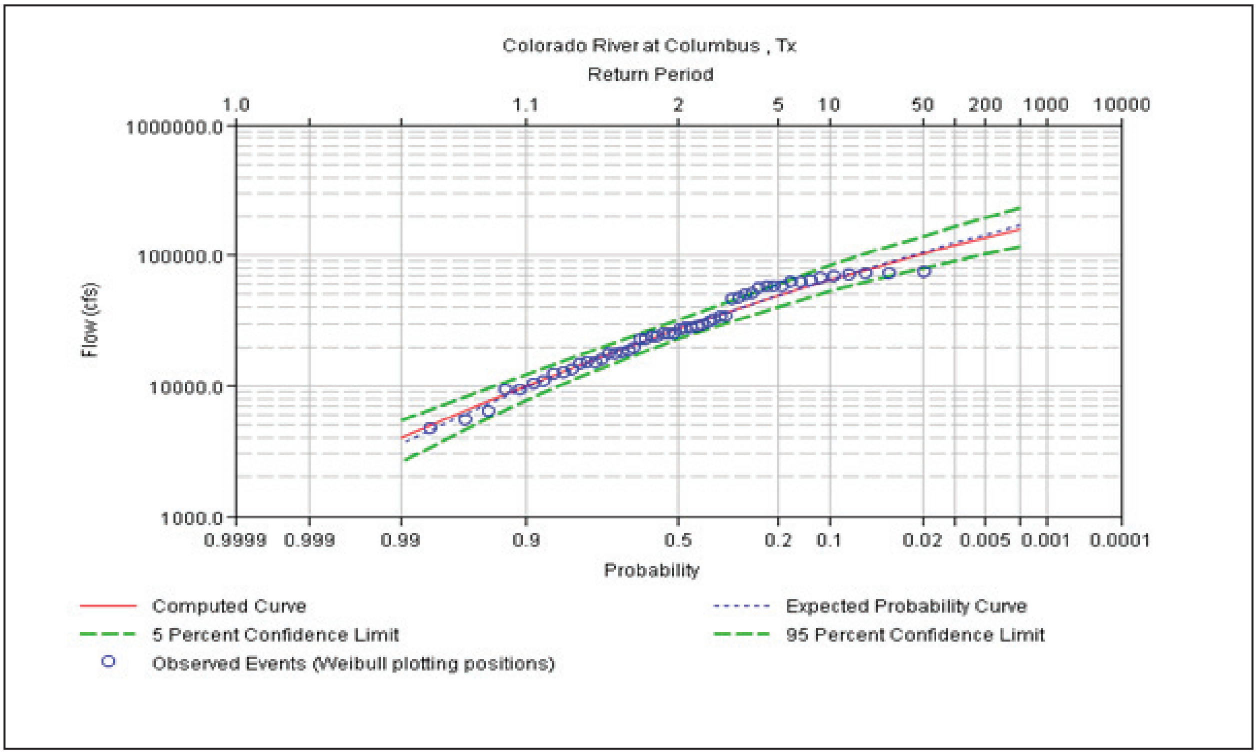


Figure 3.10.2 Annual Discharge Frequency Curve for Colorado River at Columbus

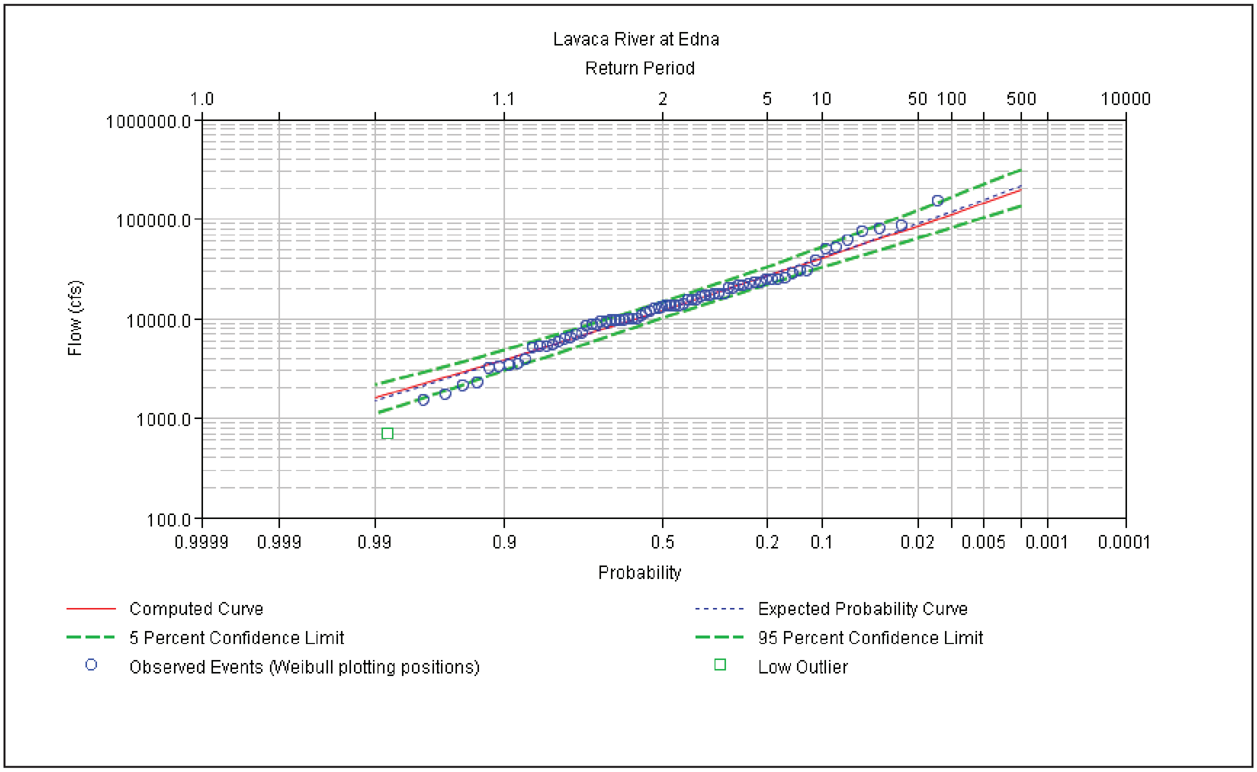


Figure 3.10.3 Annual Discharge Frequency Curve for Lavaca River near Edna

Table 3.10.1 Selected Frequencies for the Gage Locations Selected for Geomorphic Study. Annual series flow frequencies were calculated using annual instantaneous peak flow data. The adjustment to annual series frequencies suggested by Langbein (1949) was used to obtain partial series flow frequencies.

Corresponding return period in years for annual and partial series							
Partial Series	0.5	1	1.45	2	5	10	50
Annual Series	1.16	1.58	2	2.54	5.52	10.5	50.5

Annual Return Period in Years		10	5	2	1.25	1.11
Estimated Partial Return Period in Years			4.5	1.5	0.7	0.5
Percent Chance of Exceedence in One Year		10	20	50	80	90
River	Location	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)
Colorado	San Saba	48,709	38,628	23,126	12,568	8,775
Colorado	Columbus	64,587	48,723	27,188	14,288	9,959
Lavaca	Edna	40,479	26,646	12,196	5,717	3,884

3.10.5 Discharge Rating Curves

The existing channel should be analyzed to insure that it is reasonably stable and that it has adjusted to its existing hydrologic regime for the effective discharge calculation to be meaningful and provide guidance in how a future hydrologic regime might affect channel stability. One relatively simple and quick way to do this is to analyze how the long-term stage discharge curve (also known as the "rating curve") has changed over time. All three sites, Colorado River near San Saba, Colorado River at Columbus, and the Lavaca River near Edna, are USGS field measurement sites and have adequate periods of record to analyze for channel stability. Rating curves that remain stable over time are one indication that the channel in that reach of the river has remained stable. An alluvial channel that is either degrading or aggrading will show a distinct change in the stage-discharge relationship over time. Incising (degrading) channels that are eroding the stream bottom will exhibit a decreasing gage height for the same discharge while the gage height for an aggrading channel, which is filling with sediment, will exhibit an increase in gage height for the same discharge.

Figure 3.10.4 shows the rating curve for the Colorado River near San Saba, which has changed very little over the time that the USGS discharge measurements are available. This gage appears to have adjusted to existing hydrologic conditions and the effective discharge analysis will provide useful information regarding how the channel will react to future hydrologic regimes.

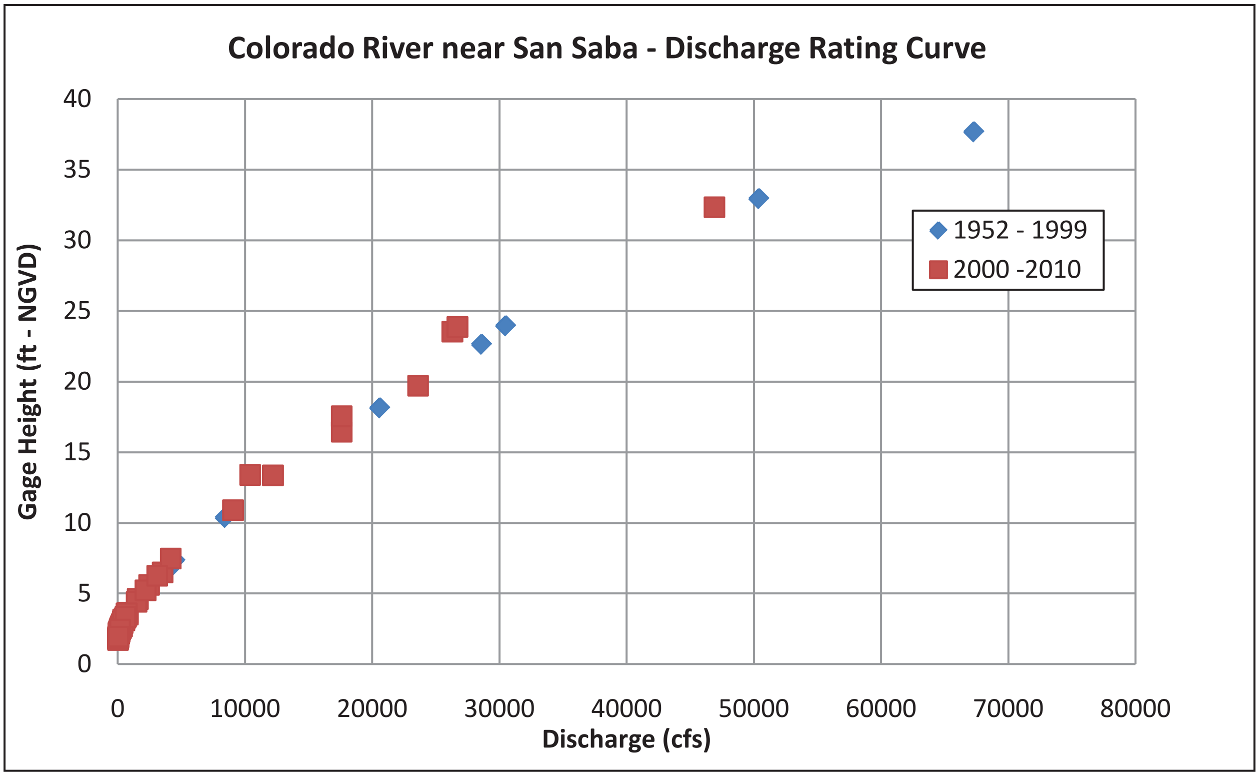


Figure 3.10.4 Discharge Rating Curve for Colorado River near San Saba

Figure 3.10.5 shows the rating curve for the Colorado River at Columbus gage. The figure appears to show some stream incision or degradation is occurring, indicating that the channel may not be currently stable at this location. The plot shows about 0.5 feet of incision from the 1979–1989 time frame to the 1990–1999 time frame at flows below 6000 cfs. There appears to have been another 0.5–0.75 feet of degradation in the 2000–2011 time frame. The total amount of degradation at this gage from 1979 to present appears to be approaching 1 ft. This is a relatively small amount of degradation over 30 years of record and could be within the normal fluctuation expected of a stable channel. To determine if channel degradation is occurring would require studies outside the scope of this work, including looking at how gages upstream and downstream of this gage have changed during this same time period, examining changes in channel shape in this reach of the Colorado River and consulting with USGS to determine if changes in field measurements may be causing the gage to appear to be reflecting lower stages for the same discharge. Considering the small amount of change occurring at this site, it is being kept as a geomorphic study location for the current BBEST work effort.

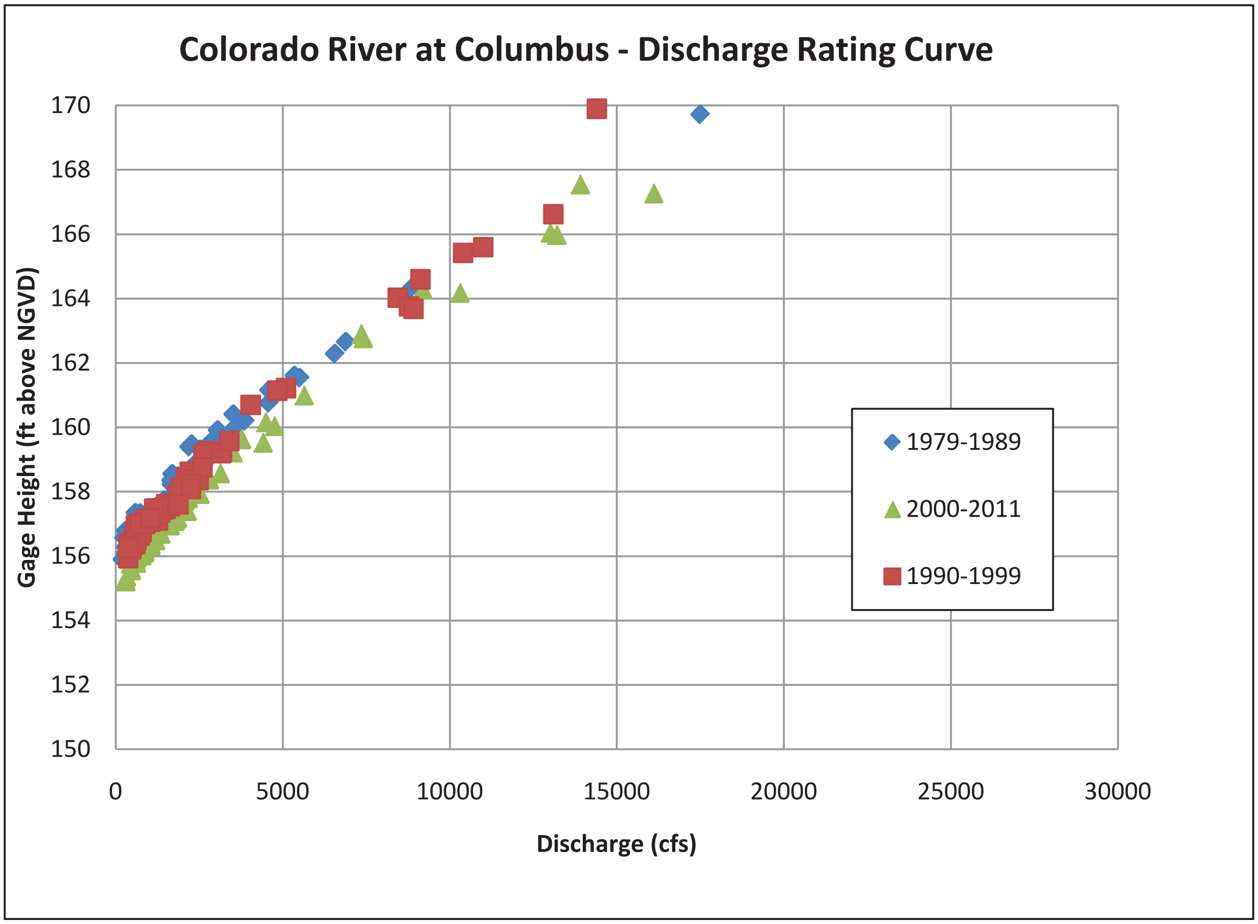


Figure 3.10.5 Discharge Rating Curve for Colorado River at Columbus

The following two figures, Figures 3.10.6 and 3.10.7, show that the rating curve for the Lavaca River near Edna has not changed over the period that USGS field discharge measurements are available (1938–2010). This gage appears to have adjusted to existing hydrologic conditions and the effective discharge analysis will provide useful information regarding how the channel might react to future alternative hydrologic regimes.

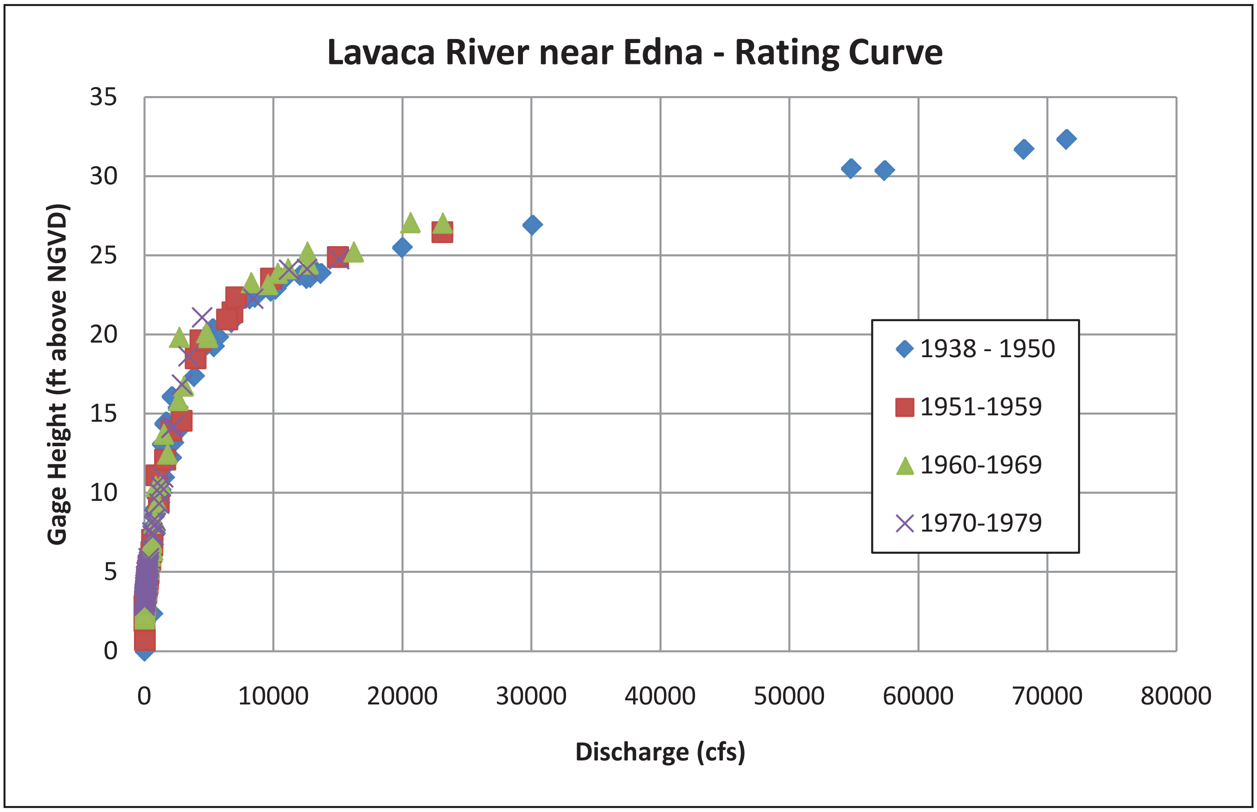


Figure 3.10.6 Discharge rating Curve for Lavaca River near Edna

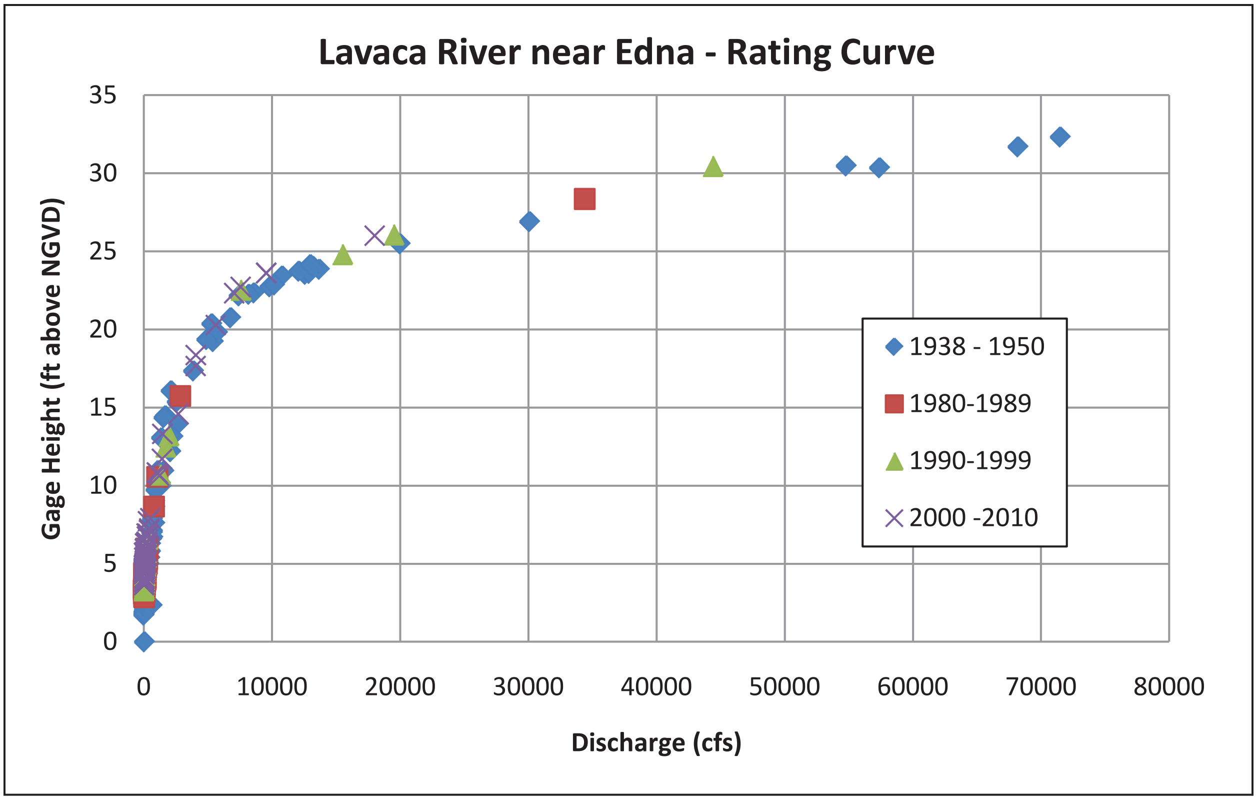


Figure 3.10.7 Discharge rating Curve for Lavaca River near Edna

3.10.6 Sediment Rating Curves

A hybrid approach using both measured and computer modeled sediment-discharge data was used to develop sediment rating curves at the study locations. Sediment rating curves estimate the amount of sediment moved by flows of various sizes. Data from USGS discharge measurements and bed material gradations collected by TWDB staff during cross-sectional surveys in support of Dr. Thom Hardy's Comparative Cross Section analysis were used in the computer program SAMWin to compute the sediment rating curves. In addition to the USGS discharge measurements, the USGS also has taken suspended sediment measurements at the three study locations. The decision was made not to rely solely on the USGS measurements because the measurements did not cover the entire flow range; most notably measurements at higher discharges had not been taken. The suspended sediment measurements taken in the last century are summarized as follows.

- Colorado River near San Saba: 124 measurements from October 1960 to August 1993.
- Colorado River at Columbus: 43 measurements from October 1960 to April 1973.
- Lavaca River near Edna: 95 measurements from November 1977 to August 1993.

At the Columbus site, more than 100 suspended load measurements were taken but only 43 contained a particle size breakdown necessary to separate sand load from silts and clays in suspension.

Channel parameters (velocity, discharge, channel width, channel depth, computed energy slopes, and bed gradation) at each gage site were input to SAMWin and a sediment rating curve was computed. A number of different equations for sediment transport were applied and the equation that fit the measured data most closely was chosen as a guide for developing the sediment rating curve used in the effective discharge calculation. At some discharges, the computed sediment load was above or below the observed data. Therefore, the sediment loads at these discharges were adjusted to better fit the observed data. Figures 3.10.8 - 3.10.10 show the measured sediment data, the computed sediment rating curves, the manually adjusted data points and the sediment rating curves used to compute effective discharge for the Colorado River near San Saba, Colorado River at Columbus, and the Lavaca River near Edna, respectively. The sediment function used is also shown on the plots. The Yang function worked best for the Colorado River near San Saba because of the bed gradation, which went from sands to large gravels. The Ackers-White function was used for the Colorado River at Columbus and Lavaca River near Edna. The Ackers-White function is often used to accurately reproduce measured load in sand bed channels.

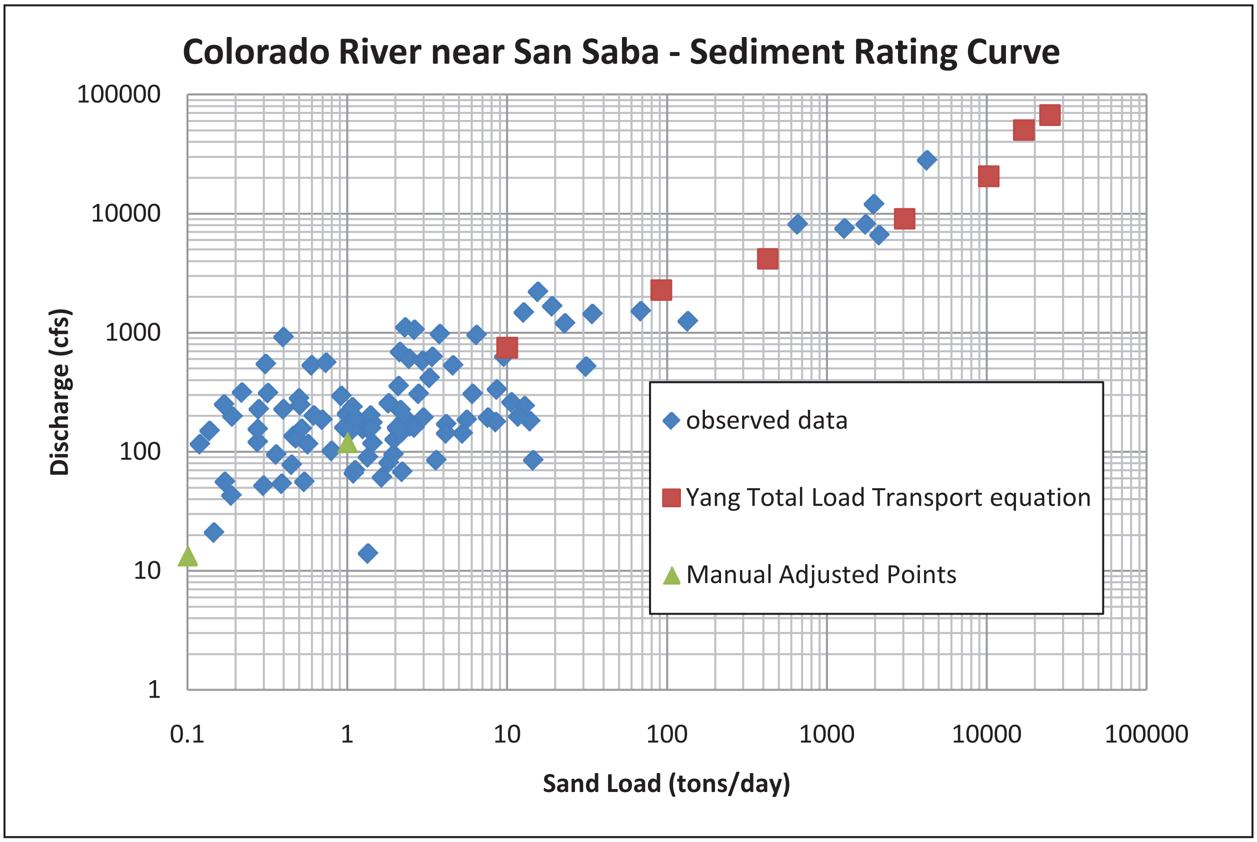


Figure. 3.10.8 Sediment Rating Curve for the Colorado River near San Saba

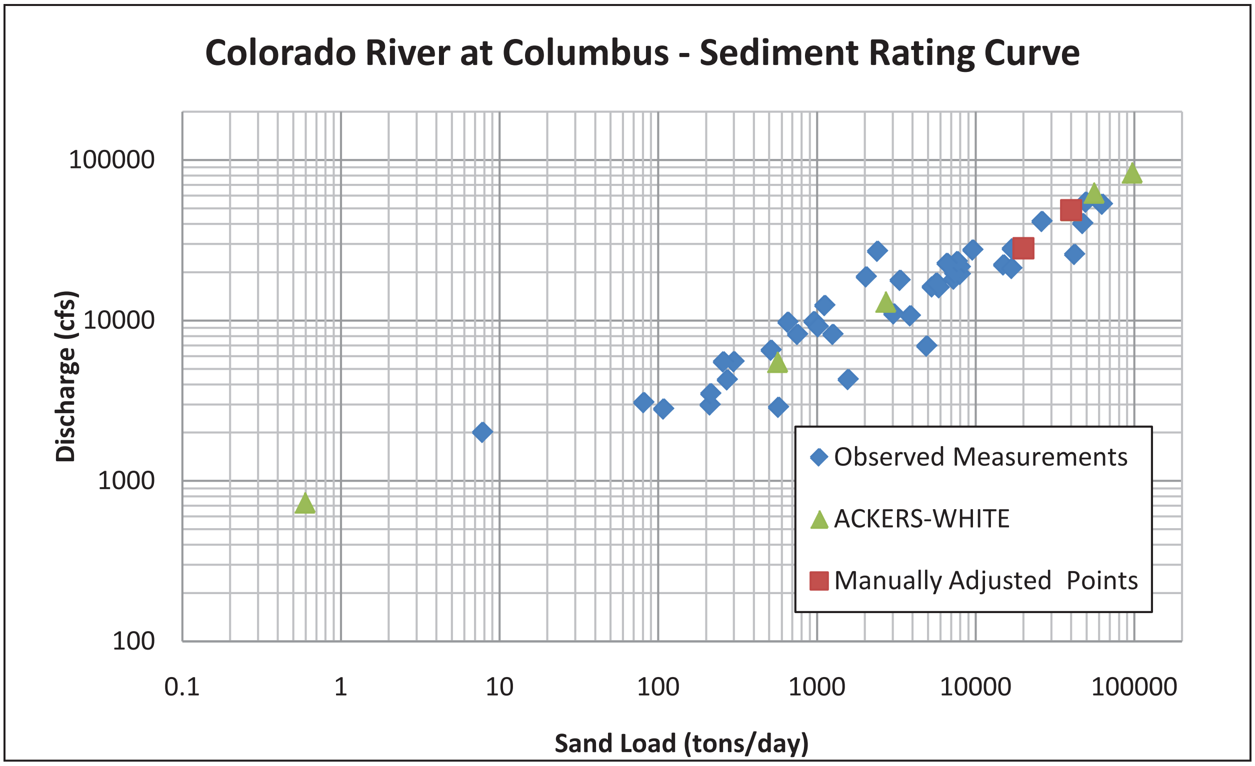


Figure 3.10.9 Sediment Rating Curve for the Colorado River at Columbus

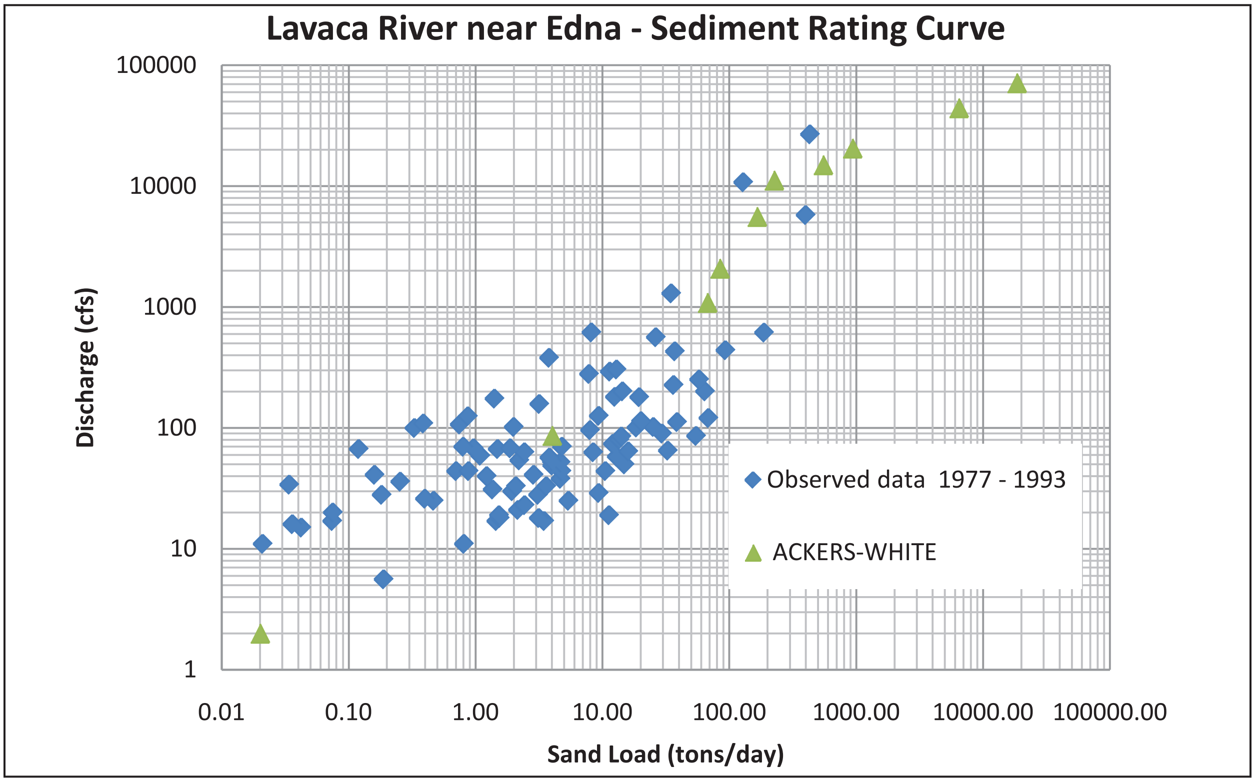


Figure 3.10.10 Sediment Rating Curve for the Lavaca River near Edna

3.10.7 Hydrology

In addition to the sediment rating curves discussed in the previous section, a flow duration curve developed from a time series of flow values is required in order to compute effective discharge. The hydrologic time series can be daily, hourly, every 15 minutes, etc., depending on flow characteristics of the stream. Daily time step data was available at all three locations and flow characteristics of the streams are such that the daily flow is a fairly accurate description of the flow regime. Smaller time steps are required when the flow events rise and fall within a short time span and are not accurately reflected in the average daily flow computation.

The observed gage flows at each of the gaging stations from January 1, 1940 to December 31, 1998 were used as the baseline hydrology for this study. For comparisons to the baseline or "existing conditions" a number of alternative flow regimes were used.

The first alternative used in the analysis was the HEFR-only flow regime. The HEFR-only regime used in this analysis was a preliminary HEFR analysis using seasons of December through February for winter, March through May for spring, June through August for summer, and September through November for fall. In this section, this HEFR regime is referred to as the draft HEFR since values vary slightly from the final HEFR regimes (calculated using slightly different seasons, see Section 3.2) which are illustrated elsewhere in this report. The difference in values from the draft HEFR regime used in this analysis and the final HEFR regimes in this report do not affect the analysis or conclusions described in this section.

This alternative assumed that the only flow remaining in a stream at each gage location was the flow shown in the HEFR table for subsistence, base, and seasonal pulse flows, mimicking the implementation example developed by the Sabine-Neches BBEST (SN BBEST Section 6.1.4) and adopted in the draft rules by TCEQ (2010). Annual high flow pulses and overbank flows, which have been adopted as part of the BBEST recommendation, have not been included in the development of the hydrologic data for this alternative. Moderate-magnitude bankfull flows and overbank flow do provide important channel maintenance functions.

> "Moderate-magnitude bankfull floods are effective at flushing accumulated fine sediments from gravels, scouring pools, building riffles, removing vegetation from active channel areas, inundating bars, and maintaining channel capacity. Overbank floods can create new side channels, form or erode islands, build log jams, cut off meander bends, and deposit fresh sediment and viable seeds on the floodplain. These processes maintain channel complexity and habitat diversity, as well as provide the disturbance needed for recruitment of certain riparian plants" (BIO-WEST, Inc. 2008a).

However, the approaches to either explicitly protect these high flow events or to evaluate the likelihood that they will occur without any explicit requirements has been the subject of much discussion (SAC 2010) and the tool thus far developed to evaluate the implementation of flow recommendations (FRAT) does not include these events. The occurrence of high flow events in the future will depend in part on a combination of the water projects that are developed and the regulations that may be imposed upon them. The analysis in this document suggests that the occurrence of episodic, infrequent high flow events, while providing some of the benefits described above, would not likely change the sediment transport distributions or the effective discharge and thus would not be expected to maintain long term dynamic stability in the channel. (The figures describing HEFR Regime Flows for each site would include several peaks at the prescribed flows but otherwise the conclusions would be unchanged.) Should the BBASC develop a more refined recommendation for implementation of these high flow events, the existing tools could be updated to incorporate these recommendations and the sediment transport analysis could be re-run. The preliminary HEFR flow regimes for the three locations that were analyzed are shown in Tables 3.10.2, 3.10.3, and 3.10.4.

Table 3.10.2 Preliminary HEFR Tables Colorado River near San Saba

Month	Season	Subsistence Flow (cfs)	Dry Base Flow (cfs)	Avg Base Flow (cfs)	Wet Base Flow (cfs)
Jan	Winter	58	107	163	226
Feb	Winter	58	107	163	226
Mar	Spring	41	122	198	354
Apr	Spring	41	122	198	354
May	Spring	41	122	198	354
June	Summer	10	101	179	332
Jul	Summer	10	101	179	332
Aug	Summer	10	101	179	332
Sept	Fall	28	102	163	262
Oct	Fall	28	102	163	262
Nov	Fall	28	102	163	262
Dec	Winter	58	107	163	226

Month	Season	Dry Pulse Frequency (# per season)	Dry Pulse Peak (cfs)	Dry Pulse Duration (days)	Dry Pulse Volume (acft)	Avg Pulse Peak (cfs)	Avg Pulse Duration (days)	Avg Pulse Volume (acft)
Jan	Winter	1	436	3	2,606	5,800	4	40,791
Feb	Winter	1	436	3	2,606	5,800	4	40,791
Mar	Spring	1	3,640	4	21,072	21,000	5	111,722
Apr	Spring	1	3,640	4	21,072	21,000	5	111,722
May	Spring	1	3,640	4	21,072	21,000	5	111,722
June	Summer	1	2,790	4	16,926	6,550	4	45,217
Jul	Summer	1	2,790	4	16,926	6,550	4	45,217
Aug	Summer	1	2,790	4	16,926	6,550	4	45,217
Sept	Fall	1	1,550	3	15,217	14,500	5	85,850
Oct	Fall	1	1,550	3	15,217	14,500	5	85,850
Nov	Fall	1	1,550	3	15,217	14,500	5	85,850
Dec	Winter	1	436	3	2,606	5,800	4	40,791

Month	Season	Wet Pulse Frequency (# per season)	Wet Pulse Peak (cfs)	Wet Pulse Duration (days)	Wet Pulse Volume (acft)	Wet Pulse Peak (cfs)	Wet Pulse Duration (days)	Wet Pulse Volume (acft)
Jan	Winter	2	5,800	4	40,791	1,400	6	12,650
Feb	Winter	2	5,800	4	40,791	1,400	6	12,650
Mar	Spring	2	21,000	5	111,722	9,250	6	59,235
Apr	Spring	2	21,000	5	111,722	9,250	6	59,235
May	Spring	2	21,000	5	111,722	9,250	6	59,235
June	Summer	2	6,550	4	45,217	7,850	6	48,565
Jul	Summer	2	6,550	4	45,217	7,850	6	48,565
Aug	Summer	2	6,550	4	45,217	7,850	6	48,565
Sept	Fall	2	14,500	5	85,850	6,300	6	38,763
Oct	Fall	2	14,500	5	85,850	6,300	6	38,763
Nov	Fall	2	14,500	5	85,850	6,300	6	38,763
Dec	Winter	2	5,800	4	40,791	1,400	6	12,650

Table 3.10.3 Preliminary HEFR Table Colorado River at Columbus

Month	Season	Subsistence Flow (cfs)	Dry Base Flow (cfs)	Avg Base Flow (cfs)	Wet Base Flow (cfs)
Jan	Winter	328	628	895	1,248
Feb	Winter	328	628	895	1,248
Mar	Spring	317	808	1,340	2,098
Apr	Spring	317	808	1,340	2,098
May	Spring	317	808	1,340	2,098
June	Summer	226	705	1,060	1,710
Jul	Summer	226	705	1,060	1,710
Aug	Summer	226	705	1,060	1,710
Sept	Fall	207	610	928	1,400
Oct	Fall	207	610	928	1,400
Nov	Fall	207	610	928	1,400
Dec	Winter	328	628	895	1,248

Month	Season	Dry Pulse Frequency (# per season)	Dry Pulse Peak (cfs)	Dry Pulse Duration (days)	Dry Pulse Volume (acft)	Avg Pulse Peak (cfs)	Avg Pulse Duration (days)	Avg Pulse Volume (acft)
Jan	Winter	1	5,800	4	40,791	5,800	4	40,791
Feb	Winter	1	5,800	4	40,791	5,800	4	40,791
Mar	Spring	1	21,000	5	111,722	21,000	5	111,722
Apr	Spring	1	21,000	5	111,722	21,000	5	111,722
May	Spring	1	21,000	5	111,722	21,000	5	111,722
June	Summer	1	6,550	4	45,217	6,550	4	45,217
Jul	Summer	1	6,550	4	45,217	6,550	4	45,217
Aug	Summer	1	6,550	4	45,217	6,550	4	45,217
Sept	Fall	1	14,500	5	85,850	14,500	5	85,850
Oct	Fall	1	14,500	5	85,850	14,500	5	85,850
Nov	Fall	1	14,500	5	85,850	14,500	5	85,850
Dec	Winter	1	5,800	4	40,791	5,800	4	40,791

Month	Season	Wet Pulse Frequency (# per season)	Wet Pulse Peak (cfs)	Wet Pulse Duration (days)	Wet Pulse Volume (acft)	Wet Pulse Peak (cfs)	Wet Pulse Duration (days)	Wet Pulse Volume (acft)
Jan	Winter	2	5,800	4	40,791	13,200	7	111,268
Feb	Winter	2	5,800	4	40,791	13,200	7	111,268
Mar	Spring	2	21,000	5	111,722	32,000	6	182,959
Apr	Spring	2	21,000	5	111,722	32,000	6	182,959
May	Spring	2	21,000	5	111,722	32,000	6	182,959
June	Summer	2	6,550	4	45,217	15,600	6	150,724
Jul	Summer	2	6,550	4	45,217	15,600	6	150,724
Aug	Summer	2	6,550	4	45,217	15,600	6	150,724
Sept	Fall	2	14,500	5	85,850	41,600	6	270,798
Oct	Fall	2	14,500	5	85,850	41,600	6	270,798
Nov	Fall	2	14,500	5	85,850	41,600	6	270,798
Dec	Winter	2	5,800	4	40,791	13,200	7	111,268

Table 3.10.4 Preliminary HEFR Table Lavaca River near Edna

Month	Season	Subsistence Flow (cfs)	Dry Base Flow (cfs)	Avg Base Flow (cfs)	Wet Base Flow (cfs)
Jan	Winter	5	6	6	6
Feb	Winter	5	6	6	6
Mar	Spring	5	5	6	6
Apr	Spring	5	5	6	6
May	Spring	5	5	6	6
June	Summer	5	5	5	5
Jul	Summer	5	5	5	5
Aug	Summer	5	5	5	5
Sept	Fall	4	5	6	6
Oct	Fall	4	5	6	6
Nov	Fall	4	5	6	6
Dec	Winter	5	6	6	6

Month	Season	Dry Pulse Frequency (# per season)	Dry Pulse Peak (cfs)	Dry Pulse Duration (days)	Dry Pulse Volume (acft)	Avg Pulse Peak (cfs)	Avg Pulse Duration (days)	Avg Pulse Vol-ume (acft)
Jan	Winter	1	14	5	103	5,800	4	40,791
Feb	Winter	1	14	5	103	5,800	4	40,791
Mar	Spring	1	16	5	127	21,000	5	111,722
Apr	Spring	1	16	5	127	21,000	5	111,722
May	Spring	1	16	5	127	21,000	5	111,722
June	Summer	1	7	2	38	6,550	4	45,217
Jul	Summer	1	7	2	38	6,550	4	45,217
Aug	Summer	1	7	2	38	6,550	4	45,217
Sept	Fall	1	13	4	63	14,500	5	85,850
Oct	Fall	1	13	4	63	14,500	5	85,850
Nov	Fall	1	13	4	63	14,500	5	85,850
Dec	Winter	1	14	5	103	5,800	4	40,791

Month	Season	Wet Pulse Frequency (# per season)	Wet Pulse Peak (cfs)	Wet Pulse Duration (days)	Wet Pulse Volume (acft)	Wet Pulse Peak (cfs)	Wet Pulse Duration (days)	Wet Pulse Volume (acft)
Jan	Winter	2	5,800	4	40,791	16	6	133
Feb	Winter	2	5,800	4	40,791	16	6	133
Mar	Spring	2	21,000	5	111,722	22	9	220
Apr	Spring	2	21,000	5	111,722	22	9	220
May	Spring	2	21,000	5	111,722	22	9	220
June	Summer	2	6,550	4	45,217	12	6	103
Jul	Summer	2	6,550	4	45,217	12	6	103
Aug	Summer	2	6,550	4	45,217	12	6	103
Sept	Fall	2	14,500	5	85,850	18	6	130
Oct	Fall	2	14,500	5	85,850	18	6	130
Nov	Fall	2	14,500	5	85,850	18	6	130
Dec	Winter	2	5,800	4	40,791	16	6	133

A second set of alternatives was developed that not only protects the flows in the HEFR regime tables but also provides specific levels of protection for the average annual flow. This approach limited the removal of water from the stream to a maximum diversion rate plus the recommended HEFR flow regime values for subsistence, base and pulse flow. In addition to the HEFR flow regime, flows in excess of the maximum diversion rate would remain in the channel. The alternatives examined for the three gages included flows resulting from providing the HEFR regime and setting either a maximum diversion rate of 10,000 cfs or a maximum diversion rate equal to the 75th percentile flow. The 75th percentile flow at each of the gages is:

- Colorado River near San Saba – 540 cfs,
- Colorado River at Columbus – 2,770 cfs,
- Lavaca River near Edna – 132 cfs.

Additional hydrologic flow regimes were analyzed using a maximum diversion rate equal to the 30th percentile flow at the Colorado River at Columbus and the 60th percentile flow for the Lavaca River near Edna gages. The additional alternatives were analyzed as time permitted to give the BBEST information on how limiting the diversion rate might affect the effective discharge calculations. The flow duration curves used for the effective discharge calculations are shown in Figures 3.10.11, 3.10.12, and 3.10.13 for the three study sites.

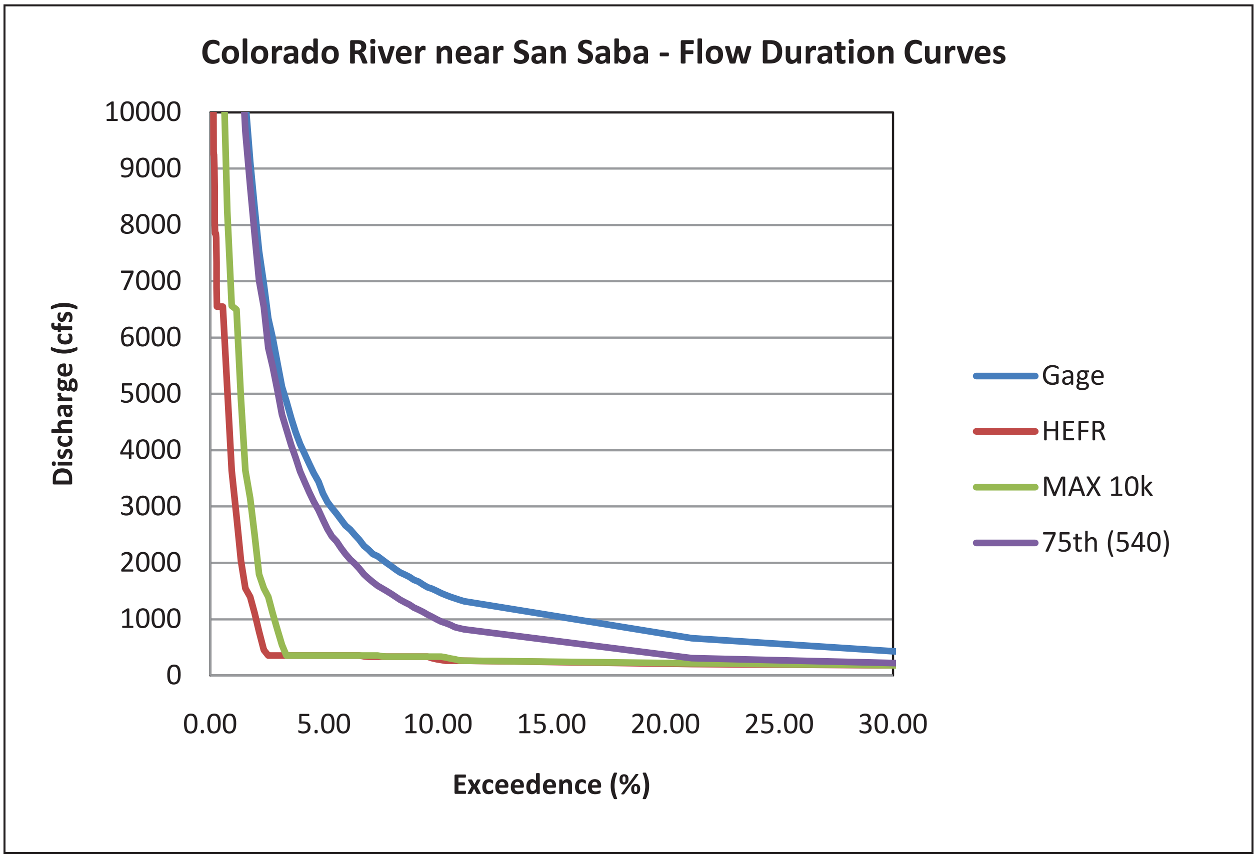


Figure 3.10.11 Flow Duration Curves for the Colorado River near San Saba

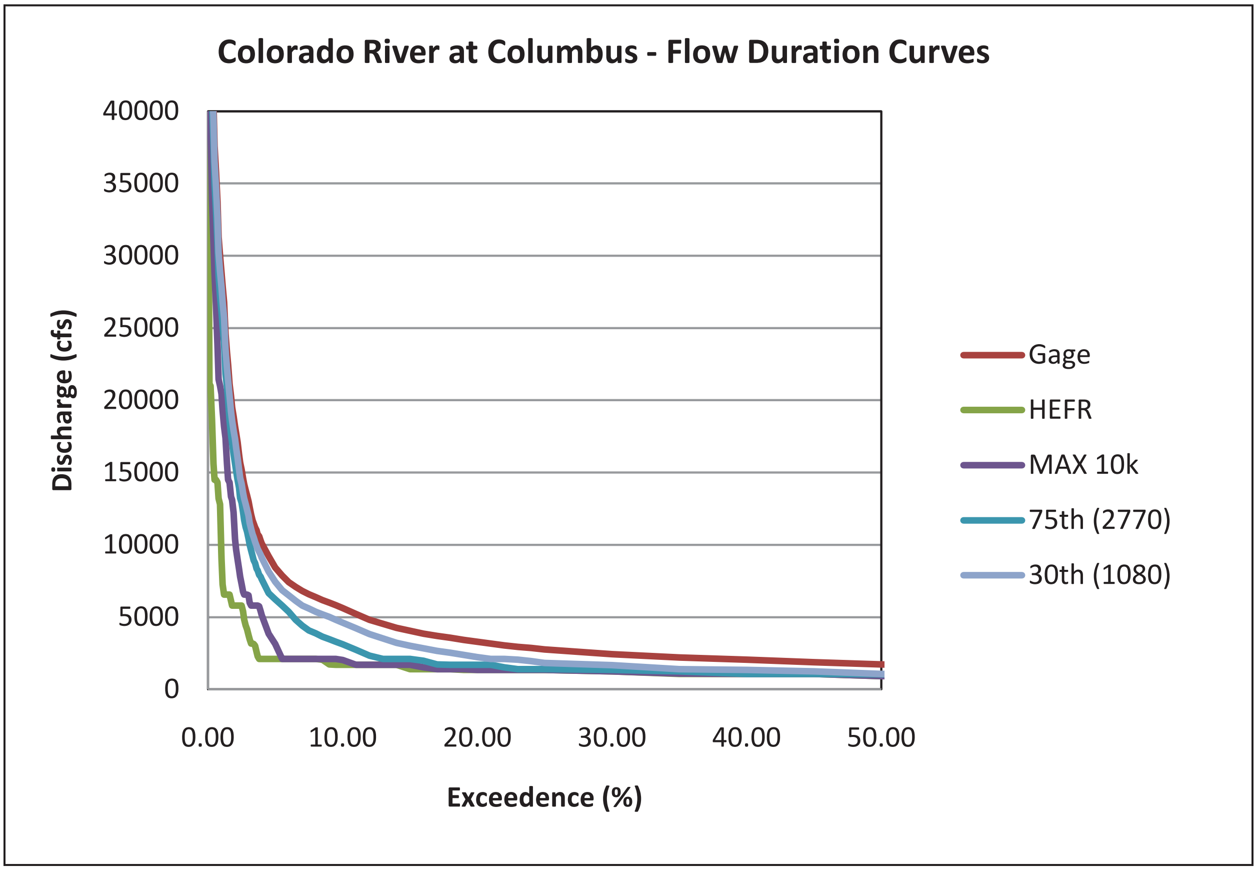


Figure 3.10.12 Flow Duration Curves for the Colorado River at Columbus

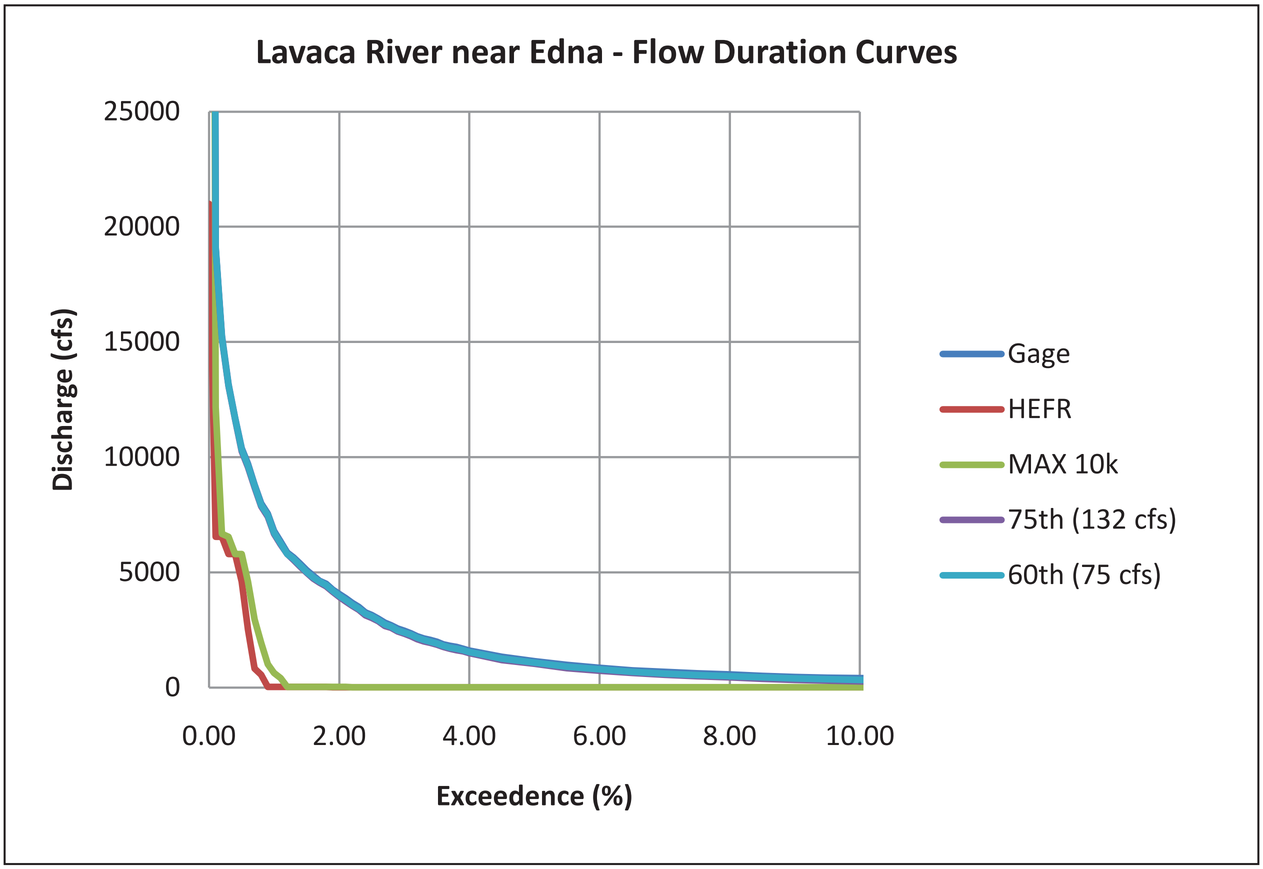


Figure 3.10.13 Flow Duration Curves for the Lavaca River near Edna

3.10.8 Effective Discharge Calculations

SAMWin calculates the annual sediment yield by integrating the flow duration and sediment rating curves discussed in previous sections. The effective discharge is determined from analyzing the results of the "bin" computations created by SAMWin, which are output during computation of the annual sediment yield. The effective discharge is the mid-point flow of the bin (also called classes or intervals) that transports the largest sediment load. The following example describes how bin size is determined. If the minimum flow for the hydrologic period of record is 0 cfs, the maximum is 100,000 cfs, and 50 bins are chosen for the analysis, each bin would be 2,000 cfs. Bin one would bracket flows from 0 to 2,000 cfs, bin 2 from 2,000 to 4,000 cfs, and so forth until bin 50 encompasses the range from 98,000 to 100,000 cfs. There are no definite rules for selecting the bin size (or interval) to be used in the effective discharge computation (Biedenharn et al. 2000). Hey (1997) found that in rivers with a high incidence of very low flows, a large number of bins (thus small intervals) can bias the computed effective discharge towards the lowest discharge class (bin). Hey also found that in channels where the effective discharge corresponded relatively close to the bankfull flow, 25 bins produced a continuous flow frequency distribution with a smooth sediment-load histogram while using more than 25 bins produced inconsistent results. Experience has shown that in some cases, 25 bins produce unsatisfactory results and that up to 250 bins may be required (Biedenharn et al. 2000).

There is no standard method to validate or check the results of an effective discharge calculation. However, as a first step, the bed material load histogram can be analyzed to insure that the computed effective discharge does not occur in the first bin (the bin with the lowest discharge class). An effective discharge taken from the lowest discharge bin is most likely erroneous according to Biedenharn et al. (2000).

The second step to determine the reasonableness of the effective discharge computed flow value is to determine the return period of the computed value. Both Hey (1994 and 1997) and Biedenharn et al. (2000) have reported that effective discharge return periods are normally in 1–3 year return frequencies. Discharges outside the 1–3 year return frequency range should be queried (Biedenharn et al. 2000).

Effective Discharge Results

Results of the SAMWin computations show that under existing conditions the effective discharge for the three study sites are:

- Colorado River near San Saba – 14,858 cfs,
- Colorado River at Columbus – 29,907 cfs,
- Lavaca River near Edna – 3,660 cfs.

These values all fall within expected return period frequency ranges of 1–3 year return period events. Also for existing conditions, none of the effective discharges fall within the lowest discharge bin. The effective discharge at the Colorado River near San Saba and Columbus is lower than the NWS flood stage, i.e. 43,500 cfs and 45,000 cfs for the Colorado River near San Saba and at Columbus, respectively. This could be a result of natural topography or channel incision may have occurred at these sites. Channel incision is a possibility since the Colorado River upstream of both sites has been subject to reservoir construction, land use, and numerous other natural and anthropogenic changes. The NWS reports that at the Lavaca River near Edna, flows above 5,000 cfs start exceeding the lowest section of both banks. The effective discharge of 3,660 cfs fits well within the observed bankfull flow at this gage.

The existing conditions computations and plots (see Table 3.10.5, Figures 3.10.14 – 3.10.16) show that most of the bed material sediment is moved by lower pulse flows which occur a large percentage of the time. Although higher flows move higher concentrations of bed material sediments, they occur less frequently and therefore move a smaller percentage of sediment per bin. It should also be noted that the effective discharge of 29,907 cfs at the Colorado River at Columbus compares favorably with the value of 31,500 cfs obtained by BIO-WEST Inc. (2008a) as the effective discharge for this site.

Shown on the results of geomorphic overlay analysis table and the HEFR Regime flows (Figures 3.10.17 – 3.10.19) are the effective discharge values for the HEFR Regime only flows. The annual flow volumes using only the HEFR Regime flows are reduced below the historic annual flow volumes by 73% at the Colorado River near San Saba, 57% at the Colorado River at Columbus, and 86% at the Lavaca River near Edna. The bed material histograms show that the channel at all three sites would be unstable and transition to a much smaller channel under the HEFR-only regimes. Also shown in Table 3.10.5, the sediment yield would be reduced significantly at the three sites. The effective discharge at the Lavaca River near Edna is shown in the lowest discharge bin. As stated previously, this is a condition that normally raises concern about the validity of the computation. However, breaking the computation into as many as 250 bins did not move the effective discharge result away from the smallest bin. In this case, the effective discharge may be relegated to the lowest bin because of the frequency of low flows in this flow regime as well as the presence of fine bed material that can be mobilized by even low flows.

The results of the effective discharge computations for a maximum diversion rate of 10,000 cfs are shown in Table 3.10.5 and Figures 3.10.20 – 3.10.22 below. In this alternative, daily values were changed to the higher of the HEFR Regime for subsistence, base and pulse flows or to the daily flow value reduced by 10,000 cfs. This alternative reduced the effective discharge at all sites and significantly reduced water and sediment bed material yield.

The results of the effective discharge computations for the hydrologic regime that includes a maximum diversion rate corresponding to the 75th percentile flow at each site are shown in Table 3.10.5 and Figures 3.10.23 – 3.10.25. In this alternative, daily values were changed to the greater of the HEFR Regime values for subsistence, base and pulse flows or the daily flow minus the maximum diversion rate (set to the 75th percentile daily flow for the specific site). As stated previously, the 75th percentile flow for the Colorado River near San Saba is 540 cfs, 2070 cfs at the Colorado River at Columbus, and 132 cfs at the Lavaca River near Edna. This alternative reduces the effective discharge by 27% at the Colorado River near San Saba gage, 15% at the Colorado River at Columbus gage, and 0% at the Lavaca River near Edna. The hydrologic regime that includes a 75th percentile diversion rate greatly reduces water and sediment bed material yield at the stations on the Colorado River (near San Saba and Columbus), but has only a small effect on annual water and sediment bed material yield for the Lavaca River at Edna.

The results of the effective discharge computations at the Lavaca River near Edna site for a hydrologic regime with a maximum diversion rate equal to the 60th percentile flow are shown in Table 3.10.5 and Figure 3.10.26. The average daily flow values for this alternative were changed to the higher of the HEFR Regime flow values for subsistence, base, and pulse flows or the 60th percentile flow. The 60th percentile flow is 75 cfs at the Lavaca River near Edna gage. Results from analysis of this alternative agree with results from the 75th percentile flow maximum diversion rate alternative at this gage. Only small changes in effective discharge and annual water and sediment bed material yield are associated with these regimes. Time did not permit analysis of the hydrologic regime associated with the 60th percentile flow diversion rate at the other sites.

The lowest maximum diversion rate analyzed was the 30th percentile flow for the Colorado River at Columbus, which is equal to 1,080 cfs. The results for this analysis are shown in Table 3.10.5 and Figure 3.10.27. The maximum diversion rate of 1,080 cfs and protection of the HEFR Regime flow values for subsistence, base, and pulse flows reduced the effective discharge to 26,864 cfs from 29,907 cfs for existing conditions (approximately 10%). Annual bed material load and water yield were also reduced 19% and 10%, respectfully.

Table 3.10.5 Results of geomorphic overlay analysis for existing and potential future hydrologic regimes

		Avg. Annual Water Yield (ac-ft/year)	Avg. Annual Sediment Yield (tons/ year)	Effective Discharge (cfs)	Sediment Load in Effective Discharge Bin (tons)	Annual Frequency of Effective Discharge	Partial Duration Frequency of Effective Discharge
Colorado River near San Saba							
Existing		654,208	66,932	14,858	3,221	1.5	1.0
HEFR		179,841	10,844	20,790	335	ND	ND
MAX Diversion (cfs)	Percentile						
10,000	98th	262,315	28,652	9,282	978	ND	ND
540	75th	506,499	61,661	10,891	3,034	ND	ND
Colorado River at Columbus							
Existing		2,108,198	235,979	29,907	18,752	2.1	1.6
HEFR		900,217	28,384	14,632	3,473	ND	ND
MAX Diversion (cfs)	Percentile						
10,000	96th	1,143,464	118,824	19,894	9219	ND	ND
2,770	75th	1,455,153	182,202	26,543	15,673	ND	ND
1080	30th	1,711,370	210,325	26,864	16,508	ND	ND
Lavaca River at Edna							
Existing		224,984	8,725	3,660	703	1.2	0.6
HEFR		30,782	550	210	190	ND	ND
MAX Diversion (cfs)	Percentile						
10,000	99.80th	63,677	4,285	1,120	480	ND	ND
132	75th	209,116	8,329	3,656	647	ND	ND
75	60th	215,305	8,481	3,658	669	ND	ND

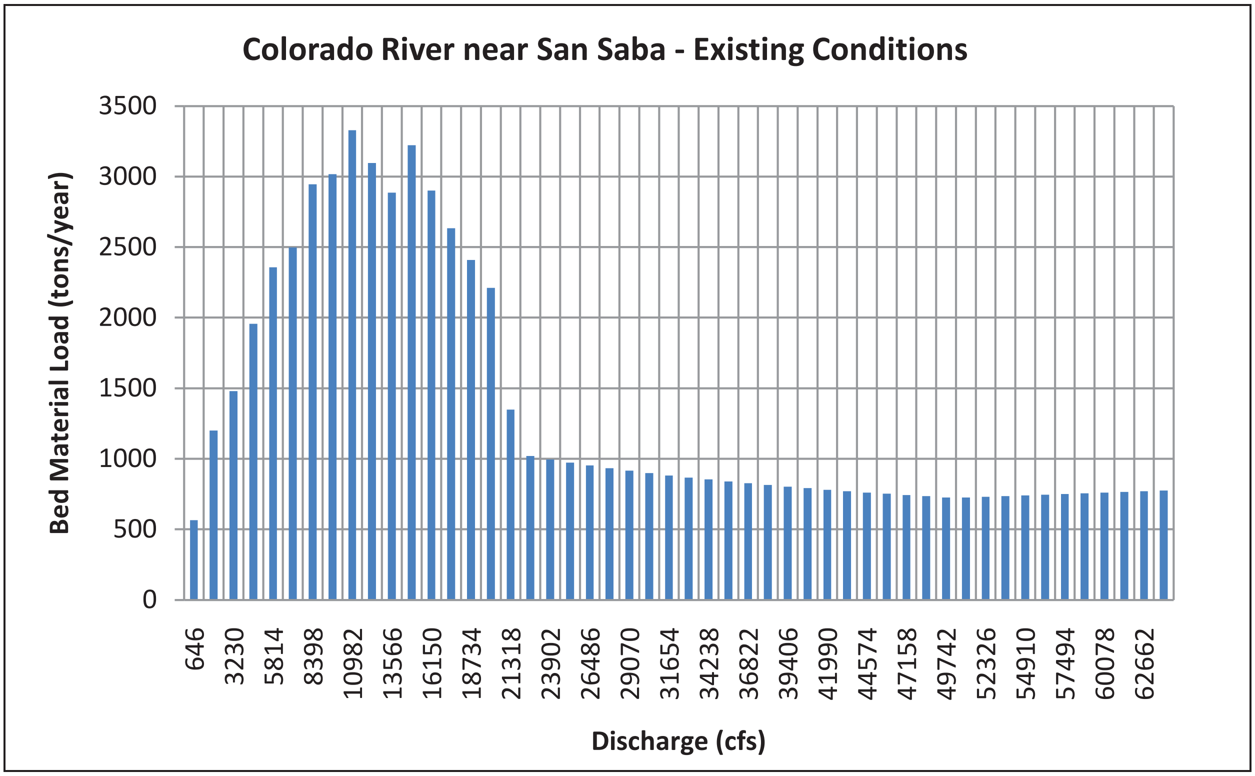


Figure 3.10.14 Existing Conditions for the Colorado River near San Saba

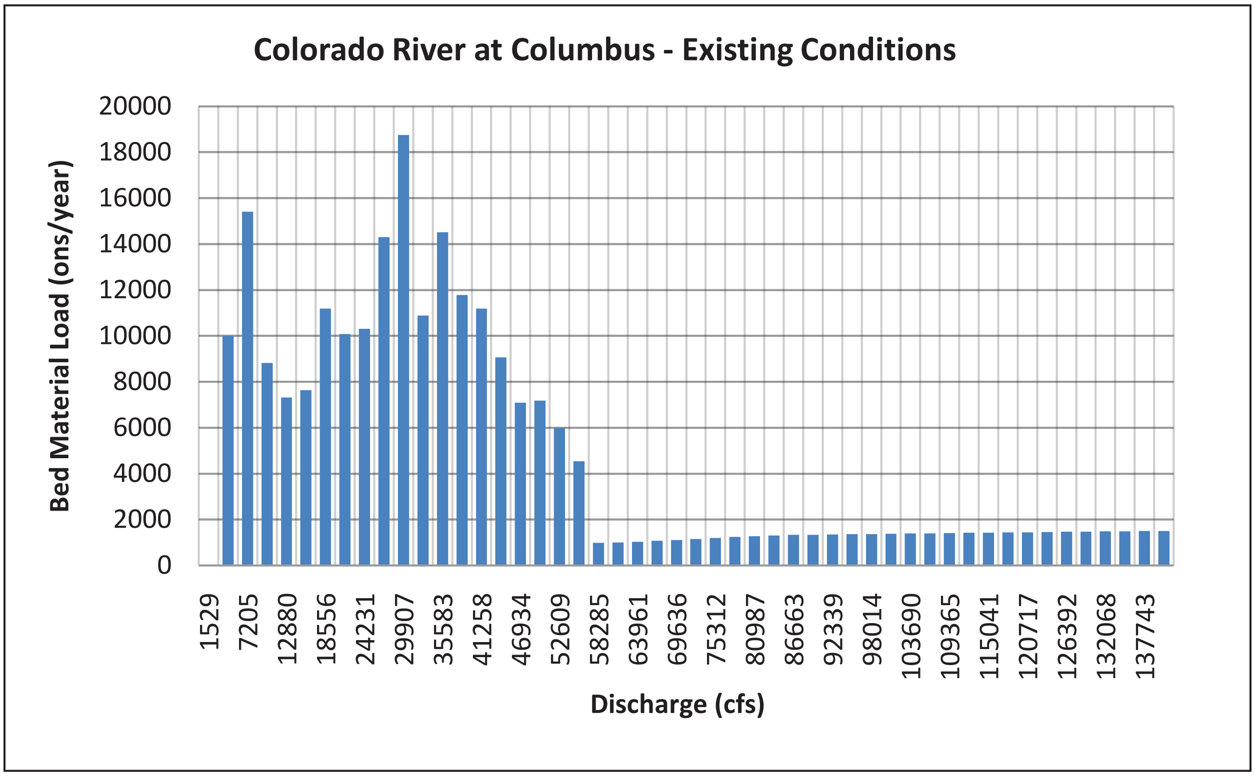


Figure 3.10.15 Existing Conditions for the Colorado River at Columbus

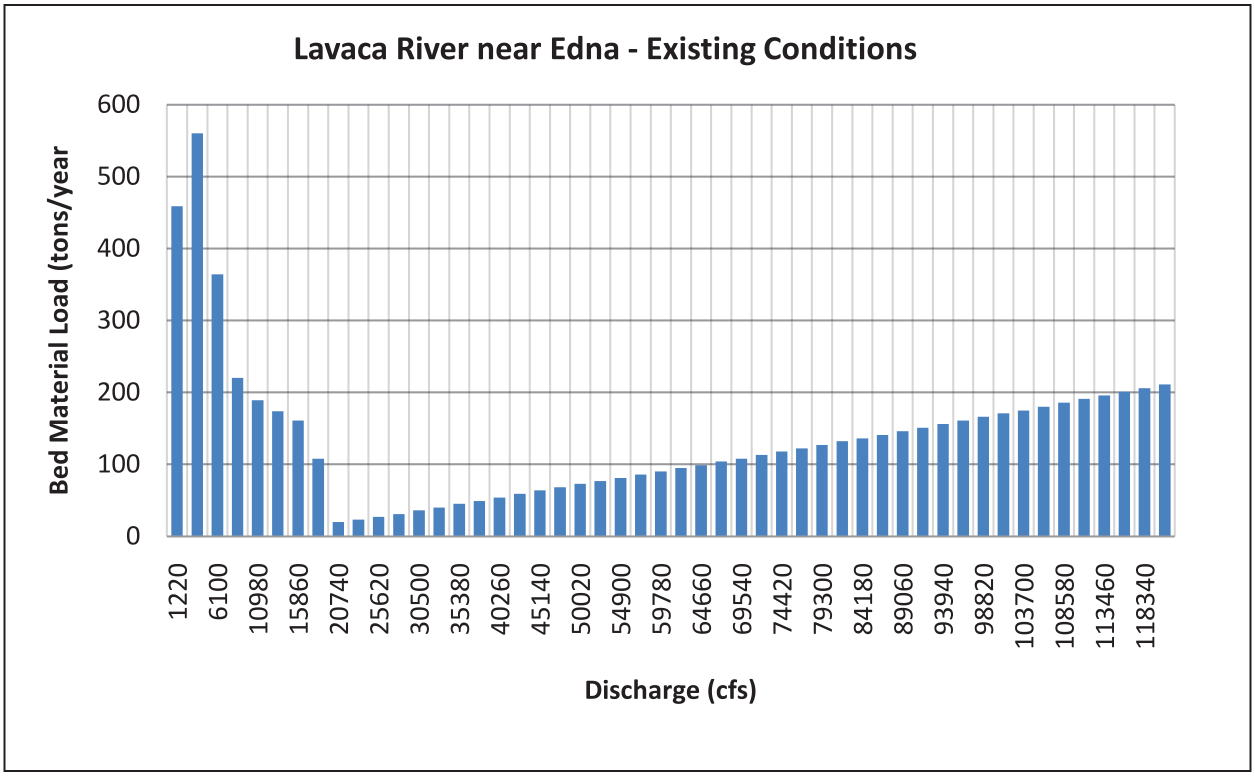


Figure 3.10.16 Existing Conditions for the Lavaca River near Edna

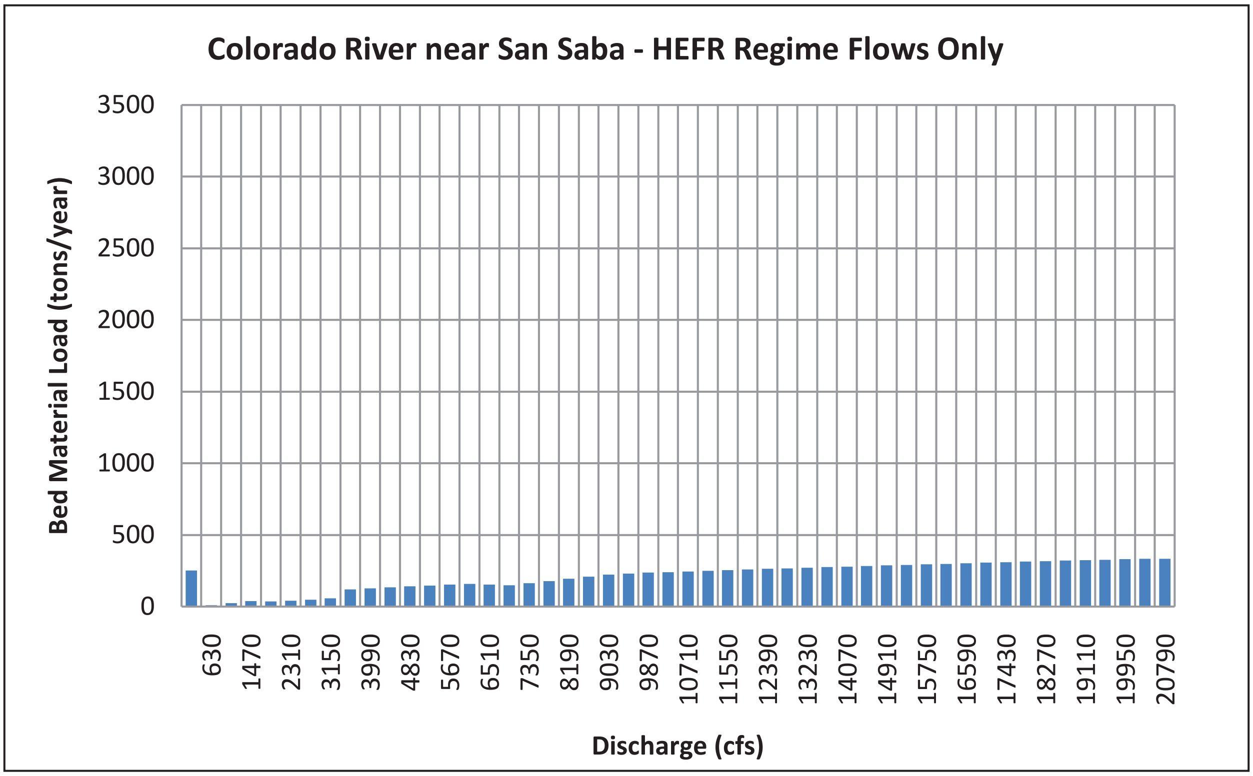


Figure 3.10.17 HEFR Regime Flows for the Colorado River near San Saba

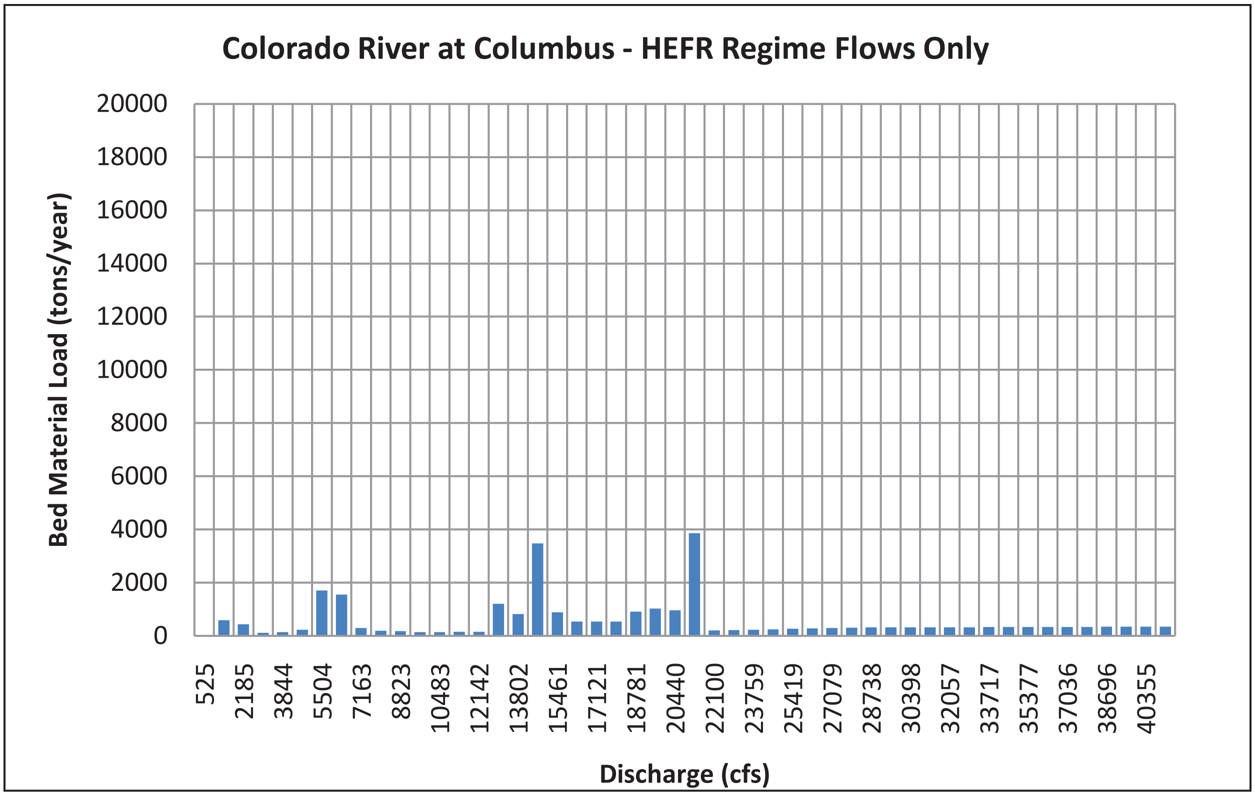


Figure 3.10.18 HEFR Regime Flows for the Colorado River at Columbus

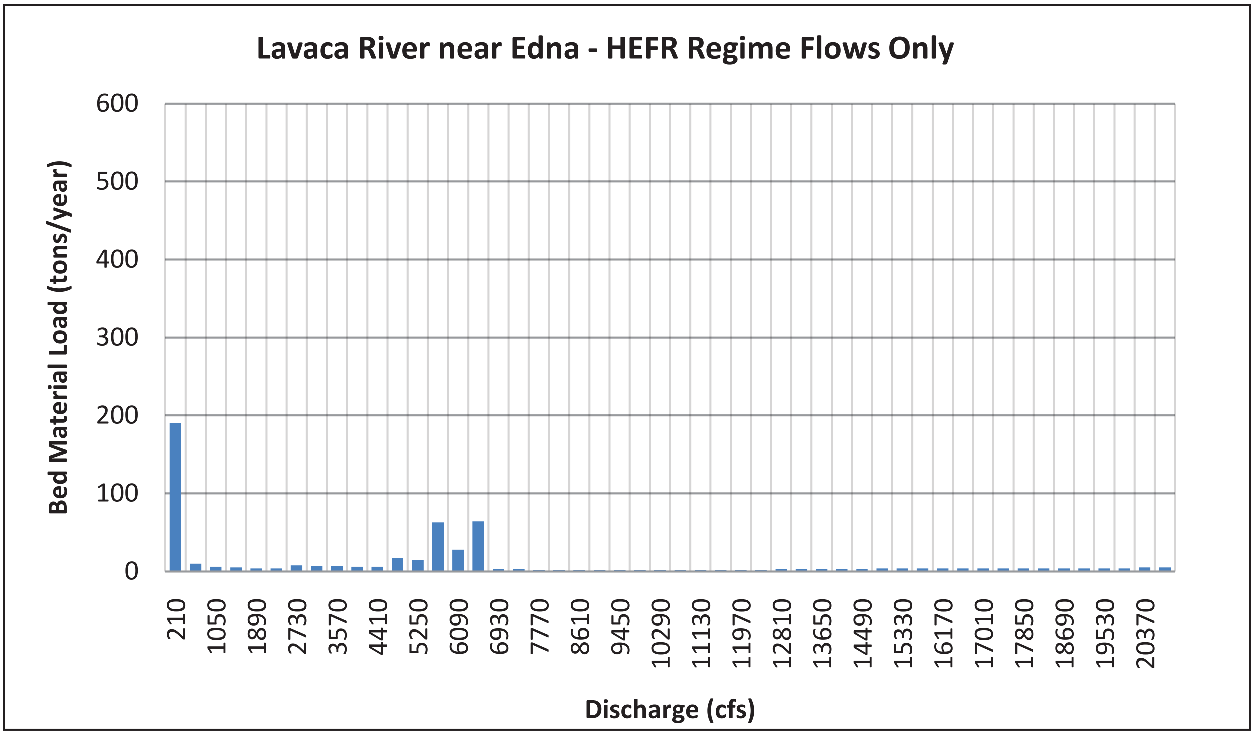


Figure 3.10.19 HEFR Regime Flows for the Lavaca River near Edna

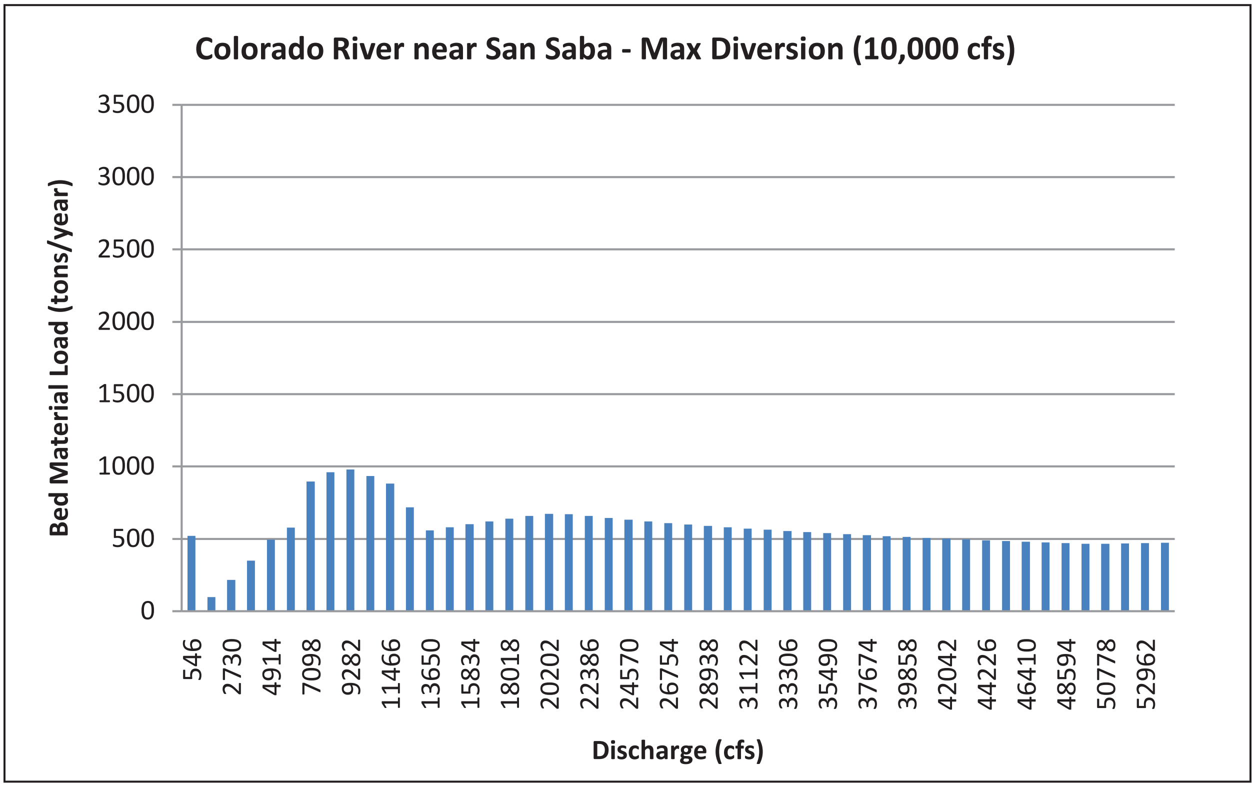


Figure 3.10.20 Maximum Diversion Rate 98th Percentile Flow (10,000 cfs) Colorado River near San Saba

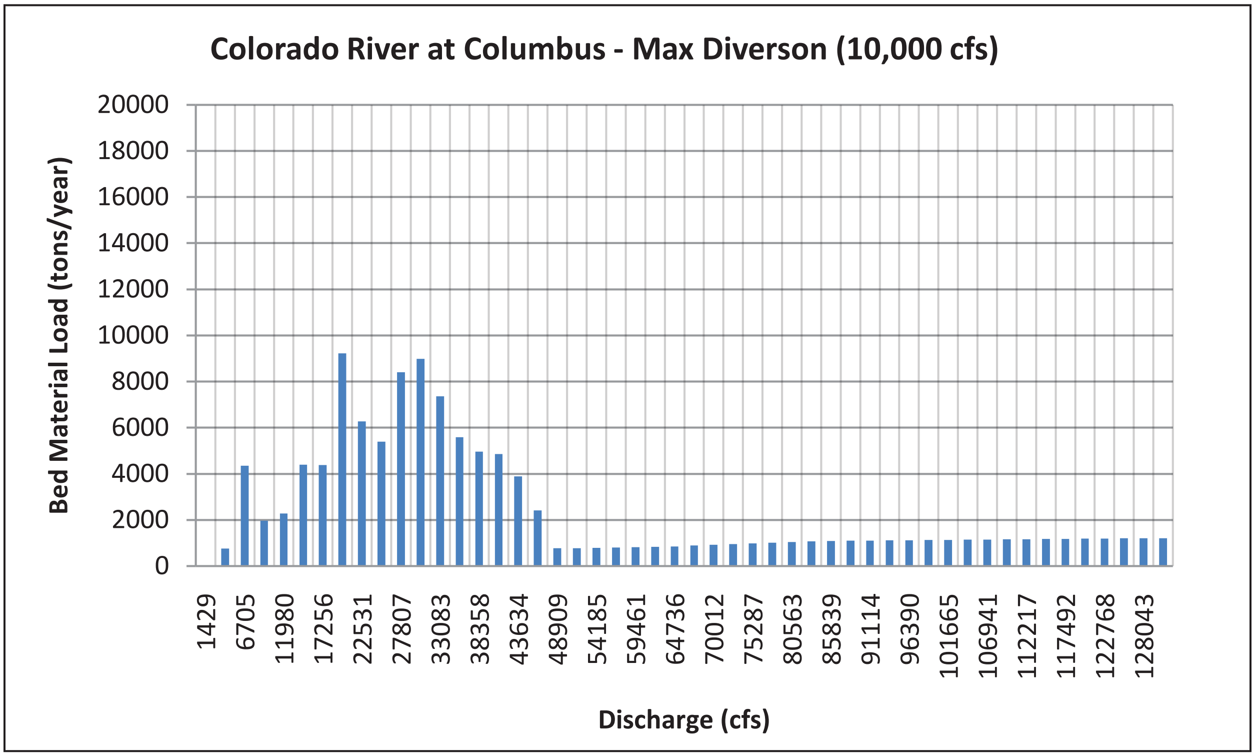


Figure 3.10.21 Maximum Diversion Rate 96th Percentile Flow (10,000 cfs) Colorado River at Columbus

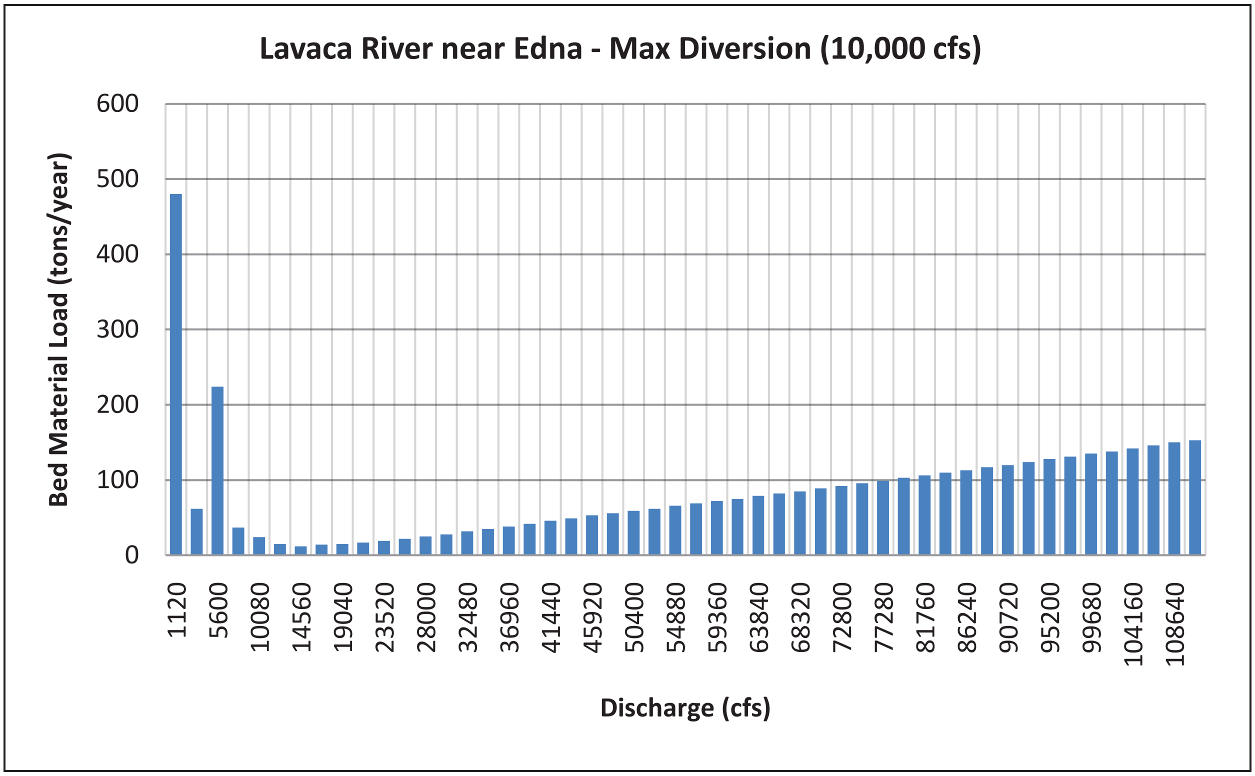


Figure 3.10.22 Maximum Diversion Rate 99.8th Percentile Flow (10,000 cfs) Lavaca River near Edna

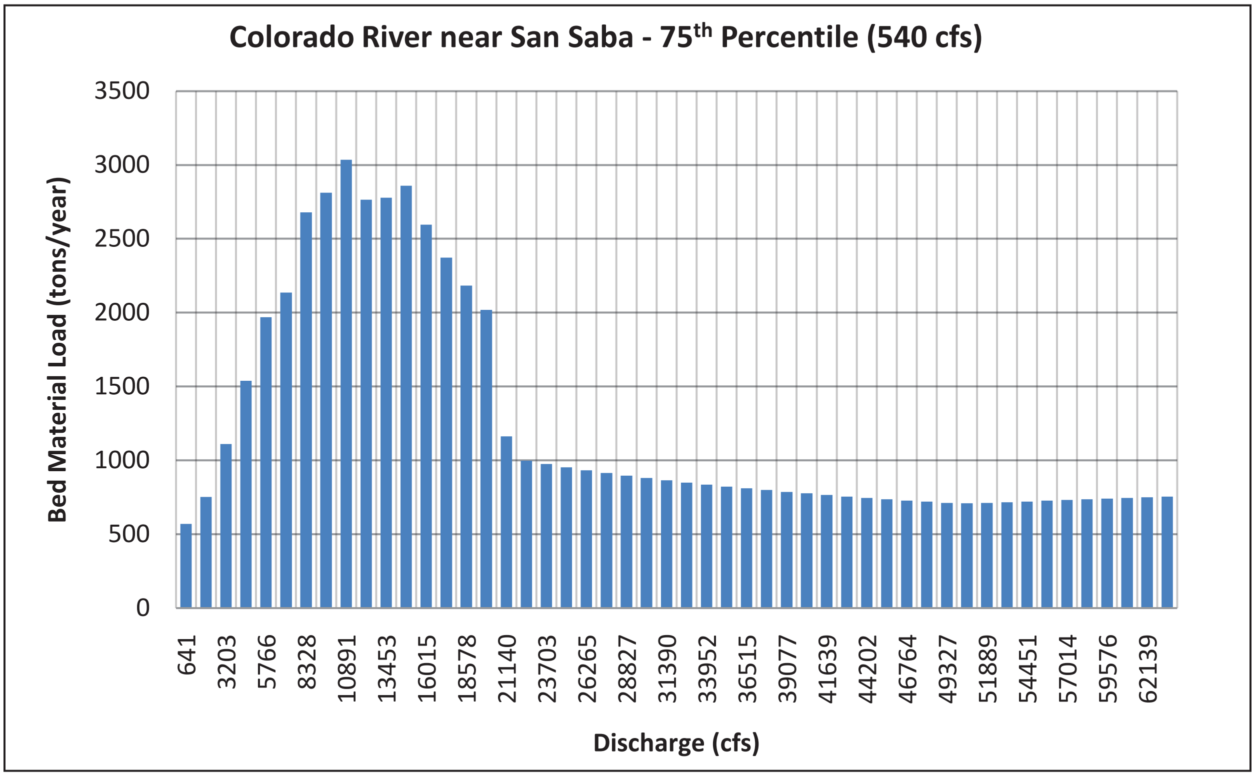


Figure 3.10.23 Maximum Diversion Rate 75th Percentile Flow for the Colorado River near San Saba

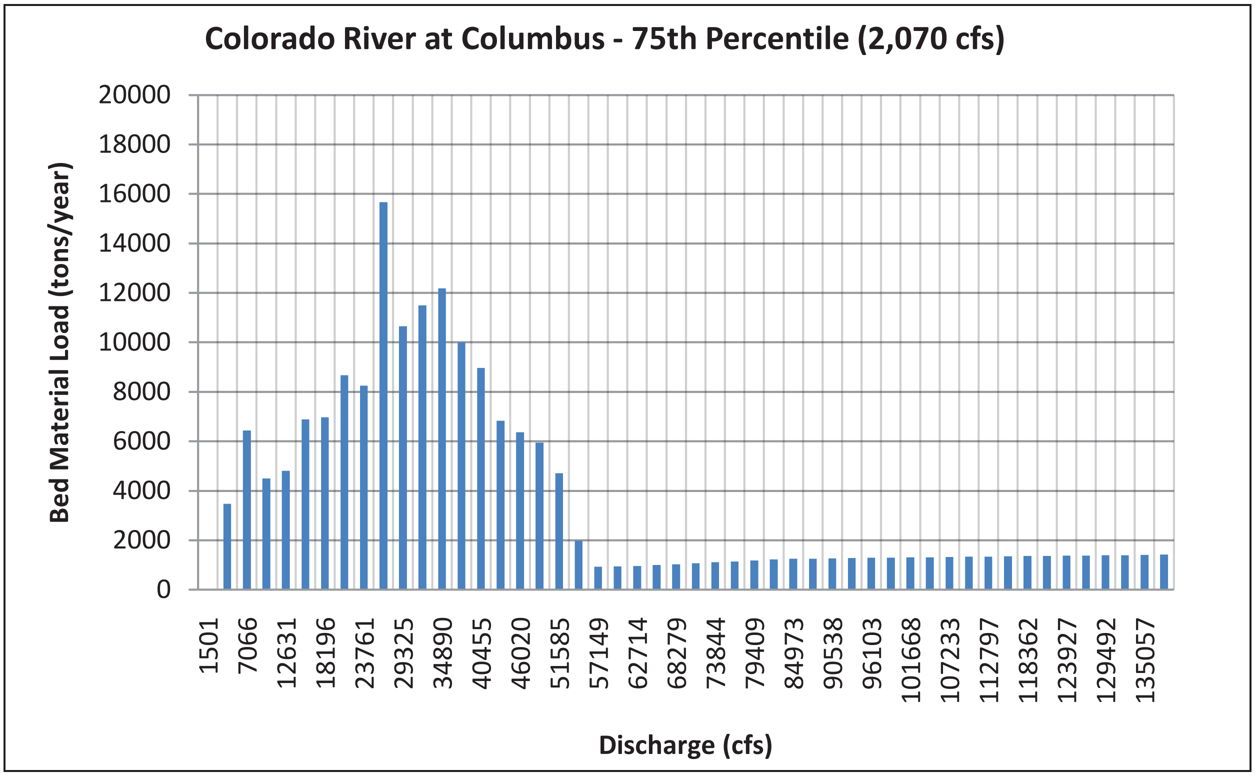


Figure 3.10.24 Maximum Diversion Rate 75th Percentile Flow for the Colorado River at Columbus

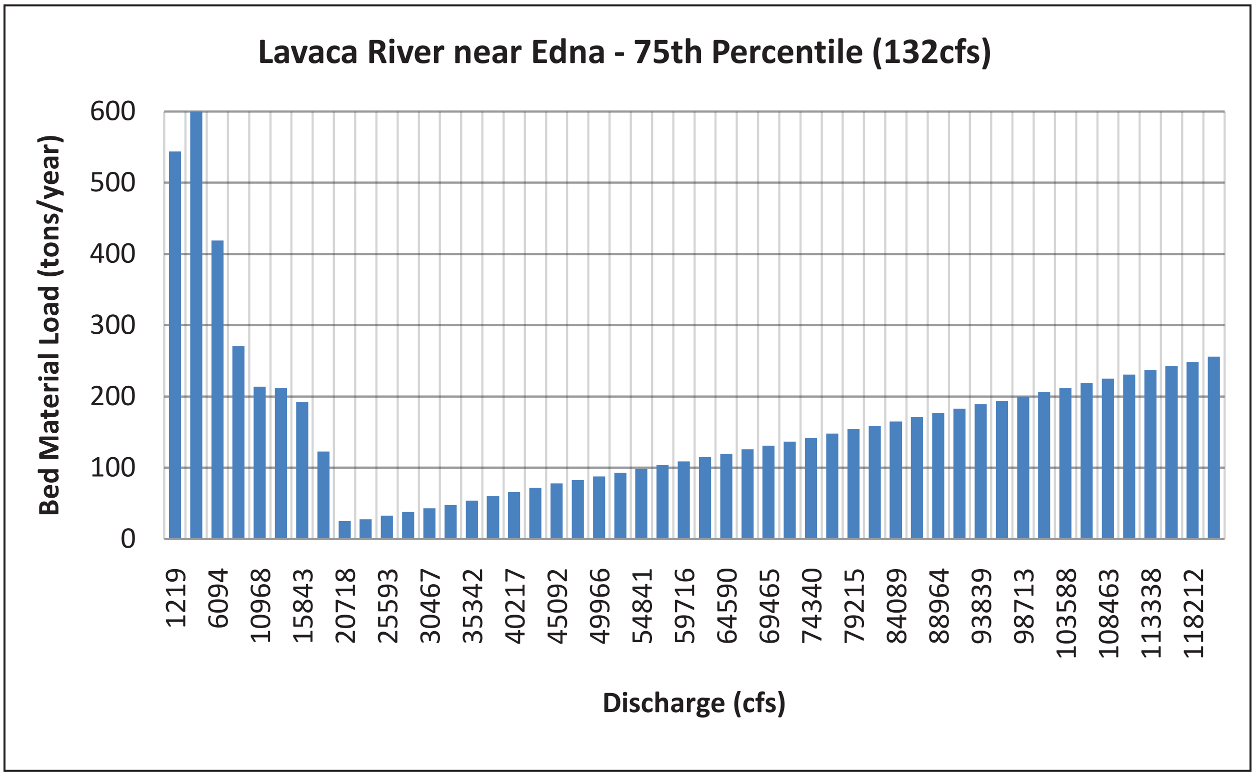


Figure 3.10.25 Maximum Diversion Rate 75th Percentile Flow for the Lavaca River near Edna

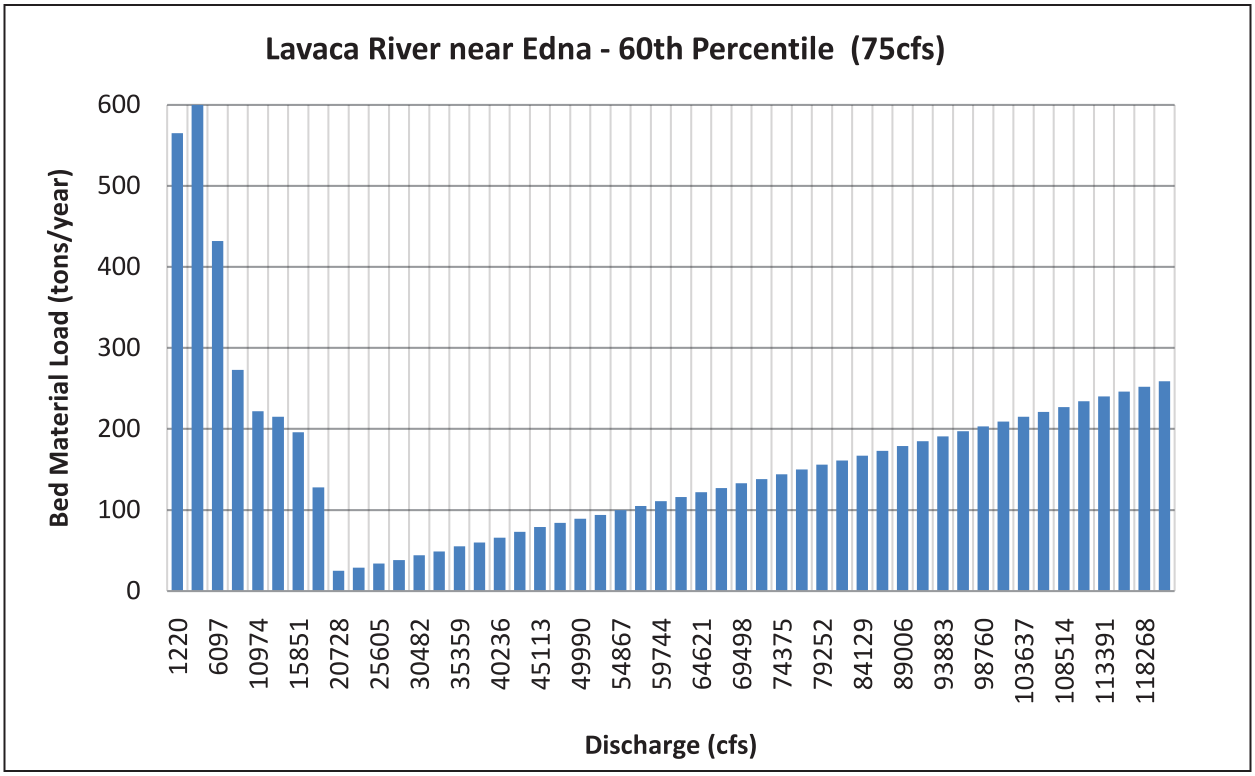


Figure 3.10.26 Maximum Diversion Rate 60th Percentile Flow for the Lavaca River near Edna

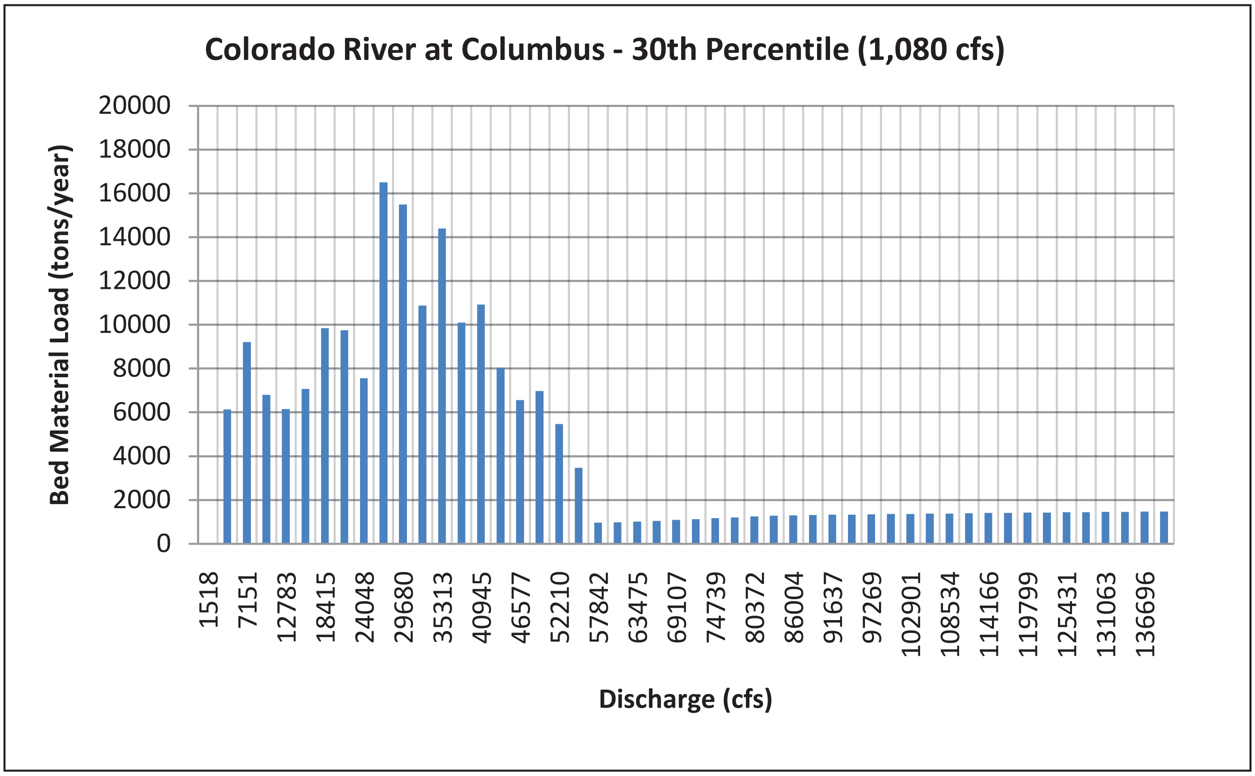


Figure 3.10.27 Maximum Diversion Rate 30th Percentile Flow for the Colorado River at Columbus

Conclusions

The effective discharge computations show:

1. The existing channels at the three sites examined during this effort all appear to be stable. Rating curves confirm the stability of the channels at the Colorado River near San Saba and Lavaca River near Edna gages. The rating curve at the Colorado River at Columbus does show a slow degradational trend that, if confirmed, may warrant monitoring during the adaptive management phase of the SB 3 process.

2. The HEFR Regime flow values for subsistence, base and pulse flows will not provide the variability and magnitude of flows needed to maintain the current channel shape (bathymetry). Use of the HEFR flows alone would result in major channel instabilities including incision in some areas and aggradation in others. Incision could cause bank failure in some areas due to over steepening of banks. Increased rates of channel meandering could occur in other areas where channel aggradation occurs. The current aquatic habitats within the river channel would not be maintained.

3. The use of a maximum diversion rate along with the HEFR Regime flow values appears capable of providing a future flow regime that maintains the channel shape (bathymetry) and thus the aquatic habitat.

4. The maximum diversion rate allowable while maintaining channel shape appears to be a function of the stream characteristics and natural hydrology. The computations show the Lavaca River near Edna could be stable if the maximum diversion rate were limited to a value as high as the 75th percentile flow, while channel stability for the Colorado River at Columbus appears to require a maximum diversion rate less than the 30th percentile flow.

5. Use of a maximum diversion rate would likely require a basin wide analysis to insure consistency of the diversion rate at each gage location along the channel.

The effective discharge and desktop computational methods provide a means to rapidly compare the geomorphic impacts of current and proposed flow regimes. In this analysis for the three sites in the Colorado-Lavaca Basin, these techniques have been utilized to the extent that they can reasonably be expected to provide useful, valid and supportable results. As noted by Shafroth et al. (2009), approaches that account for geomorphic processes (including models of sediment transport, channel migration and sediment budgets) hold great potential for advancing efforts to link flow variables and flow regime changes to changes in channel geometry, aquatic habitats, and biotic responses, thereby strengthening the scientific basis of environmental flow assessments and implementation strategies. The development of basin-wide sediment transport models should be considered in order to more accurately account for geomorphic processes during future study efforts.

To accurately model the effect of future flow regimes on the physical characteristics of a channel, the future flow regime must be accurately portrayed. The details of how environmental flow recommendations will be implemented for the Colorado-Lavaca basin are unknown at this time. Those details may greatly influence the flow regimes (particularly the pulse and overbank flow components) that are actually achieved at locations within the basin and therefore the extent to which channel change may or may not occur. Analysis of HEFR Regime flow values for subsistence, base and pulse flows at select sites in the basin has determined that these components alone would not be sufficient to maintain the current physical characteristics of the channel. Failure to maintain the physical characteristics of the channel would inherently alter the aquatic and riparian habitats within the basin. However, depending on the scheme used to implement environmental flows, there is a high probability that in the future the channel would continue to receive considerable flow in excess of the HEFR flow regime. It is unknown at present what the future flow regime may look like, and therefore, it is unknown if it would be sufficient to maintain the physical characteristics of the channel.

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4. Comparison of Stream to Bay Flow Regime Recommendations

The BBEST has made instream flow recommendations for river segments in the basin and freshwater inflow recommendations for Matagorda and Lavaca bays. The analyses performed to develop these recommendations were conducted independent of one another. Following SAC guidance, the instream flow recommendations were based on the application of overlays from different scientific disciplines to flows derived from a hydrological analysis of the historical flow regime. The freshwater inflow recommendations were based on analyses of the relationship of inflow to salinity and the salinity preferences of key estuarine organisms. While both of these approaches have the goal of identifying conditions comparable to the natural habitat of the region, these habitats are a result of the same historical flow conditions. There was no attempt during the development of the recommendations to compare the results of the instream flow analysis with the results of the freshwater inflow analysis.

Flow recommendations for rivers and bays differ in several important ways. First, the habitat response to flows is felt at different time scales. Rivers typically respond very quickly to changes in flows. Flow cessation, even for short periods, can fragment longitudinal connectivity resulting in a series of disconnected pools, which has important implications for predation and competition, and can adversely impact water quality. The effect of changes on freshwater inflows into bays and estuaries is typically slower, as saltwater gradually migrates up bays over days and weeks as freshwater inflow declines. The specific indicators of ecological health are also somewhat different between rivers and bays. While the term habitat may be used generally in both settings to describe the response variable of greatest interest during normal flow conditions, it is quantified differently in both settings. In the riverine setting, parameters of interest are typically depth and velocity, while their correlate in the bays is salinity. Extreme high and low flow conditions are also important to both systems but for somewhat different reasons.

While the analyses for rivers and bays may be performed independently, this separation is an artificial construct imposed on a system that is integrally linked. Obviously, the flows needed to protect the downstream end of the river would end up in the bay. It is therefore necessary to evaluate their consistency with one another. The time step and the natural variability of these systems allows for the possibility that these recommendations will not match exactly, although given their dependency on historical flow, recommendations that are strongly at odds with one another should elicit a re-evaluation of one or the other. It is also important to understand that a sound ecological environment for either system does not imply that any particular parameter be optimal all of the time. Natural systems have evolved to a range of variability, and while one species may benefit from a particular flow event, another may respond negatively to the same event. Nonetheless, it is prudent to evaluate consistency between instream flows and bay inflows to help support decisions that affect both parts of the system simultaneously.

The BBEST recommendations of instream flows and bay inflows were compared based on the long-term annual volumetric estimates of the riverine flow regime with the long-term average targets recommended for the bay (see table below). The estimates of volumes produced by the riverine recommendations were calculated by converting the instantaneous base flow rates and the episodic pulse events into an annual volume.

Long-term percent engagement frequencies for the base flow recommendations were set according to the 25-50-25 percent split between base high-medium-low hydrologic conditions. This mimics the approach taken by TCEQ in the draft rules for the Sabine-Neches Basin (TCEQ 2011). When pulse flow volumes are added to the base flow volumes, the numbers of pulse flow days are used to remove the corresponding base flow volume.

Long-term percent engagements for the pulse flow recommendations are presented in two separate calculations (see table below). Where every single larger pulse flow event meets all of the lower tier pulse flow requirements, the calculation is labeled as "With Replacement" to indicate that a higher pulse flow replaces the need for lower pulses. Where every single larger pulse flow event occurs independently without replacing any lower tier pulse flow requirement, the calculation is labeled as "Without Replacement." Real-world events will meet the requirements with some combination of with and without replacement. Given the number of seasonal and annual pulse events in the recommended regime, it is likely that large events will also meet at least one of the lower tier pulse requirements. This might favor the With Replacement volume estimate over time.

In the With Replacement scenario, only one annual pulse event occurs every year. This annual pulse event may be the 1 in 1-, the 1 in 2-, or the 1 in 5-year event. For example, if the 1 in 5-year event occurs, it meets the requirement for the 1 in 2- and 1 in 1-year event. The 1 in 2- or the 1 in 1-year event is engaged only when the higher tier pulse does not occur that year. The probability that the single annual event falls within any particular season is computed as the number of days per season divided by 365. For example, the winter season has 90 days. Therefore, the probability of the annual pulse falling within the winter season is 24.7%. The annual pulse will replace the 1-per-season pulse and one of the 2-per-season pulses. One of the 2-per-season pulses will always be satisfied by either the annual pulse or the 1-per-season pulse.

The calculated long-term volumes for base flows and pulse flows in the figure below are NOT an assumption that the stream actually produces this volume each year. Rather, it reflects an assumption that these inflows are being engaged with the specified frequency. The stream may produce more or less than this long-term average volume in any given year.

The Colorado River at Bay City HEFR regime is not used by the BBEST. However, it was calculated for this analysis for comparison purposes only to the long-term BBEST-recommended Matagorda Bay freshwater inflow. The BBEST recommendation was to adopt the freshwater inflow values developed in the Matagorda Bay Health study (BIO-WEST, 2008). Several freshwater inflow levels are recommended in that study (Section 2.7) including a long-term volume and variability of 1.4 to 1.5 million ac-ft per year. The value compares closely with the long-term average contribution calculated based on the HEFR estimates for the Colorado River at Bay City gage, which is 1,374,074 ac-ft per year with replacement and 1,778,565 ac-ft per year without replacement (Table 4.1).

Table 4.1 Matagorda Bay Freshwater Inflow Requirement from the Bay City Gaging Station

LONG-TERM VOLUME CALCULATION of BASEFLOW RECOMMENDATIONS		Long-Term Avg Contribution, ac-ft per season
ALL BASE	Winter	149,837
	Spring	231,799
	Summer	74,905
	Fall	131,782
	Annual	588,323

LONG-TERM VOLUME CALCULATION including SEASONAL PULSE RECOMMENDATIONS		Long-Term Avg Contribution With Replacement,	Long-Term Avg Contribution Without Replacement,
BASE + SEASONAL PULSE	Winter	204,229	264,278
	Spring	393,681	497,817
	Summer	72,090	71,514
	Fall	185,453	209,313
	Annual	855,453	1,042,922

LONG-TERM VOLUME CALCULATION including ANNUAL PULSE RECOMMENDATION	Long-Term Avg Contribution With Replacement, ac-ft per year	Long-Term Avg Contribution Without Replacement, ac-ft per year
BASE + SEASONAL PULSE + ANNUAL PULSE	1,374,074	1,778,565

Table 4.2 Lavaca Bay Freshwater Inflow Requirement from the Six Contributing Gaging Stations

LONG-TERM VOLUME CALCULATION of BASEFLOW RECOMMENDATIONS		Long-Term Avg Contribution, ac-ft per season
ALL BASE	Winter	22,227
	Spring	32,856
	Summer	16,230
	Fall	22,044
	Annual	93,357

LONG-TERM VOLUME CALCULATION including SEASONAL PULSE RECOMMENDATIONS		Long-Term Avg Contribution With Replacement,	Long-Term Avg Contribution Without Replacement,
BASE + SEASONAL PULSE	Winter	85,479	121,740
	Spring	136,387	212,479
	Summer	22,290	24,189
	Fall	84,301	118,298
	Annual	328,457	476,706

LONG-TERM VOLUME CALCULATION including ANNUAL PULSE RECOMMENDATION	Long-Term Avg Contribution With Replacement, ac-ft per year	Long-Term Avg Contribution Without Replacement, ac-ft per year
BASE + SEASONAL PULSE + ANNUAL PULSE	525,876	777,225

For Lavaca Bay, the contribution from riverine sources, based on the sum of six gages (USGS 08164000 Lavaca River near Edna, USGS 08164390 Navidad River at Strane Park near Edna, USGS 08164450 Sandy Creek near Ganado, USGS 08164503 West Mustang Creek near Ganado, USGS 08164504 E Mustang Creek near Louise, and USGS 08164600 Garcitas Creek near Inez), was used to estimate a total inflow comparable to the bay analysis based on salinity regression (Section 2.8). Similar to Matagorda Bay, the Lavaca Bay freshwater inflow regime recommendations include several levels (See Section 2.8). However, the Lavaca recommendations do not explicitly include a long-term average. Therefore, a long-term average volume for Lavaca Bay was approximated by calculating the area under the volume-exceedence curve derived from these recommended freshwater inflow volumes and their associated exceedence targets. (see Table 4.3 and Figure 4.1 below)

Table 4.3 Lavaca Bay Freshwater Inflow Regime

Lavaca Bay Freshwater Inflow Regime (LBFIR)		
Regime	Exceedance, %	Volume, ac-ft/yr
minumum	100	0
Subsistence	95	30,000
Base Low	85	122,400
Base Medium	55	284,400
Base High	35	496,800
maximum	0	1,000,000

*The curve was extended to zero ac-ft/yr with 100% exceedance as a minimum, and extended to 1,000,000 ac-ft/yr with 0% exceedance as a maximum flow.

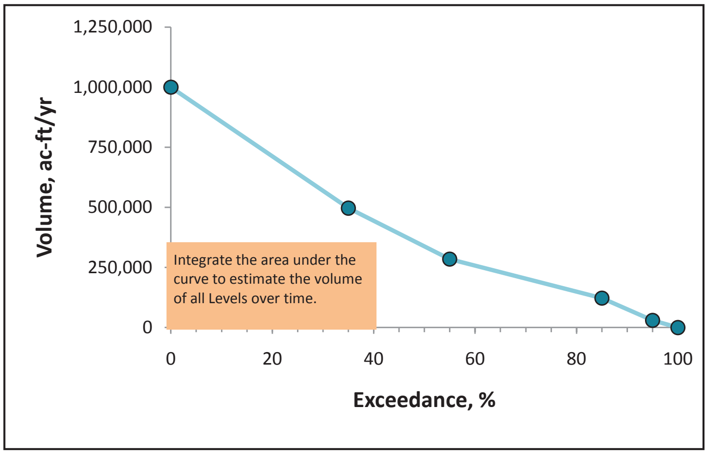

Figure 4.1 Volume-Exceedance Curve of the Lavaca Bay Freshwater Inflow Regime

Piecewise integration of the area under the volume-exceedance curve results in 409,450 ac-ft/yr. The greatest contribution to long-term volume occurs in the interval between Base High and the maximum value. Therefore, the integration is most sensitive to the maximum value and its assigned percent exceedance.

The Lavaca Bay inflow recommendation also included a 450,000 ac-ft one-month pulse, which was not considered in the integration above. This large pulse recommendation might increase the estimated long-term freshwater inflow volume depending on the assumptions chosen for event frequency and replacement of volume used to meet the Subsistence through Base High inflow regime recommendations. With the addition of this value, the Lavaca Bay inflow recommendations derived from the river and the bay also compare reasonably well with one another.

5. Preliminary Evaluation of Instream Flow Recommendations with WAMs

The TCEQ WAM System is comprised of generalized computer modeling software, input files representing a specific level of surface water right utilization for each river basin in Texas, geospatial data for each river basin, and other relevant data base files. WAMs are used to simulate the priority-order based allocation of surface water by water rights through repetition of a period of naturalized hydrology. Water availability information, among other output, is used by TCEQ staff in the evaluation of new surface water permits and amendments to existing permits. The full-authorization WAM input dataset, RUN3, is used in evaluating applications and amendments to perpetual water rights. The current conditions WAM input dataset, RUN8, is used in evaluating applications for term water rights. This section identifies which parts of the recommendations appear to be satisfied under various assumptions and which would require strategies be developed in an attempt to try to satisfy them.

5.1 Method for WAM RUN3 and RUN8 Applications

A spreadsheet process was developed for determining the extent to which output from the TCEQ WAMs meet the BBEST's final flow recommendations. Two spreadsheets were used to make this determination. The first spreadsheet calculated daily distribution factors to convert a monthly WAM-regulated flow quantity into a representation of daily regulated flows within the month. Once the daily distribution factors were determined for each site, they were input into the second spreadsheet with the monthly regulated flow from WAM and the BBEST recommendations for each of the 21 BBEST sites. In the second spreadsheet, the following logic was used to evaluate the frequency at which the recommendations were met with the WAM flows:

Non-pulse Recommendations – The number of days Subsistence, Base Low, Base Medium, and Base High are met or exceeded was counted for each of the prescribed seasons, and divided by the total number of days in each season expressed as a percentage for the period of record by season. The column labeled "AVG" for each of the non-pulse flow regimes is simply an average of the result for the four seasons.

Pulse Recommendations – The spreadsheet determined if the recommended peak flow was encountered. Once encountered, the event is counted as a qualifying event and the total numbers of events are reported for the period of record by season for the seasonal pulse recommendations or by years for all other pulse recommendations. It should be noted that once a pulse peak has been exceeded and counted, any subsequent daily flows exceeding the peak event are not counted as another qualifying event until the prescribed duration from the BBEST recommendations has ended.

5.2 Description of WAM Models

Generally, two different versions of WAM models were used to assess BBEST flow regimes under a wide range of water utilization assumptions. Each of the basic WAM models is described as follows:

TCEQ WAM RUN3

- All water rights divert the full amount they are entitled to divert.
- All reservoirs are operated at their fully authorized capacity, without regard to whether their capacity may have been reduced by sedimentation.
- Return flows are zero. (Some water right authorizations are required to return flow.)
- Prior appropriation is fully implemented. Water rights are satisfied in priority order, based on priority date, thus junior water rights cannot impound or divert water until downstream senior water rights are fully satisfied.

TCEQ WAM RUN8

- All water rights are diverting their current demand, generally based on their maximum annual reported water use for the past 10 years.
- All reservoirs are assumed to be operated at their current capacity, acknowledging reduced capacity due to sedimentation.
- Return flows are included, generally based on the minimum observed return flow occurring over the past five years.
- Prior Appropriation is fully implemented.

For the Colorado River Basin, an additional pair of WAM RUN3 and RUN8 models were used to represent the regional planning assumptions used for Regions K and F's water planning. This approach differs from the above described models in that water rights downstream of the O.H. Ivie Reservoir and Lake Brownwood dams are assumed to never make priority calls on water rights upstream of these dams even if the downstream water rights priority dates would otherwise enable them to do so.

Accordingly, all water rights upstream of these dams are operated in priority order only with respect to other water rights upstream of these dams and thus are able to impound and divert all of the water that enters the water courses upstream of these dams, to the extent their water rights will allow. This model has been described as "the cut-off model" because it results in a priority cutoff, between water rights upstream and downstream of these reservoirs. Each of these WAM models is described as follows.

TCEQ WAM RUN3 CUT-OFF Model

- Same as TCEQ RUN3 except Prior Appropriation is implemented separately within two areas in the Colorado Basin. No water right located downstream of O.H. Ivie Reservoir and Lake Brownwood is able to call on inflows from water rights upstream of these reservoirs regardless of priority dates.

TCEQ WAM RUN8 CUT-OFF Model

- Same as TCEQ RUN8 except Prior Appropriation is implemented as in TCEQ WAM RUN3 CUT-OFF MODEL (see above).

It should be noted that the WAM flow being compared to the historical flow is a quantity extracted from WAM known as regulated flow. WAM regulated flows are those flows which would be physically present at a location if viewed in the real world. WAM regulated flows are comprised of the inflows already allocated to downstream water rights or instream flow requirements, any remaining portion of the inflows that are still available for appropriation and reservoir releases traveling to downstream diversion points or to meet instream flow requirements. Regulated flows are output as a single total monthly flow value at each location in the model. Unappropriated flows can also be examined as a separate value in the WAM output. Unappropriated flows are that portion of the regulated flow that is still available for appropriation after all existing water rights have been simulated.

5.3 Comparing WAM Model Results

Note that the assumptions established in the above WAM runs often lead to results that might need a deeper explanation to be fully understood. This is especially true for the Colorado River Basin, where two different priority assumptions are represented and numerous large water rights and reservoirs are upstream of many of the BBEST sites. The following is offered as a general guideline that should be considered when making comparisons of WAM results for several of the BBEST sites.

(1) Colorado Basin – TCEQ RUN3 compared to TCEQ RUN3 CUT-OFF

The different approach to prior appropriation between the TCEQ RUN3 and the TCEQ RUN3 CUT-OFF models often results in regulated flows in TCEQ RUN3 being higher than those reported in the TCEQ RUN3 CUTOFF model. This is because many of the largest and most senior water rights are located in the lower Colorado basin. Thus, if operated on a legal priority basis, more water is passed from the upper Colorado basin to satisfy the senior rights in the lower basin. The lower basin priority calls on the upper portion of the basin result in higher flows being reported for many of the sites in the TCEQ RUN3 model as water is required to pass downstream to senior water rights in the lower basin.

(2) Colorado Basin – TCEQ RUN3 compared to TCEQ RUN8

Because the TCEQ RUN8 model does not have the fully authorized demands represented, the demands for the large senior water rights in the lower basin are not as high as they are in the TCEQ RUN3 model. As a result, the upper basin water rights do not have to pass as much water to the downstream senior water rights, even if operated on a legal priority basis. Therefore, the flows reported for some of the upper basin sites are often lower in TCEQ RUN8 than in TCEQ RUN3 due to junior water rights in the upper basin being able to impound more of the water originating upstream of their locations.

(3) All Other Basins – TCEQ RUN3 compared to TCEQ RUN8

While some water rights are located upstream of all of the BBEST sites in the Lavaca, Colorado/Lavaca, and Lavaca/Guadalupe basins, they are generally relatively small. Therefore, for many sites in those basins, there is little difference in WAM results for RUN3 verses RUN8.

5.4 Details of Comparison Process

In order to make meaningful determinations of how often the WAM results met the BBEST recommendation's historical frequencies, it was necessary to shorten the period of record for which the BBEST frequencies were evaluated so that the same hydrologic period of record could be compared with the WAMs. To accomplish this, each of the BBEST recommendations was applied to the same spreadsheet process described in section 5.1 using the actual historical flows used to derive the BBEST recommendation. The frequencies at which the non-pulse flow recommendations were met were verified. The process for counting qualifying high flow pulses as described in section 3.6 was applied so that the method for counting qualifying pulses was consistent between the historical flows the BBEST recommendations were based on and the WAM flows being analyzed. Tables 5.1 through 5.4 report comparisons of WAM flows to the non-pulse flow recommendations and Tables 5.5 though 5.8 report comparisons of WAM flows to pulse flow recommendations for the various WAM models analyzed.

Table 5.1 Summary of Colorado/Lavaca BBEST Recommendations for Non-pulse Flows Using the Various TCEQ WAM RUN3 Models

PERIOD OF RECORD FOR COLORADO WAM IS 1940-1998 (59 YEARS); LAVACA, COL/LAVACA, LAVACA/GUAD IS 1940-1996 (57 YEARS)
PERCENT OF DAYS MEETING OR EXCEEDING THE VARIOUS BBEST RECOMMENDATIONS

BBEST SITE ID INFORMATION		NON PULSE FLOWS																							
ID	USGS GAGE NAME	SUBSISTENCE						BASE LOW						BASE MED						BASE HIGH					
		WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST
1	Colorado R abv Silver (1)	92%	85%	70%	83%	82%	81%	84%	81%	70%	83%	79%	79%	74%	71%	59%	68%	68%	67%	63%	57%	47%	53%	55%	51%
2	Colorado R nr Ballinger	90%	90%	82%	89%	88%	84%	79%	82%	79%	76%	79%	75%	65%	71%	70%	69%	68%	60%	53%	60%	59%	58%	57%	46%
3	Elm Ck at Ballinger	68%	71%	55%	56%	62%	51%	68%	71%	55%	56%	62%	51%	68%	71%	55%	56%	62%	51%	47%	50%	55%	56%	52%	42%
4	South Concho R at Christoval (2)	92%	90%	93%	93%	92%	92%	65%	63%	67%	66%	65%	65%	47%	43%	43%	46%	45%	45%	30%	25%	20%	28%	26%	26%
5	Concho R at Paint Rock	93%	92%	87%	88%	90%	82%	79%	85%	87%	78%	82%	76%	61%	68%	79%	65%	68%	61%	42%	52%	67%	50%	53%	46%
6	Pecan Bayou nr Mullin	86%	90%	80%	83%	85%	70%	80%	87%	80%	80%	82%	66%	63%	72%	74%	67%	69%	53%	45%	56%	64%	54%	55%	41%
7	San Saba R at San Saba	97%	97%	87%	91%	93%	89%	85%	80%	81%	76%	80%	74%	69%	66%	66%	57%	65%	60%	48%	51%	51%	43%	48%	44%
8	Colorado R nr San Saba	97%	96%	95%	96%	96%	92%	86%	84%	87%	80%	84%	76%	68%	70%	75%	66%	70%	60%	49%	47%	54%	53%	51%	44%
9	Llano R at Llano	92%	90%	73%	84%	85%	84%	80%	74%	68%	72%	74%	72%	60%	56%	55%	58%	57%	57%	44%	44%	40%	39%	42%	42%
10	Pedernales R. nr Johnson City	94%	95%	79%	89%	89%	89%	77%	77%	60%	71%	71%	72%	59%	59%	46%	53%	54%	55%	39%	41%	31%	37%	37%	37%
11	Onion Ck near Driftwood (3)	89%	96%	83%	71%	85%	83%	83%	86%	83%	71%	80%	79%	62%	67%	62%	54%	61%	61%	40%	50%	46%	37%	43%	44%
12	Colorado R at Bastrop	78%	97%	100%	94%	92%	94%	62%	95%	100%	80%	84%	89%	NOT APPLICABLE						43%	80%	97%	64%	71%	82%
13	Colorado R at Columbus	75%	96%	100%	96%	91%	95%	60%	87%	100%	77%	81%	88%							40%	64%	97%	59%	65%	77%
14	Colorado R at Wharton	84%	93%	99%	95%	93%	99%	66%	57%	86%	67%	69%	88%							46%	40%	59%	42%	47%	71%
15	Colorado R nr Bay City	FOR B&E USE - NO INSTREAM FLOW RECOMMENDATIONS MADE BY BBEST FOR THIS SITE																							
16	West Mustang Creek nr Ganado	89%	87%	78%	88%	85%	93%	76%	73%	47%	72%	67%	74%	65%	55%	34%	56%	53%	58%	46%	39%	21%	42%	37%	41%
17	East Mustang Creek nr Louise	80%	82%	76%	81%	80%	82%	80%	82%	66%	81%	77%	81%	72%	63%	44%	66%	61%	62%	56%	45%	32%	48%	45%	44%
18	Navidad nr Edna	92%	94%	77%	89%	88%	92%	78%	78%	57%	70%	71%	75%	55%	63%	39%	53%	53%	60%	39%	46%	25%	34%	36%	43%
19	Sandy Creek nr Ganado	80%	65%	44%	79%	67%	90%	68%	58%	32%	61%	55%	74%	55%	45%	21%	44%	41%	57%	42%	32%	14%	29%	29%	40%
20	Lavaca nr Edna	84%	89%	70%	73%	79%	81%	73%	76%	65%	66%	70%	73%	55%	60%	47%	50%	53%	55%	38%	42%	35%	34%	37%	39%
21	Tres Palacios nr Midfield	80%	83%	42%	64%	67%	72%	73%	76%	42%	64%	64%	68%	61%	65%	30%	51%	51%	54%	51%	45%	19%	44%	40%	40%
22	Garcitas Creek nr Inez	91%	89%	55%	79%	78%	82%	84%	79%	55%	79%	74%	76%	66%	62%	44%	66%	60%	59%	50%	47%	33%	44%	44%	42%

SHADED CELLS INDICATE THAT THE WAM FLOW FREQUENCY WAS LESS THAN THE HISTORICAL FLOW FREQUENCY BY MORE THAN 1% FOR ALL SEASONS OVER THE SAME PERIOD OF RECORD.
"HIST" MEANS HISTORICAL FREQUENCY BBEST RECOMMENDATIONS WERE MET DURING THE WAM MODEL'S PERIOD OF RECORD.
(1) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1957-1998.
(2) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1940-1994.
(3) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1980-1998.

Table 5.2 Summary of Colorado/Lavaca BBEST Recommendations for Non-pulse Flows Using the Various TCEQ WAM RUN8 Models

PERIOD OF RECORD FOR COLORADO WAM IS 1940-1998 (59 YEARS); LAVACA, COL/LAVACA, LAVACA/GUAD IS 1940-1996 (57 YEARS)
PERCENT OF DAYS MEETING OR EXCEEDING THE VARIOUS BBEST RECOMMENDATIONS

BBEST SITE ID INFORMATION		NON PULSE FLOWS																							
ID	USGS GAGE NAME	SUBSISTENCE						BASE LOW						BASE MED						BASE HIGH					
		WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST
1	Colorado R abv Silver (1)	73%	74%	59%	70%	69%	81%	65%	68%	59%	70%	66%	79%	53%	56%	48%	56%	53%	67%	40%	42%	36%	42%	40%	51%
2	Colorado R nr Ballinger	87%	85%	76%	83%	83%	84%	74%	77%	72%	72%	74%	75%	58%	65%	62%	62%	62%	60%	46%	52%	50%	50%	49%	46%
3	Elm Ck at Ballinger	68%	70%	54%	55%	62%	51%	68%	70%	54%	55%	62%	51%	68%	70%	54%	55%	62%	51%	48%	49%	54%	55%	52%	42%
4	South Concho R at Christoval (2)	93%	92%	92%	92%	92%	92%	67%	65%	65%	65%	65%	65%	51%	44%	42%	49%	46%	45%	31%	26%	21%	28%	26%	26%
5	Concho R at Paint Rock	91%	90%	84%	86%	88%	82%	78%	82%	84%	73%	79%	76%	65%	63%	74%	59%	65%	61%	44%	45%	58%	46%	48%	46%
6	Pecan Bayou nr Mullin	97%	93%	82%	90%	90%	70%	96%	91%	82%	88%	89%	66%	89%	78%	75%	79%	80%	53%	74%	59%	66%	65%	66%	41%
7	San Saba R at San Saba	97%	97%	88%	91%	93%	89%	86%	81%	80%	76%	81%	74%	70%	67%	63%	60%	65%	60%	50%	51%	50%	45%	49%	44%
8	Colorado R nr San Saba	97%	95%	94%	94%	95%	92%	84%	79%	83%	73%	80%	76%	62%	63%	69%	55%	62%	60%	45%	43%	48%	42%	44%	44%
9	Llano R at Llano	92%	90%	73%	85%	85%	84%	81%	75%	68%	72%	74%	72%	61%	57%	56%	59%	58%	57%	44%	45%	40%	40%	42%	42%
10	Pedernales R. nr Johnson City	94%	96%	81%	90%	90%	89%	78%	78%	61%	72%	72%	72%	60%	59%	46%	53%	55%	55%	39%	41%	31%	37%	37%	37%
11	Onion Ck near Driftwood (3)	88%	96%	82%	69%	84%	83%	80%	84%	82%	69%	79%	79%	61%	66%	60%	50%	59%	61%	40%	49%	45%	36%	43%	44%
12	Colorado R at Bastrop	91%	97%	100%	97%	96%	94%	73%	96%	100%	89%	90%	89%	NOT APPLICABLE						54%	84%	98%	72%	77%	82%
13	Colorado R at Columbus	84%	96%	100%	98%	95%	95%	65%	87%	100%	82%	83%	88%							49%	65%	97%	62%	68%	77%
14	Colorado R at Wharton	91%	93%	100%	98%	95%	99%	69%	57%	81%	72%	70%	88%							53%	43%	43%	45%	46%	71%
15	Colorado R nr Bay City	FOR B&E USE - NO INSTREAM FLOW RECOMMENDATIONS MADE BY BBEST FOR THIS SITE																							
16	West Mustang Creek nr Ganado	89%	97%	99%	95%	95%	93%	76%	87%	93%	84%	85%	74%	65%	72%	86%	73%	74%	58%	46%	54%	74%	59%	58%	41%
17	East Mustang Creek nr Louise	80%	83%	77%	81%	80%	82%	80%	83%	68%	81%	78%	81%	72%	64%	48%	66%	63%	62%	56%	46%	37%	48%	47%	44%
18	Navidad nr Edna	92%	94%	77%	89%	88%	92%	78%	79%	56%	70%	71%	75%	55%	63%	38%	53%	52%	60%	39%	46%	24%	34%	36%	43%
19	Sandy Creek nr Ganado	80%	86%	96%	88%	87%	90%	68%	80%	92%	70%	78%	74%	55%	68%	88%	58%	67%	57%	42%	54%	79%	48%	56%	40%
20	Lavaca nr Edna	85%	89%	68%	74%	79%	81%	74%	76%	61%	67%	70%	73%	56%	60%	45%	51%	53%	55%	38%	42%	33%	35%	37%	39%
21	Tres Palacios nr Midfield	84%	87%	82%	76%	82%	72%	76%	80%	82%	76%	78%	68%	64%	68%	54%	56%	61%	54%	53%	48%	30%	47%	44%	40%
22	Garcitas Creek nr Inez	91%	89%	55%	79%	78%	82%	84%	79%	55%	79%	74%	76%	66%	62%	44%	66%	60%	59%	50%	47%	33%	44%	44%	42%

SHADED CELLS INDICATE THAT THE WAM FLOW FREQUENCY WAS LESS THAN THE HISTORICAL FLOW FREQUENCY BY MORE THAN 1% FOR ALL SEASONS OVER THE SAME PERIOD OF RECORD.
"HIST" MEANS HISTORICAL FREQUENCY BBEST RECOMMENDATIONS WERE MET DURING THE WAM MODEL'S PERIOD OF RECORD.
(1) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1957-1998.
(2) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1940-1994.
(3) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1980-1998.

Table 5.3 Summary of Colorado/Lavaca BBEST Recommendations for Non-pulse Flows Using the TCEQ WAM RUN3 CUT-OFF Model

PERIOD OF RECORD FOR COLORADO WAM IS 1940-1998 (59 YEARS)
PERCENT OF DAYS MEETING OR EXCEEDING THE VARIOUS BBEST RECOMMENDATIONS

BBEST SITE ID INFORMATION		NON PULSE FLOWS																							
ID	USGS GAGE NAME	SUBSISTENCE						BASE LOW						BASE MED						BASE HIGH					
		WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST
1	Colorado R abv Silver (1)	90%	82%	66%	80%	79%	81%	82%	77%	66%	80%	76%	79%	69%	66%	53%	62%	62%	67%	55%	47%	39%	45%	46%	51%
2	Colorado R nr Ballinger	75%	73%	62%	66%	69%	84%	56%	63%	51%	49%	55%	75%	41%	46%	30%	35%	38%	60%	32%	34%	21%	27%	28%	46%
3	Elm Ck at Ballinger	65%	67%	43%	50%	56%	51%	65%	67%	43%	50%	56%	51%	65%	67%	43%	50%	56%	51%	45%	46%	43%	50%	46%	42%
4	South Concho R at Christoval (2)	90%	89%	92%	92%	91%	92%	65%	62%	58%	59%	61%	65%	46%	41%	38%	45%	43%	45%	30%	25%	19%	27%	25%	26%
5	Concho R at Paint Rock	84%	82%	65%	74%	76%	82%	59%	69%	65%	57%	62%	76%	38%	44%	50%	38%	43%	61%	17%	25%	31%	19%	23%	46%
6	Pecan Bayou nr Mullin	86%	89%	74%	78%	82%	70%	79%	85%	74%	73%	78%	66%	62%	67%	65%	58%	63%	53%	45%	49%	50%	44%	47%	41%
7	San Saba R at San Saba	97%	97%	89%	93%	94%	89%	85%	82%	82%	78%	82%	74%	69%	68%	69%	58%	66%	60%	49%	52%	54%	44%	50%	44%
8	Colorado R nr San Saba	94%	91%	87%	90%	91%	92%	79%	72%	69%	63%	71%	76%	55%	54%	52%	46%	51%	60%	37%	36%	28%	34%	34%	44%
9	Llano R at Llano	92%	90%	75%	84%	85%	84%	80%	75%	70%	73%	74%	72%	60%	56%	57%	58%	58%	57%	44%	44%	41%	40%	42%	42%
10	Pedernales R. nr Johnson City	94%	95%	79%	89%	89%	89%	77%	77%	60%	71%	71%	72%	59%	59%	46%	53%	54%	55%	39%	41%	31%	37%	37%	37%
11	Onion Ck near Driftwood (3)	89%	96%	83%	71%	85%	83%	83%	86%	83%	71%	80%	79%	62%	67%	62%	53%	61%	61%	40%	50%	46%	37%	43%	44%
12	Colorado R at Bastrop	73%	95%	100%	91%	90%	94%	57%	89%	94%	72%	78%	89%	NOT APPLICABLE						41%	67%	66%	53%	57%	82%
13	Colorado R at Columbus	73%	90%	97%	91%	88%	95%	58%	72%	75%	67%	68%	88%							39%	51%	48%	46%	46%	77%
14	Colorado R at Wharton	82%	82%	59%	84%	77%	99%	64%	53%	33%	54%	51%	88%							45%	39%	24%	35%	36%	71%
15	Colorado R nr Bay City	FOR B&E USE - NO INSTREAM FLOW RECOMMENDATIONS MADE BY BBEST FOR THIS SITE																							

SHADED CELLS INDICATE THAT THE WAM FLOW FREQUENCY WAS LESS THAN THE HISTORICAL FLOW FREQUENCY BY MORE THAN 1% FOR ALL SEASONS OVER THE SAME PERIOD OF RECORD.
"HIST" MEANS HISTORICAL FREQUENCY BBEST RECOMMENDATIONS WERE MET DURING THE WAM MODEL'S PERIOD OF RECORD.
(1) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1957-1998.
(2) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1940-1994.
(3) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1980-1998.

Table 5.4 Summary of Colorado/Lavaca BBEST Recommendations for Non-pulse Flows Using the TCEQ WAM RUN8 CUT-OFF Model

PERIOD OF RECORD FOR COLORADO WAM IS 1940-1998 (59 YEARS)
PERCENT OF DAYS MEETING OR EXCEEDING THE VARIOUS BBEST RECOMMENDATIONS

BBEST SITE ID INFORMATION		NON PULSE FLOWS																							
ID	USGS GAGE NAME	SUBSISTENCE						BASE LOW						BASE MED						BASE HIGH					
		WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST
1	Colorado R abv Silver (1)	71%	73%	56%	69%	67%	81%	63%	68%	56%	69%	64%	79%	51%	55%	45%	53%	51%	67%	38%	41%	33%	40%	38%	51%
2	Colorado R nr Ballinger	83%	83%	63%	75%	76%	84%	71%	76%	60%	66%	68%	75%	56%	62%	51%	54%	56%	60%	44%	49%	40%	43%	44%	46%
3	Elm Ck at Ballinger	68%	69%	44%	51%	58%	51%	68%	69%	44%	51%	58%	51%	68%	69%	44%	51%	58%	51%	47%	49%	44%	51%	48%	42%
4	South Concho R at Christoval (2)	92%	90%	92%	92%	92%	92%	67%	65%	62%	64%	64%	65%	51%	43%	41%	49%	46%	45%	31%	26%	20%	28%	26%	26%
5	Concho R at Paint Rock	88%	86%	66%	79%	80%	82%	73%	77%	66%	65%	70%	76%	58%	57%	55%	50%	55%	61%	40%	39%	36%	34%	37%	46%
6	Pecan Bayou nr Mullin	97%	93%	79%	89%	90%	70%	96%	91%	79%	87%	88%	66%	89%	77%	73%	78%	79%	53%	74%	57%	63%	64%	65%	41%
7	San Saba R at San Saba	97%	97%	88%	91%	93%	89%	86%	81%	81%	76%	81%	74%	70%	68%	66%	60%	66%	60%	50%	52%	52%	46%	50%	44%
8	Colorado R nr San Saba	97%	91%	88%	91%	92%	92%	83%	73%	68%	65%	72%	76%	61%	55%	51%	49%	54%	60%	41%	37%	29%	37%	36%	44%
9	Llano R at Llano	92%	90%	74%	85%	85%	84%	81%	75%	69%	73%	74%	72%	61%	57%	57%	59%	58%	57%	44%	45%	41%	40%	43%	42%
10	Pedernales R. nr Johnson City	94%	96%	81%	90%	90%	89%	79%	78%	61%	72%	72%	72%	60%	60%	47%	54%	55%	55%	39%	41%	32%	37%	37%	37%
11	Onion Ck near Driftwood (3)	89%	96%	82%	69%	84%	83%	81%	84%	82%	69%	79%	79%	61%	67%	61%	51%	60%	61%	40%	49%	46%	36%	43%	44%
12	Colorado R at Bastrop	90%	97%	100%	97%	96%	94%	72%	95%	100%	88%	89%	89%	NOT APPLICABLE						53%	82%	98%	71%	76%	82%
13	Colorado R at Columbus	84%	95%	100%	99%	94%	95%	64%	86%	100%	82%	83%	88%							48%	62%	97%	61%	67%	77%
14	Colorado R at Wharton	90%	91%	100%	98%	95%	99%	69%	55%	79%	70%	68%	88%							53%	42%	42%	44%	45%	71%
15	Colorado R nr Bay City	FOR B&E USE - NO INSTREAM FLOW RECOMMENDATIONS MADE BY BBEST FOR THIS SITE																							

SHADED CELLS INDICATE THAT THE WAM FLOW FREQUENCY WAS LESS THAN THE HISTORICAL FLOW FREQUENCY BY MORE THAN 1% FOR ALL SEASONS OVER THE SAME PERIOD OF RECORD.
"HIST" MEANS HISTORICAL FREQUENCY BBEST RECOMMENDATIONS WERE MET DURING THE WAM MODEL'S PERIOD OF RECORD.
(1) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1957-1998.
(2) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1940-1994.
(3) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1980-1998.

Table 5.5 Summary of Colorado/Lavaca BBEST Recommendations for Pulse Flows Using the Various TCEQ WAM RUN3 Models

PERIOD OF RECORD FOR COLORADO WAM IS 1940-1998 (59 YEARS); LAVACA, COL/LAVACA, LAVACA/GUAD IS 1940-1996 (57 YEARS)
NUMBER OF EVENTS (FOR THE PERIOD OF RECORD) MEETING OR EXCEEDING THE VARIOUS BBEST RECOMMENDATIONS

BBEST SITE ID INFORMATION		PULSE FLOWS																									
		SEASONAL PULSE RECOMMENDATIONS												ANNUAL PULSE RECOMMENDATIONS													
ID	USGS GAGE NAME	2 PER SEASON						1 PER SEASON						REGULAR LOCATIONS						LSWP ADOPTED LOCATIONS							
		WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST	1PY	HIST	1P2Y	HIST	1P5Y	HIST	8PY	HIST	2P3Y	HIST	1P3Y	HIST	OB	HIST
1	Colorado R abv Silver (1)	91	71	79	67	77	71	58	35	43	41	44	40	37	31	23	21	13	10	NOT APPLICABLE							
2	Colorado R nr Ballinger	99	95	128	90	103	89	63	55	56	48	56	46	69	54	40	29	15	13								
3	Elm Ck at Ballinger	91	90	111	75	92	84	51	48	55	43	49	50	50	50	26	26	13	14								
4	South Concho R at Christoval (2)	NA	NA	NA	NA	NA	NA	NA	NA	NA	40	40	40	47	47	22	22	9	9								
5	Concho R at Paint Rock	88	97	142	93	105	98	48	54	110	52	66	53	54	49	21	20	8	10								
6	Pecan Bayou nr Mullin	91	108	162	124	121	95	54	54	105	55	67	48	61	45	27	21	10	8								
7	San Saba R at San Saba	94	96	NA	80	90	84	58	46	61	41	52	49	36	37	25	26	15	15								
8	Colorado R nr San Saba	112	80	145	97	109	101	47	41	73	45	52	53	34	43	14	21	6	12								
9	Llano R at Llano	86	72	NA	89	82	84	40	36	48	38	41	42	42	43	28	29	12	13								
10	Pedernales R. nr Johnson City	99	83	NA	96	93	92	42	45	51	44	46	46	46	46	27	27	10	11								
11	Onion Ck near Driftwood (3)	NA	31	NA	28	30	31	16	15	NA	10	14	14	14	14	7	7	3	3								
12	Colorado R at Bastrop	NOT APPLICABLE																		332	550	89	128	27	31	14	20
13	Colorado R at Columbus																			480	587	196	280	49	64	34	45
14	Colorado R at Wharton																			345	486	177	253	41	65	29	44
15	Colorado R nr Bay City	FOR B&E USE - NO INSTREAM FLOW RECOMMENDATIONS MADE BY BBEST FOR THIS SITE																									
16	West Mustang Creek nr Ganado	99	80	56	64	75	86	54	40	29	28	38	41	29	30	10	12	6	7	NOT APPLICABLE							
17	East Mustang Creek nr Louise	99	79	75	69	81	83	57	36	30	31	39	36	18	20	13	12	6	6								
18	Navidad nr Edna	62	59	65	44	58	74	24	46	28	26	31	41	38	53	23	26	11	11								
19	Sandy Creek nr Ganado	89	65	50	53	64	83	42	27	22	24	29	37	24	27	16	20	7	9								
20	Lavaca nr Edna	60	65	76	52	63	66	33	47	36	29	36	38	43	44	21	22	6	7								
21	Tres Palacios nr Midfield	77	60	53	55	61	64	42	37	22	21	31	30	38	43	21	23	7	9								
22	Garcitas Creek nr Inez	92	77	70	75	79	82	41	38	43	33	39	40	38	35	18	18	9	10								

SHADED CELLS INDICATE WHEN THE NUMBER OF PULSE EVENTS CALCULATED USING THE WAM MODEL WAS LESS THAN THE NUMBER OF PULSES THAT OCCURRED HISTORICALLY.
"HIST" MEANS HISTORICAL FREQUENCY BBEST RECOMMENDATIONS WERE MET DURING THE WAM MODEL'S PERIOD OF RECORD.
(1) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1957-1998.
(2) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1940-1994.
(3) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1980-1998.

Table 5.6 Summary of Colorado/Lavaca BBEST Recommendations for Pulse Flows Using the Various TCEQ WAM RUN8 Models

PERIOD OF RECORD FOR COLORADO WAM IS 1940-1998 (59 YEARS); LAVACA, COL/LAVACA, LAVACA/GUAD IS 1940-1996 (57 YEARS)
NUMBER OF EVENTS (FOR THE PERIOD OF RECORD) MEETING OR EXCEEDING THE VARIOUS BBEST RECOMMENDATIONS

BBEST SITE ID INFORMATION		PULSE FLOWS																													
		SEASONAL PULSE RECOMMENDATIONS												ANNUAL PULSE RECOMMENDATIONS													
ID	USGS GAGE NAME	2 PER SEASON						1 PER SEASON						REGULAR LOCATIONS						LSWP ADOPTED LOCATIONS							
		WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST	1PY	HIST	1P2Y	HIST	1P5Y	HIST	8PY	HIST	2P3Y	HIST	1P3Y	HIST	OB	HIST
1	Colorado R abv Silver (1)	57	57	65	59	60	71	36	27	36	36	34	40	29	31	18	21	8	10	NOT APPLICABLE							
2	Colorado R nr Ballinger	101	74	112	86	93	89	51	44	44	43	46	46	52	54	26	29	12	13								
3	Elm Ck at Ballinger	90	88	108	76	91	84	50	48	53	45	49	50	49	50	24	26	12	14								
4	South Concho R at Christoval (2)	NA	NA	NA	NA	NA	NA	NA	NA	NA	42	42	40	48	47	23	22	9	9								
5	Concho R at Paint Rock	94	92	133	99	105	98	43	57	95	50	61	53	46	49	26	20	7	10								
6	Pecan Bayou nr Mullin	132	113	173	141	140	95	70	61	105	58	74	48	72	45	31	21	12	8								
7	San Saba R at San Saba	92	98	NA	84	91	84	59	45	59	43	52	49	36	37	26	26	15	15								
8	Colorado R nr San Saba	101	80	129	86	99	101	49	39	59	41	47	53	33	43	17	21	8	12								
9	Llano R at Llano	86	75	NA	90	84	84	41	37	50	36	41	42	42	43	29	29	12	13								
10	Pedernales R. nr Johnson City	98	83	NA	97	93	92	41	44	50	45	45	46	47	46	24	27	10	11								
11	Onion Ck near Driftwood (3)	NA	31	NA	25	28	31	16	15	NA	10	14	14	14	14	7	7	3	3								
12	Colorado R at Bastrop	NOT APPLICABLE																		347	550	138	128	43	31	26	20
13	Colorado R at Columbus																			438	587	258	280	67	64	47	45
14	Colorado R at Wharton																			360	486	226	253	55	65	41	44
15	Colorado R nr Bay City	FOR B&E USE - NO INSTREAM FLOW RECOMMENDATIONS MADE BY BBEST FOR THIS SITE																									
16	West Mustang Creek nr Ganado	99	94	189	74	114	86	54	45	93	30	56	41	36	30	10	12	6	7	NOT APPLICABLE							
17	East Mustang Creek nr Louise	99	84	81	69	83	83	57	38	38	31	41	36	18	20	13	12	6	6								
18	Navidad nr Edna	63	59	64	44	58	74	24	46	28	26	31	41	38	53	23	26	11	11								
19	Sandy Creek nr Ganado	91	82	174	90	109	83	42	36	145	27	63	37	34	27	20	20	8	9								
20	Lavaca nr Edna	61	66	72	52	63	66	33	47	35	31	37	38	43	44	21	22	7	7								
21	Tres Palacios nr Midfield	78	61	68	55	66	64	42	38	31	21	33	30	41	43	21	23	7	9								
22	Garcitas Creek nr Inez	92	77	70	75	79	82	41	38	43	33	39	40	38	35	18	18	9	10								

SHADED CELLS INDICATE WHEN THE NUMBER OF PULSE EVENTS CALCULATED USING THE WAM MODEL WAS LESS THAN THE NUMBER OF PULSES THAT OCCURRED HISTORICALLY.
"HIST" MEANS HISTORICAL FREQUENCY BBEST RECOMMENDATIONS WERE MET DURING THE WAM MODEL'S PERIOD OF RECORD.
(1) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1957-1998.
(2) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1940-1994.
(3) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1980-1998.

Table 5.7 Summary of Colorado/Lavaca BBEST Recommendations for Pulse Flows Using the TCEQ WAM RUN3 CUT-OFF Model

PERIOD OF RECORD FOR COLORADO WAM IS 1940-1998 (59 YEARS); LAVACA, COL/LAVACA, LAVACA/GUAD IS 1940-1996 (57 YEARS)
NUMBER OF EVENTS (FOR THE PERIOD OF RECORD) MEETING OR EXCEEDING THE VARIOUS BBEST RECOMMENDATIONS

BBEST SITE ID INFORMATION		PULSE FLOWS																									
		SEASONAL PULSE RECOMMENDATIONS												ANNUAL PULSE RECOMMENDATIONS													
ID	USGS GAGE NAME	2 PER SEASON						1 PER SEASON						REGULAR LOCATIONS						LSWP ADOPTED LOCATIONS							
		WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST	1PY	HIST	1P2Y	HIST	1P5Y	HIST	8PY	HIST	2P3Y	HIST	1P3Y	HIST	OB	HIST
1	Colorado R abv Silver (1)	76	59	70	61	67	71	47	22	33	35	34	40	21	31	14	21	5	10	NOT APPLICABLE							
2	Colorado R nr Ballinger	68	39	43	46	49	89	35	15	16	19	21	46	17	54	8	29	3	13								
3	Elm Ck at Ballinger	85	82	101	72	85	84	47	47	41	42	44	50	46	50	25	26	11	14								
4	South Concho R at Christoval (2)	NA	NA	NA	NA	NA	NA	NA	NA	NA	38	38	40	46	47	23	22	9	9								
5	Concho R at Paint Rock	50	59	71	66	62	98	16	28	37	27	27	53	17	49	4	20	3	10								
6	Pecan Bayou nr Mullin	92	102	144	107	111	95	55	47	60	47	52	48	59	45	25	21	10	8								
7	San Saba R at San Saba	94	97	NA	82	91	84	58	46	67	42	53	49	37	37	25	26	15	15								
8	Colorado R nr San Saba	97	61	95	74	82	101	42	28	39	33	36	53	23	43	14	21	4	12								
9	Llano R at Llano	86	73	NA	90	83	84	39	36	50	37	41	42	42	43	28	29	11	13								
10	Pedernales R. nr Johnson City	99	83	NA	96	93	92	42	45	51	44	46	46	46	46	26	27	10	11								
11	Onion Ck near Driftwood (3)	NA	31	NA	28	30	31	16	15	NA	10	14	14	14	14	7	7	3	3								
12	Colorado R at Bastrop	NOT APPLICABLE																		256	550	94	128	24	31	14	20
13	Colorado R at Columbus																			411	587	201	280	49	64	34	45
14	Colorado R at Wharton																			319	486	184	253	43	65	29	44
15	Colorado R nr Bay City	FOR B&E USE - NO INSTREAM FLOW RECOMMENDATIONS MADE BY BBEST FOR THIS SITE																									

SHADED CELLS INDICATE WHEN THE NUMBER OF PULSE EVENTS CALCULATED USING THE WAM MODEL WAS LESS THAN THE NUMBER OF PULSES THAT OCCURRED HISTORICALLY.

"HIST" MEANS HISTORICAL FREQUENCY BBEST RECOMMENDATIONS WERE MET DURING THE WAM MODEL'S PERIOD OF RECORD.

(1) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1957-1998.

(2) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1940-1994.

(3) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1980-1998.

Table 5.8 Summary of Colorado/Lavaca BBEST Recommendations for Pulse Flows Using the TCEQ WAM RUN8 CUT-OFF Models

PERIOD OF RECORD FOR COLORADO WAM IS 1940-1998 (59 YEARS); LAVACA, COL/LAVACA, LAVACA/GUAD IS 1940-1996 (57 YEARS)
NUMBER OF EVENTS (FOR THE PERIOD OF RECORD) MEETING OR EXCEEDING THE VARIOUS BBEST RECOMMENDATIONS

BBEST SITE ID INFORMATION		PULSE FLOWS																									
		SEASONAL PULSE RECOMMENDATIONS												ANNUAL PULSE RECOMMENDATIONS													
		2 PER SEASON						1 PER SEASON						REGULAR LOCATIONS						LSWP ADOPTED LOCATIONS							
ID	USGS GAGE NAME	WIN	SPR	SUM	FAL	AVG	HIST	WIN	SPR	SUM	FAL	AVG	HIST	1PY	HIST	1P2Y	HIST	1P5Y	HIST	8PY	HIST	2P3Y	HIST	1P3Y	HIST	OB	HIST
1	Colorado R abv Silver (1)	52	53	63	57	56	71	34	25	34	31	31	40	22	31	16	21	6	10	NOT APPLICABLE							
2	Colorado R nr Ballinger	96	66	90	73	81	89	49	33	31	27	35	46	27	54	11	29	2	13								
3	Elm Ck at Ballinger	89	87	102	77	89	84	50	46	50	42	47	50	48	50	25	26	10	14								
4	South Concho R at Christoval (2)	NA	NA	NA	NA	NA	NA	NA	NA	NA	42	42	40	47	47	23	22	9	9								
5	Concho R at Paint Rock	76	80	83	83	81	98	33	45	50	37	41	53	34	49	12	20	3	10								
6	Pecan Bayou nr Mullin	128	106	177	138	137	95	70	56	85	56	67	48	70	45	31	21	11	8								
7	San Saba R at San Saba	92	99	NA	85	92	84	61	45	61	42	52	49	36	37	26	26	16	15								
8	Colorado R nr San Saba	95	74	93	76	85	101	50	35	39	35	40	53	29	43	14	21	8	12								
9	Llano R at Llano	86	76	NA	90	84	84	41	37	52	36	42	42	42	43	29	29	12	13								
10	Pedernales R. nr Johnson City	98	83	NA	97	93	92	42	45	50	45	46	46	47	46	24	27	10	11								
11	Onion Ck near Driftwood (3)	NA	31	NA	25	28	31	16	15	NA	10	14	14	14	14	7	7	3	3								
12	Colorado R at Bastrop	NOT APPLICABLE																		325	550	131	128	38	31	24	20
13	Colorado R at Columbus																			419	587	247	280	64	64	46	45
14	Colorado R at Wharton																			348	486	223	253	55	65	39	44
15	Colorado R nr Bay City	FOR B&E USE - NO INSTREAM FLOW RECOMMENDATIONS MADE BY BBEST FOR THIS SITE																									

SHADED CELLS INDICATE WHEN THE NUMBER OF PULSE EVENTS CALCULATED USING THE WAM MODEL WAS LESS THAN THE NUMBER OF PULSES THAT OCCURRED HISTORICALLY.

"HIST" MEANS HISTORICAL FREQUENCY BBEST RECOMMENDATIONS WERE MET DURING THE WAM MODEL'S PERIOD OF RECORD.

(1) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1957-1998.

(2) PERIOD OF RECORD USED FOR COMPARISON OF WAM RESULT AND HISTORICAL FREQUENCY WAS 1940-1994.

Section 6. Preliminary Implementation Guidance

The question of how the BBEST should address implementation of flow recommendations has been particularly challenging throughout the SB 3 process. On one hand, the idea that the BBEST would propose how its flow recommendations should be implemented seems outside the scope of, and perhaps at odds with, the BBEST mandate to define the flow needs of the ecosystem without regard for other uses of water. On the other hand, without explaining what the recommendations mean in practical terms relating to expected flows and potential restrictions on diversions, it is difficult to evaluate whether the recommendations would meet the objective of providing flows necessary to maintain a sound ecological environment. The sediment transport and freshwater inflow analyses (Sections 3.10 and 6.1.1), for example, could not have been conducted without some assumptions of potential future flows based on how the flow recommendation would be implemented and how this implementation could limit diversions for future projects.

These conflicting interpretations of the BBEST mandate have resulted in the use of the term “interpretation” which provides the BBEST’s understanding of how these recommendations could be implemented to produce a sound environment versus the term “implementation” which, in this context, is focused on the actual mechanics of what rules and strategies should be developed by the BBASC to meet their SB 3 mandate. The distinction is subtle, and as a practical matter there may be little or no difference in describing an “interpretation” versus an “implementation.” The purpose of this document is to provide the BBEST “interpretation” of how the flow regime might be implemented to provide a sound ecological environment. It is not the BBEST’s goal to define the strategies that might be developed to “implement” these recommendations.

The example implementation follows the approach developed by the Sabine-Neches BBEST (SN-BBEST 2009) with respect to the designation of hydrologic conditions to trigger engagement of the various levels of base flow values. The BBEST flow regime recommendation calls for variable flow levels to maintain a diversity of habitats. In order to preserve flow variability necessary to support a sound ecological environment, the BBEST selected an engagement frequency for the base flow criteria. Engagement frequency is the percent of time a particular flow recommendation value is active and, assuming flow is available, should be passed. Subsistence flows, pulses, and overbank flows are assumed to be engaged at all times. The base flow engagement frequency is not necessarily a direct reflection of the historical frequency of instream flow magnitude occurrence. The historical frequency of instream flow magnitude occurrence is provided for each selected gage in its corresponding HEFR/Hydrologic Regime table in the detailed summaries in Section 2.

The BBEST’s intent is to recommend an engagement frequency which allows the various levels of instream flow to occur with about the same frequency as the historical frequency. Actual instream flows will vary above or below the base flow or subsistence flow criterion that is engaged in any particular season. Over time, the engagement frequency coupled with the various levels of instream flow criteria will preserve the range of instream flow with sufficient variability to support a sound ecological environment. An appropriate triggering metric, preferably correlated with the current hydrologic condition of the basin, should be used to engage the flow criteria with the recommended frequency.

There are several factors that might be considered in the development of triggers to define hydrologic conditions including the indicator to be used (reservoir storage, flow rate, or some other indicator of hydro-climatology) and the time frame over which to monitor the indicator (e.g. daily, seasonally, annual, etc.). The primary objective is to select an indicator that can be implemented to achieve the desired long-term attainment targets of the various recommended flow components.

For example, reservoir level based on storage at the end of the preceding season is used to define the hydrologic condition in the current season. This approach has the advantages that it is simple to implement, and links flow targets to storage and in this sense spreads the impact of drought between instream and out-of-stream uses. One disadvantage is that it may be slow to respond to changed conditions. For example, in many systems, reservoirs fill up during the wetter seasons and it is conceivable that reservoirs may be full or spilling based on flows from an antecedent season while the current season is entering low flow or drought conditions. The example below is based on reservoir storage triggers however the same framework could be used with triggers based on antecedent streamflow. The Cypress Flows Project presents an example of this approach based on three month antecedent streamflow (Trungale 2010). Any trigger will need to balance the flexibility necessary to implement the recommendations with the complexity needed to achieve the desired goals.

A time series of reservoir storage was simulated using the fully permitted conditions WAM (TCEQ WAM Run 3). From this time series, the 75th, 25th and 5th percentile volumes were calculated for the combined volumes of lakes Travis and Buchanan (for the Colorado basin sites) and the volume of Lake Texana (for the Lavaca and Coastal basin sites). Based on the BBEST decision to set engagement frequencies for base High, Medium and Low conditions at 25, 50 and 25 percent frequencies respectively, hydrologic condition was designated as High when reservoir storage is greater than the 75th percentile volume. The 75th percentile volume is the volume that is exceeded 25% of the time in the WAM simulation. Similarly, hydrologic condition is designated as Low when reservoir storage is less than the 25th percentile volume which also occurs 25% of the time in the WAM simulation. The remaining 50% of the time when reservoir storage is between the 25th and 75th percentile volumes, hydrologic condition is designated as Medium. The 5th percentile volume is used to designate conditions when drought contingency conditions could apply and allow diversions down to subsistence values.

The objectives of the implementation approach are to never divert below subsistence values, to meet the designated base flows which vary inter and intra annually by season and hydrologic conditions, and to the extent that pulse and overbank events occur, pass them until either their designated volume or duration target is reached. Hydrologic conditions are designated for a season based on reservoir levels at the end of the preceding season. The three hydrologic conditions are shown in the table below.

Table 6.1 Hydrologic Conditions

Hydrologic Condition	Reservoir Volume at End of Preceding Season
High	Greater than or equal to the 75th percentile volume
Medium	Between the 75th and 25th percentile volumes
Low	Less than or equal to the 25th percentile volume

A drought contingency approach is also proposed that would allow diversions when reservoir levels at the end of the preceding season were below the 5th percentile value. During these times if inflow is less than the base but greater than the subsistence value, then diversions can be made down to the subsistence value.

Flows to satisfy pulse and overbank flow recommendations are active at all times without regard to hydrologic conditions. As described in Section 3.3.4, a qualifying flow pulse or overbank event begins when instantaneous flow exceeds the prescribed pulse trigger flow and has not already been satisfied within the season or years defined at the prescribed frequency (e.g. if a one in five year flood has not occurred in the last five years). The event continues (which means flows are passed up to that flow magnitude) until the prescribed volume is passed. If the prescribed volume is not met by the associated prescribed duration (calculated as the upper prediction interval of the duration regression in HEFR), the event is considered as being met. If during a qualifying event at one magnitude, flows increase to a magnitude that triggers a higher pulse event, the flow magnitude, volume, and duration of the higher qualifying flow pulse controls the flow regime and first event is ignored. In this case, the higher flow events are considered to satisfy lower flow events in the same season (e.g. an overbank event satisfies a one-per-season event and one two-per-season event).

All of the values in BBEST flow recommendations were derived from an analysis of daily average flows and therefore it is appropriate that they be implemented based on daily average flows. There are some important subtleties worth keeping in mind with regards to this issue. The base and subsistence flows are assumed to be maintained continuously. While the daily average is the metric used for the implementation approach presented here, a flow regime that would dry up the river for parts of the day and flood it for other parts, and thus may meet the daily average recommendation, would not provide the desired ecological benefit that is intended by these recommendations. For pulse and overbank analysis, the more common metric, than daily average, is instantaneous flow rate. The BBEST considered this in developing the recommendations and determined that daily average was acceptable given the level of data resolution available for the analysis. Nonetheless it is worth recognizing that when daily average flows are at the peak threshold values included in this report, the instantaneous flow for those days would likely be much higher.

Rules for Implementation

1. If inflow is less than the subsistence value, then all inflow must be passed and none impounded or diverted.

2. If no qualifying pulse or overbank flow is currently occurring, then inflows can be diverted down to the designated base value. No diversions can be made when inflows are below the designated base values. This means that if reservoir storage is below the 75th percentile and above the 25th percentile volume (i.e. the hydrologic condition is designated as Medium), and stream flow was less than the Base-medium flow, diversions could not be made.

3. A drought contingency rule would allow diversions if the reservoir level in the preceding season was less than the 5th percentile volume. During these times if inflow is less than the base-low value, then flows may be diverted down to the subsistence value. Inflow greater than the base-low

value, would still need to be passed up to the base-low value. Whenever this drought contingency is not active, flows below the designated base cannot be diverted. This drought contingency exception allows some additional diversions only during exceptional low flow periods.

4. If a qualifying pulse or overbank flow is currently active, flows must be passed up to the event peak magnitude until the prescribed volume or duration is satisfied. Flows above the peak magnitude may be impounded.

A Flow Regime Application Tool (FRAT) originally developed by the Sabine Neches BBEST and subsequently updated by TPWD can be used to simulate the implementation of the BBEST flow recommendations as described above. Although preliminary analyses have been conducted using FRAT for select sites in the Colorado-Lavaca basins, a number of important decisions will need to be made by the BBASC to more fully evaluate the implementation approach both in terms of the ability of the system to provide the recommended flow regimes and the impact that doing so may have on proposed or potential future water supply projects. The BBEST has been working with the BBASC to evaluate different assumptions for WAM modeling that will be necessary to perform these analyses.

Another issue that may need to be resolved relates to the question of whether any flow not explicitly defined in the BBEST recommendations can be assumed to remain in the river, either because of infrastructure constraints on diversions or future water planning assumptions. According to this perspective much of the flow regime will be protected because it is inconceivable, under reasonable assumptions of how water will be used, to suggest that nothing but the flows provided by the BBEST recommendation would remain in the river. (The Sabine-Neches BBEST performed analysis that suggested that a reservoir many times larger than Toledo Bend would be required to remove all the water in excess of the flow explicitly included in their recommendations.) Proponents of this outlook contend that analysis to determine whether the flow recommendations would maintain a sound ecological environment should take these infrastructure limitations into consideration.

An alternative view is that an analysis should be performed to determine if the proposed flow recommendations, in and of themselves, are sufficient to maintain a sound ecological environment perhaps recognizing that this assumption presents what is likely an unrealistic portrayal of future conditions. The BBEST has attempted to address this issue, particularly with regard to sediment transport and to some extent freshwater inflow, but the analysis has required assumptions and simplifications that are inextricably linked with issues associated with implementation and future water use. The tools and available analysis do not resolve all questions related to implementation, rather they provide a framework for evaluating different implementation options and assumptions that can be employed in what will likely be an iterative process to balance the needs of the environment with water diversions necessary for people.

The BBEST anticipates supporting the BBASC in their task of balancing trade-offs between the expected environmental effects of meeting or modifying the flow recommendations with the potential impacts on water supply of having to pass water for instream flows. The available tools are flexible to evaluate these different alternatives, prioritize the most significant issues and support the generation of strategies to meet long-term needs for water supply and instream flow protection.

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7. Research and Adaptive Management

Adaptive management (Hollings 1978, Walters 1986) is an iterative process of recognizing and minimizing the uncertainties associated with the ecological flow regime recommendations provided by the BBEST. The adaptive management process consists of monitoring, evaluation, and adjustment of these recommendations after implementation. The purpose of this section is to recognize uncertainties associated with the flow regime recommendations, to identify gaps in existing knowledge and to recommend monitoring protocols for future evaluation and adjustments to the flow regime recommendations.

Instream Flows

The BBEST relied on the best available science in formulating its instream flow recommendations at all sites. The amount and breadth of available data and/or study results however, varied between sites. For example, at the Lower Colorado River sites, detailed multidisciplinary studies were available from the LSWP efforts that had received extensive independent review while at some sites, only water quality monitoring data and field based rapid assessment results were available. This difference in available data or study sources should not be construed to imply that the flow recommendations at these later sites are invalid, but rather that the level of uncertainty is somewhat higher. It also does not imply that insufficient data or knowledge existed to preclude making defensible flow recommendations necessary to protect a sound ecological environment at these sites.

The Instream Flow subcommittee used a limited number of overlays to evaluate the adequacy of subsistence, base, pulse and overbank flow recommendations. In most instances, overlays were based on existing data or new information that could be gathered in less than 1 year (i.e., rapid assessments). Although we used best available information, the Instream Flow subcommittee recognizes limitations of the following aspects of biotic, water quality, and fluvial geomorphology overlays:

1. Using fishes and their associated habitats as surrogates for all aquatic fauna and flora—We are confident that aquatic fauna, flora, and habitats are protected by the instream flow recommendations based on the fish habitat guild approach. However, we recognize that aquatic macrophytes, algal communities, platyhelminths, mollusks, annelids, crustaceans, aquatic insects, amphibians, and birds might have life histories dependent upon specific elements of the hydrograph and not assessed as a biological overlay. Even various life history parameters of fishes (i.e., larval drift, dispersion) were not specifically included in the biological overlay. In general, there is a paucity of biotic information available throughout the basin, and additional research is needed to provide greater understanding on the interactions among species occurrences, abundances, habitat associations and instream flow components. Without this greater understanding, modification of the BBEST flow recommendations will increase the uncertainty of biotic responses.

2. Relationships among riparian flora and fauna and their response to flow regimes were necessarily based on application of fundamental principals related to pulse and overbank flow regimes that were derived from an extensive body of peer reviewed literature rather than detailed site specific studies at all sites. The evaluation of the existing distribution and characteristics of the riparian communities at sites at the corresponding flow levels associated with recommended pulse and

overbank flows clearly supported the application of the flow regime components identified by the scientific literature.

3. The habitat versus flow relationships derived from the integration of the habitat guild suitability curves and rapid assessment data have an inherent degree of uncertainty. This arises from both the limited field data at sites as well as the use of broad guild based habitat suitability curves. Although this is a well established and scientifically defensible approach, we recognize that many other factors contribute to the requirements of an ecological flow regime that ensures a sound ecological environment can be maintained.

4. Although water quality and temperature evaluations were made based on a detailed and exhaustive evaluation of available monitoring data, we recognize that without detailed modeling studies at each site, the ability to assess flow dependant changes in water quality and temperature for flows significantly lower than our recommendations are impossible.

5. The geomorphic overlay relied on the principal of maintaining the annual sediment yield and effective discharge within 10% of the historical values based on the preponderance of evidence within the published scientific literature. We recognize however, that these types of estimates have an inherent degree of uncertainty due to scatter in the data and even choice of the sediment transport equation utilized. Additional studies on maintenance of the natural fluvial geomorphology (i.e., channel stability/mobility, channel width and depth, meander wavelength, gravel bar formation) would be beneficial to evaluate, test, and inform the current instream flow recommendations.

Monitoring Recommendations

At least two biomonitoring frameworks are considered acceptable by regulatory agencies for the use in monitoring changes in the riverine flora and fauna. The Regionalized Index of Biotic Integrity (IBI) (Karr 1981; Linam et al. 2002) is available and currently used for monitoring of the fish community in several Texas rivers and a generalized IBI is used to monitor macroinvertebrates. The Biological Condition Gradient (BCG) (Davies and Jackson 2006) is a more comprehensive approach to biological monitoring with the benefits of explicitly defining a "sound ecological environment," which is useful for restoration purposes. With some effort, the BCG can be developed for various reaches of streams and rivers within the Colorado-Lavaca River basin with information currently available. As a more sensitive model of biological changes associated with modified flow regimes or some other anthropogenic disturbance, the Instream Flow subcommittee highly recommends the use of BCG to validate flow regimes recommendations made by Colorado-Lava River BBEST and the validation process should begin simultaneously with the adoption of the flow regime.

The sediment transport analyses used by the BBEST at three sites, clearly indicate the importance of sediment transport to channel stability and maintenance, and ultimately the ability to maintain a sound ecological environment. We recommend that monitoring of river reaches in terms of basic channel geometry, aquatic habitat distributions, and riparian community structure and distribution be incorporated into the adaptive management monitoring plans.

Freshwater Inflows

An extensive body of scientific literature from the past 40 years has clearly recognized the importance of freshwater inflows as a critical component of maintaining the ecological integrity of bay and estuaries in Texas.

Freshwater inflow studies from the 1970s (TDWR 1980a, 1980b, 1981c, 1981d, 1981e, 1983) presented hydrology data for the coast from 1941–1976 (Longley 1994).

Policy decisions must depend on the latest analytical procedures and methodologies:

- Hydrology updates
- Sediment loading
- Hydrodynamic and conservative transport models
- Inflow-salinity regressions
- Nutrient balance
- Effects of salinity and inflow on zooplankton
- Effects of salinity and inflow on benthic organisms and processes
- Effects of inflow on primary production (phytoplankton, submerged and emergent vegetation)
- Fishery response equations and harvest-inflow analyses
- Areal distribution of wetlands and other habitats
- Inventory of secondary and tertiary resource consumers by area
- Abundance of major secondary and tertiary resource consumers

Both field sampling techniques and sophistication of modeling approaches have been refined over time and a number of modeling tools currently exist to aid in the adaptive management process:

- TXBLEND — Texas Hydrodynamic and Conservative Transport Model
- TXEMP—Texas Estuary Mathematical Programming
- HEFR— Hydrologic Environmental Flow Regime
- TIFP—Texas Instream Flows Program
- WAM—Water Availability Modeling
- ELMR—Estuarine Living Marine Resources, provides estuarine spatial and temporal distribution, and relative abundance information on marine species
- TxRR — Texas Rainfall Runoff Model
- RIBI — Regionalized Index of Biotic Integrity

The specific research needs to assist the evaluation of the existing fresh water inflow recommendations to support the adaptive management program are:

Austin Lake/Caney Creek

- Conduct research on the effect of bulkheading on marsh and seagrass habitats
- Investigate if Dermo is a threat to this area

Colorado Tidal

- Study the influence of grass carp on resident and migratory species and their impact on associated habitats

East Matagorda Bay

- Acquire more information on the effects of Dermo and Oyster drills on the oyster population
- Acquire more information on plankton
- Study the effects of subsidence in the area in terms of habitat and aquatic communities

Matagorda Bay

- Review long-term trends in fishery populations
- Acquire more information on nutrients and plankton
- Acquire more information on oyster recruitment

Lavaca Bay

- Study the decline in Rangia abundance
- Study mercury contamination issues

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Appendix

Water Quality Analysis

The TCEQ's CRP water quality data for each site was evaluated using an Excel spreadsheet model developed by the Lower Colorado River Authority's Water Quality Protection Division (LCRA 2010) to evaluate water quality in the middle, lower, and coastal portions of the Colorado River Basin. The model calculates summary statistics for user-specified water quality parameters at each study site, plots the constituent concentrations versus flow, and plots a summary chart indicating which parameters, if any, are significantly correlated ($p<0.05$) with flow and whether the relationship is positive or negative. A positive correlation with flow indicates that the historical water quality observations tended to increase as flow increased, while negative correlations indicates that the parameter tended to decrease as flow increased.

Example output from the spreadsheet model for the Colorado River at Columbus is presented in this appendix. The results for all sites evaluated in this study are available on the TCEQ's website for the Colorado-Lavaca BBEST. The output includes a table summarizing significant correlations of water quality parameters with flow as well as pages with descriptive statistics and graphs for each water quality parameter. The parameters evaluated for this study included water temperature, dissolved oxygen, specific conductance, chloride, pH, nitrate plus nitrite nitrogen, and total phosphorus.

Colorado River at Columbus

Significant Correlations

Parameter	Parameter vs Flow — Season: All (Jan-Dec)	Cool (Nov-Apr)	Warm (May-Oct)
Water Temperature			
Specific Conductance	-	-	-
Dissolved Oxygen			
pH	+		+
NO2+NO3 - Nitrogen	-	-	
Total Phosphorus	-	-	
Chloride			

\+ Values increase with increasing flow

\- Values decrease with increasing flow

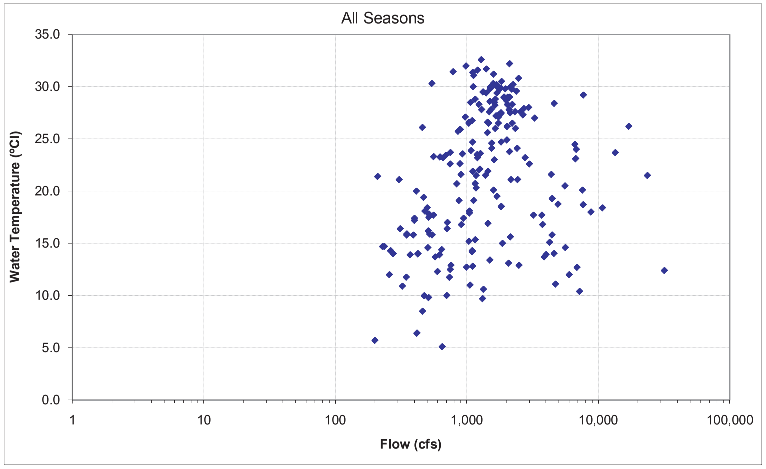
Notes:

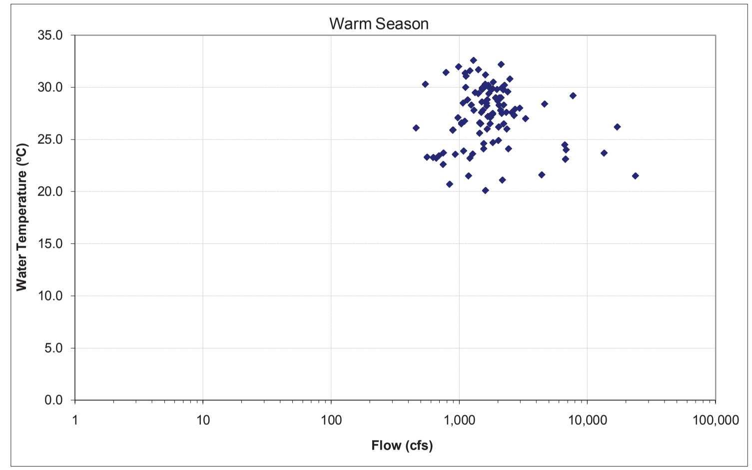
Colorado River at Columbus

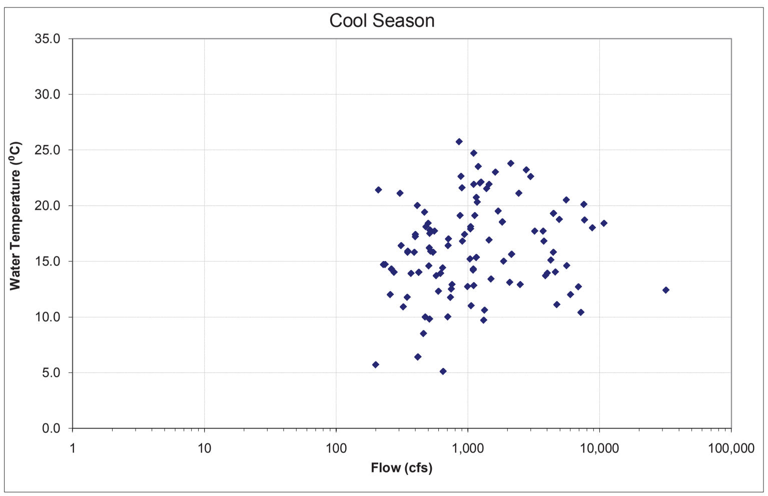
Water Temperature vs Flow

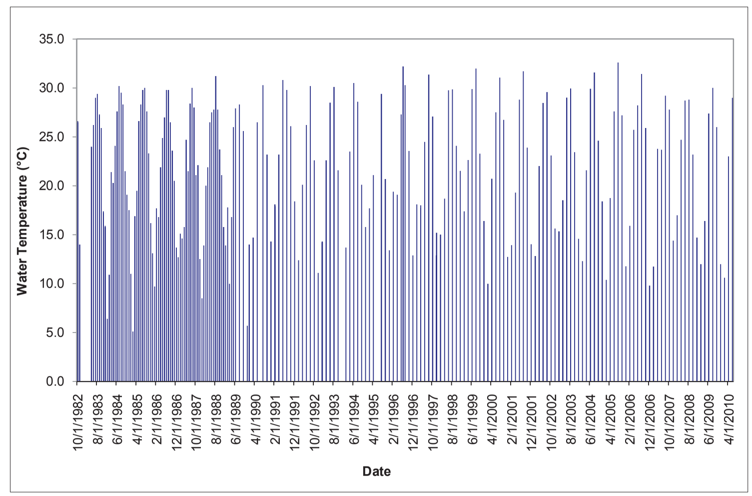
Flow Analysis

Trend Analysis POR: 10/4/1982 thru 6/2/2010









Summary statistics by season for Water Temperature vs Flow

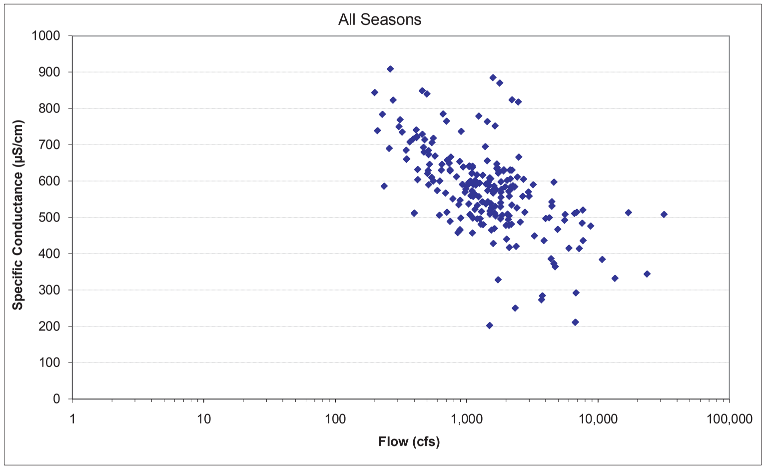
Season	n	% censored	Minimum	1st Quartile	Median	3rd Quartile	Maximum	IQ Range	Range	Mean	Standard Deviation	Standard Error	± 95% Conf Limit	Skewness	Kurtosis	Normality Check	r^2	t	p
All	221	0.0	5.10	15.80	22.60	27.60	32.59	11.80	27.49	21.68	6.697	0.450	0.883	-0.309	-0.988	2/2	0.001	-0.355	0.723
Cool	111	0.0	5.10	13.55	15.80	18.93	25.73	5.38	20.63	16.08	4.247	0.403	0.790	-0.154	-0.125	2/2	0.000	0.090	0.929
Warm	110	0.0	20.10	25.90	27.70	29.79	32.59	3.89	12.49	27.33	2.872	0.274	0.537	-0.497	-0.481	2/2	0.011	-1.152	0.252

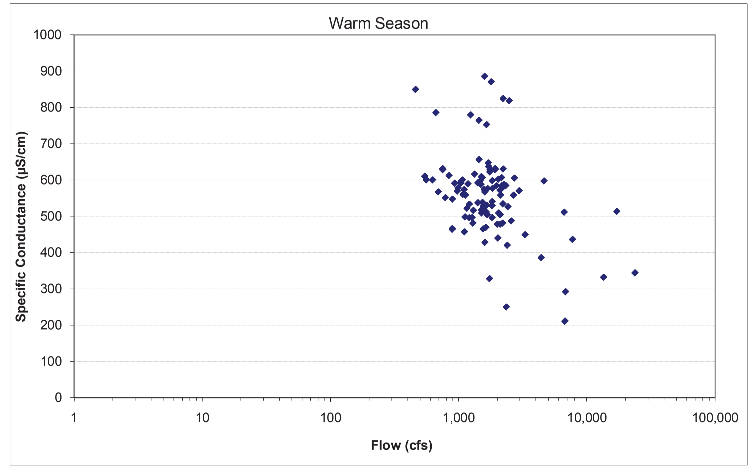
Colorado River at Columbus

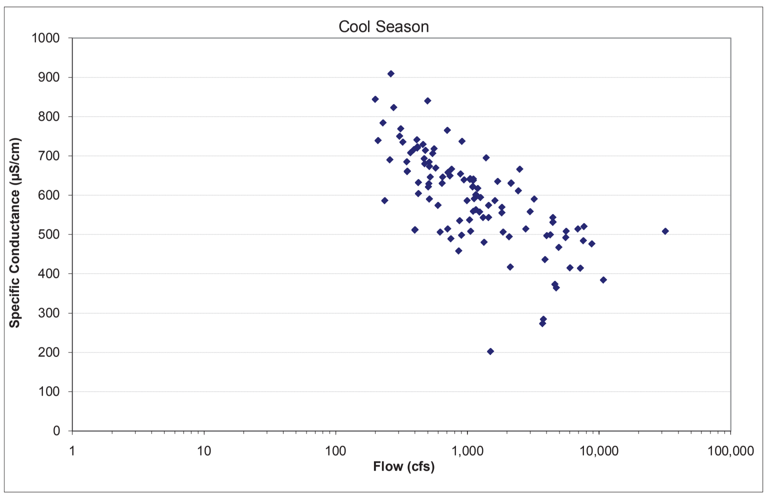
Specific Conductance vs Flow

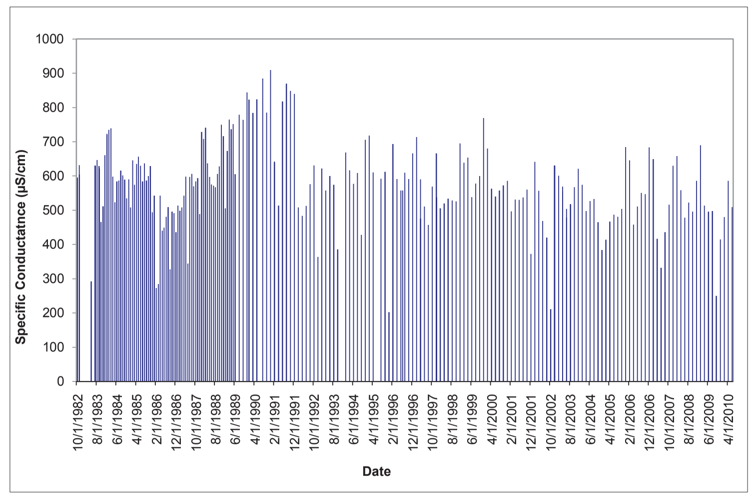
Flow Analysis

Trend Analysis POR: 10/4/1982 thru 6/2/2010









Summary statistics by season for Specific Conductance vs Flow

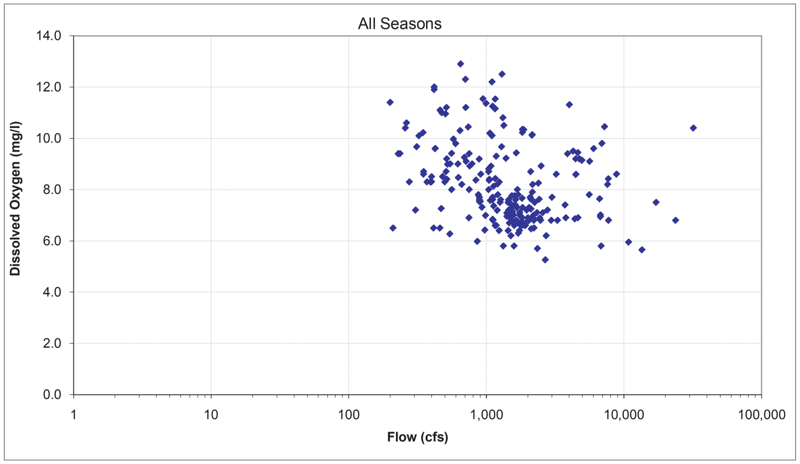
Season	n	% censored	Minimum	1st Quartile	Median	3rd Quartile	Maximum	IQ Range	Range	Mean	Standard Deviation	Standard Error	± 95% Conf Limit	Skewness	Kurtosis	Normality Check	r^2	t	p
All	219	-	202.00	508.50	576.00	633.50	909.00	125.00	707.00	574.28	120.331	8.131	15.937	-0.172	1.145	1/2	0.046	-3.409	0.001
Cool	111	-	202.00	513.00	601.00	667.50	909.00	154.50	707.00	594.05	119.839	11.375	22.294	-0.369	0.861	2/2	0.047	-2.411	0.017
Warm	108	-	211.00	502.50	563.50	600.50	885.00	98.00	674.00	553.96	117.960	11.351	22.247	0.005	1.994	2/2	0.041	-2.297	0.023

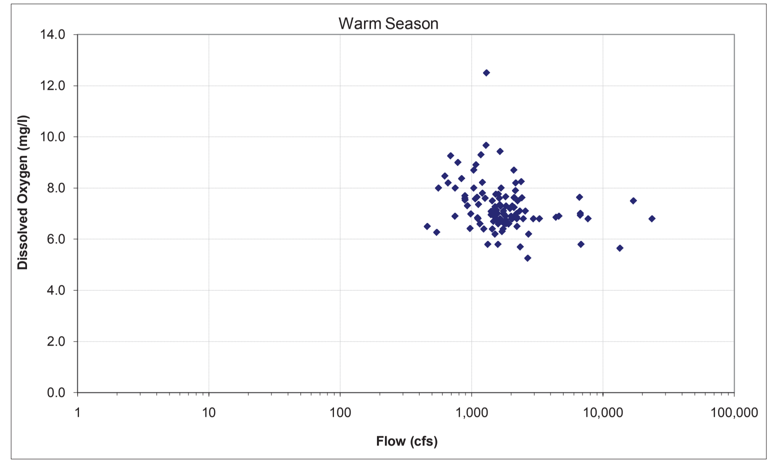
Colorado River at Columbus

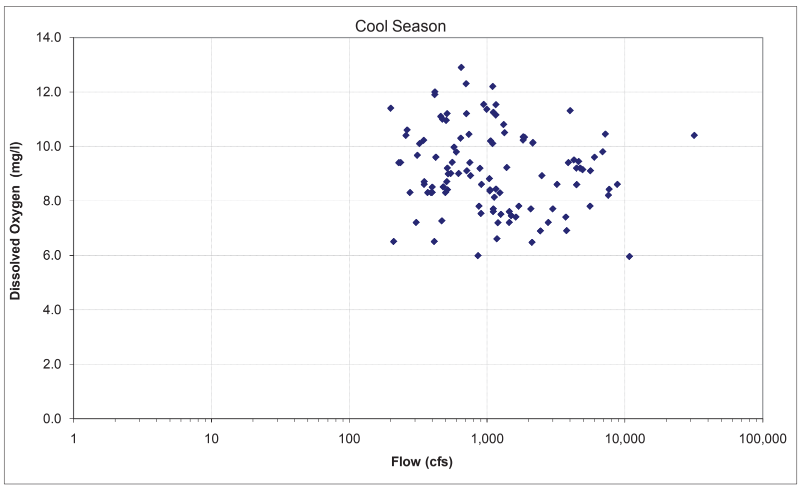
Flow Analysis

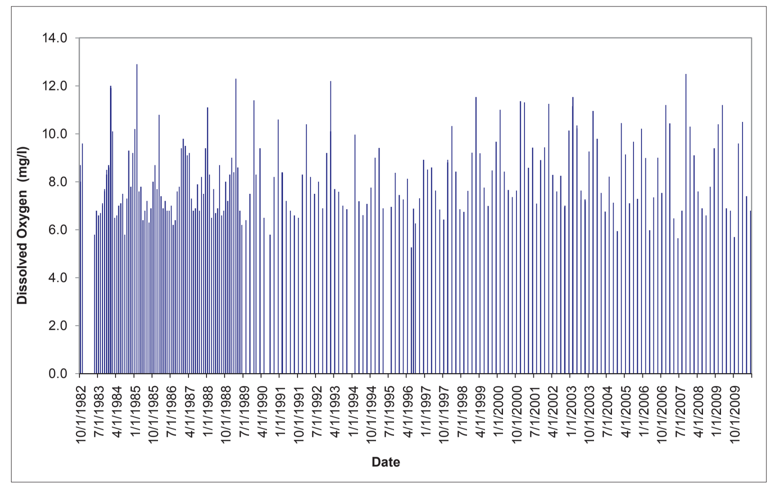
Dissolved Oxygen vs Flow

Trend Analysis POR: 10/4/1982 thru 6/2/2010









Summary statistics by season for Dissolved Oxygen vs Flow

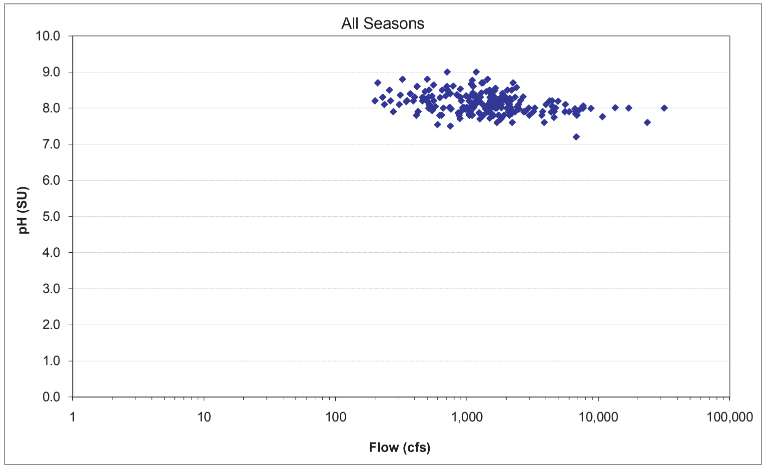
Season	n	% censored	Minimum	1st Quartile	Median	3rd Quartile	Maximum	IQ Range	Range	Mean	Standard Deviation	Standard Error	± 95% Conf Limit	Skewness	Kurtosis	Normality Check	r^2	t	p
All	221	-	5.26	6.90	7.76	9.20	12.90	2.30	7.64	8.20	1.575	0.106	0.208	0.766	-0.069	1/2	0.004	-0.949	0.343
Cool	111	-	5.95	8.25	9.10	10.23	12.90	1.98	6.95	9.13	1.507	0.143	0.280	0.159	-0.486	2/2	0.000	-0.090	0.929
Warm	110	-	5.26	6.80	7.00	7.63	12.50	0.83	7.24	7.25	0.956	0.091	0.179	1.879	7.763	2/2	0.009	-1.054	0.294

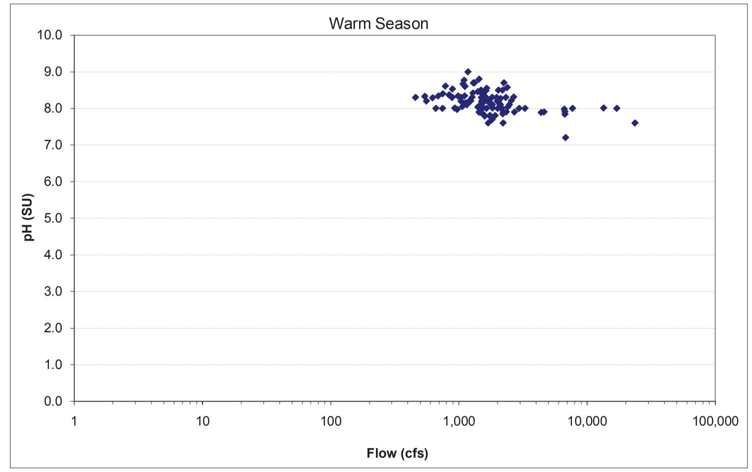
Colorado River at Columbus

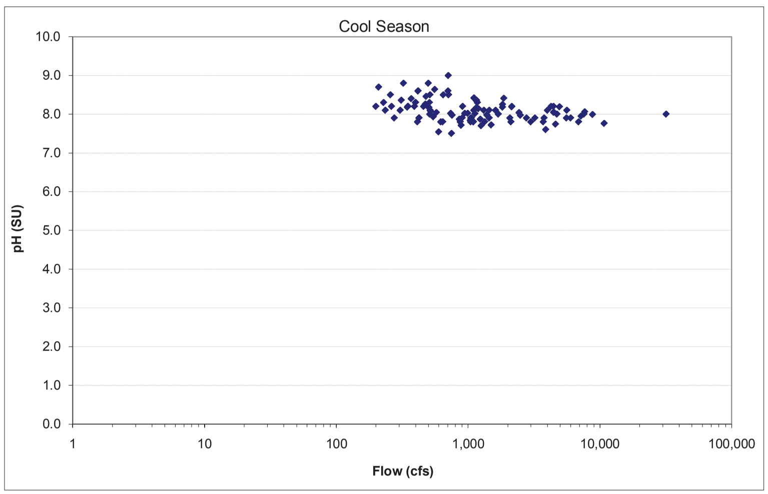
pH vs Flow

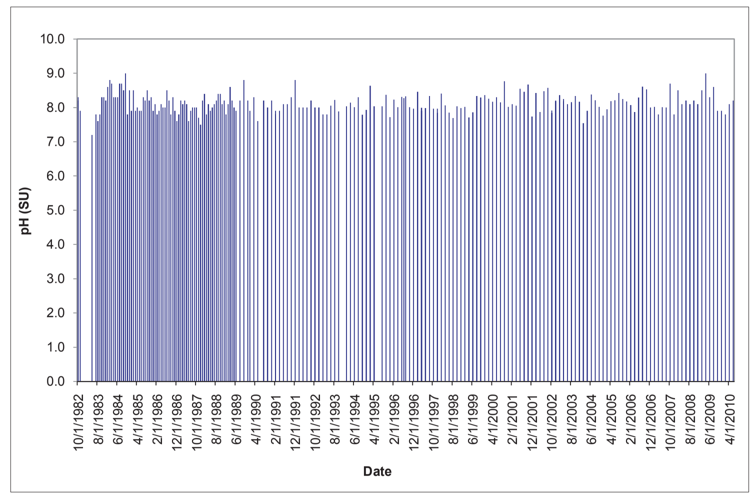
Flow Analysis

Trend Analysis POR: 10/4/1982 thru 6/2/2010









Summary statistics by season for pH vs Flow

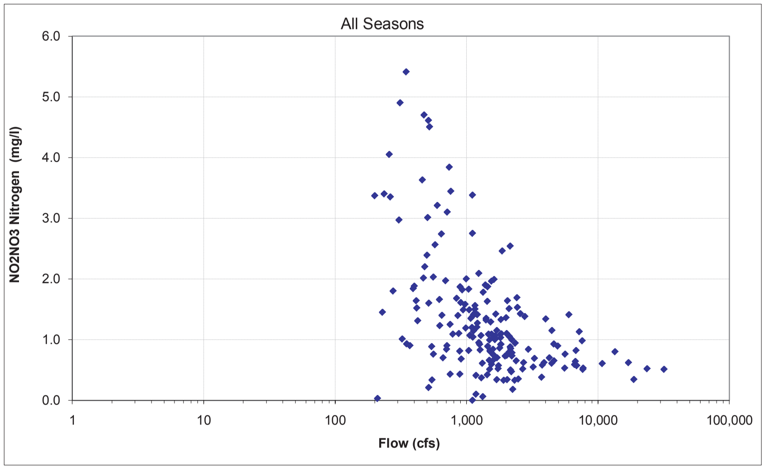
Season	n	% censored	Minimum	1st Quartile	Median	3rd Quartile	Maximum	IQ Range	Range	Mean	Standard Deviation	Standard Error	± 95% Conf Limit	Skewness	Kurtosis	Normality Check	r^2	t	p
All	219	-	7.20	7.90	8.10	8.30	9.00	0.40	1.80	8.04	0.545	0.037	0.072	3.356	22.633	0/2	0.041	3.230	0.001
Cool	111	-	7.50	7.90	8.06	8.20	9.00	0.30	1.50	8.02	0.241	0.023	0.045	1.178	2.342	1/2	0.016	1.401	0.164
Warm	108	-	7.20	8.00	8.20	8.30	9.00	0.30	1.80	8.07	0.072	0.007	0.014	4.423	29.976	2/2	0.080	3.246	0.002

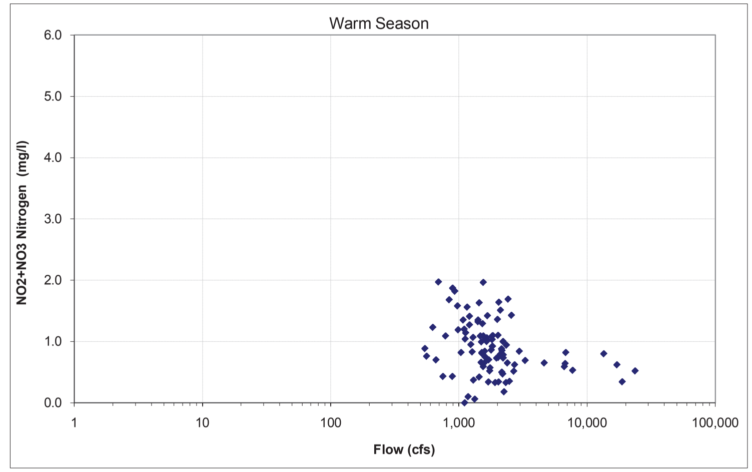
Colorado River at Columbus

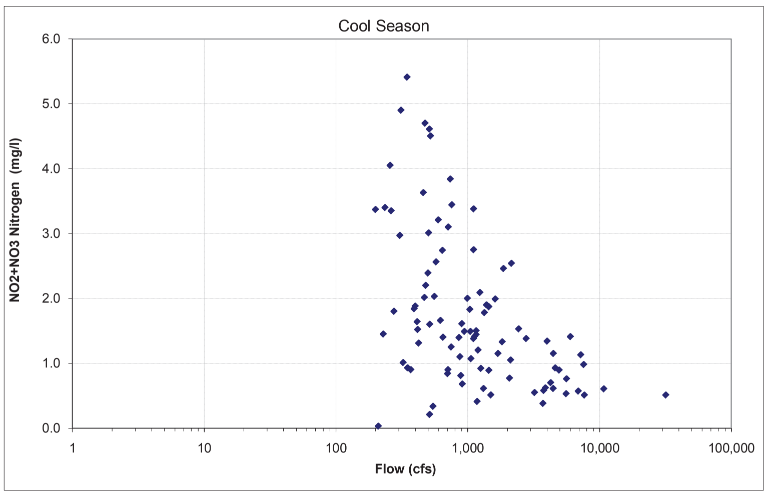
NO_2+NO_3 Nitrogen vs Flow

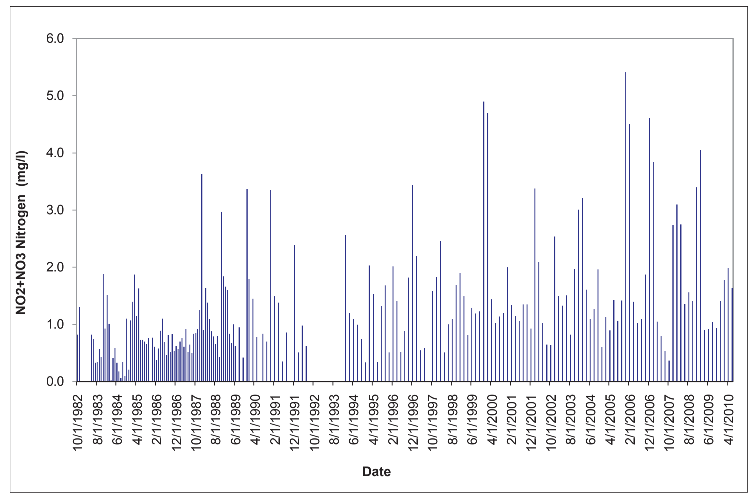
Flow Analysis

Trend Analysis POR: 10/4/1982 thru 6/2/2010









Summary statistics by season for NO2+NO3 Nitrogen vs Flow

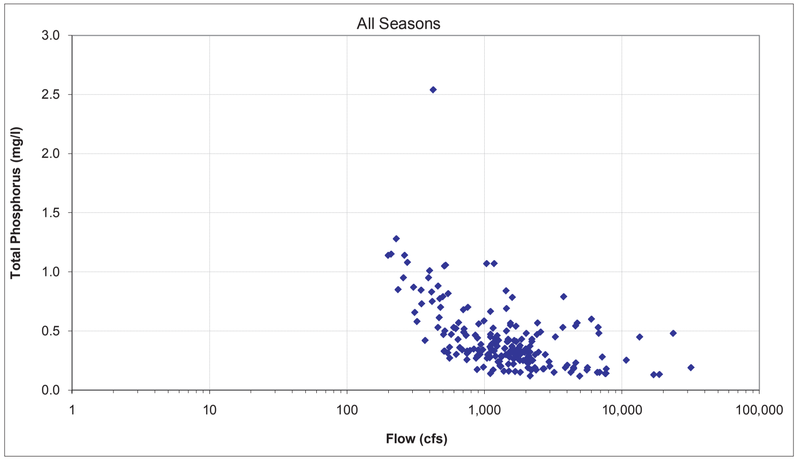
Season	n	% censored	Minimum	1st Quartile	Median	3rd Quartile	Maximum	IQ Range	Range	Mean	Standard Deviation	Standard Error	± 95% Conf Limit	Skewness	Kurtosis	Normality Check	r^2	t	p
All	190	0.5	0.03	0.70	1.06	1.60	5.41	0.90	5.38	1.32	0.971	0.070	0.138	1.833	3.696	0/2	0.039	-3.127	0.002
Cool	95	0.0	0.03	0.90	1.41	2.15	5.41	1.25	5.38	1.73	1.174	0.120	0.236	1.158	0.846	2/2	0.062	-2.812	0.006
Warm	95	0.0	0.06	0.63	0.84	1.12	1.97	0.49	1.91	0.92	0.425	0.044	0.085	0.473	-0.133	2/2	0.009	-1.038	0.301

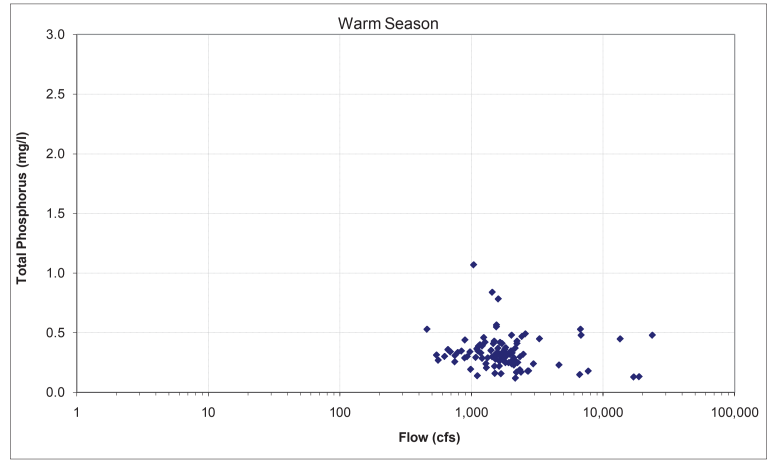
Colorado River at Columbus

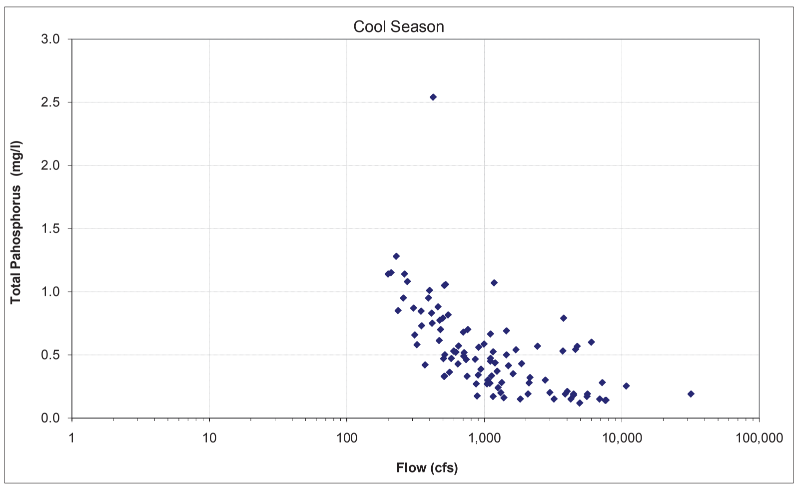
Total Phosphorus vs Flow

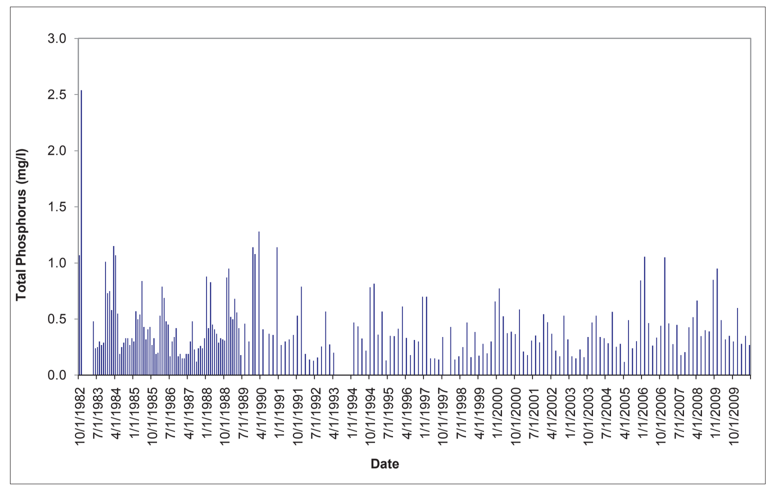
Flow Analysis

Trend Analysis POR: 10/4/1982 thru 6/2/2010









Summary statistics by season for Total Phosphorus vs Flow

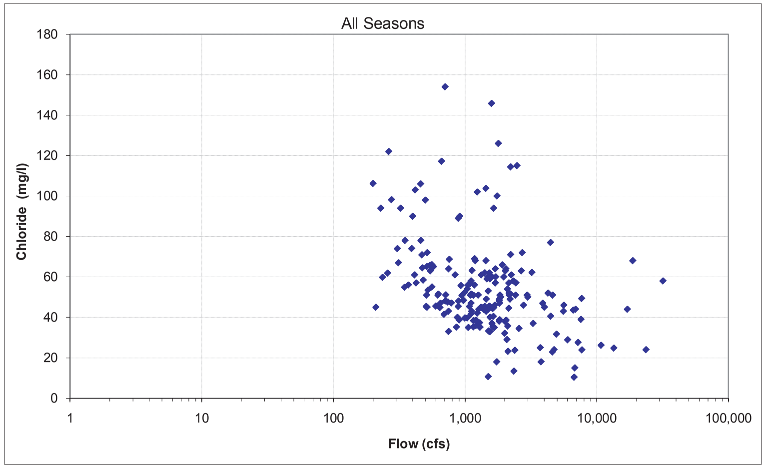
Season	n	% censored	Minimum	1st Quartile	Median	3rd Quartile	Maximum	IQ Range	Range	Mean	Standard Deviation	Standard Error	± 95% Conf Limit	Skewness	Kurtosis	Normality Check	r^2	t	p
All	197	0.0	0.12	0.26	0.35	0.52	2.54	0.26	2.42	0.43	0.286	0.020	0.040	2.816	14.685	0/2	0.028	-2.667	0.008
Cool	98	0.0	0.12	0.28	0.47	0.70	2.54	0.42	2.42	0.53	0.355	0.036	0.070	2.187	9.426	2/2	0.064	-2.854	0.005
Warm	99	0.0	0.12	0.25	0.32	0.39	1.07	0.14	0.95	0.33	0.144	0.014	0.028	2.063	7.761	2/2	0.000	0.092	0.927

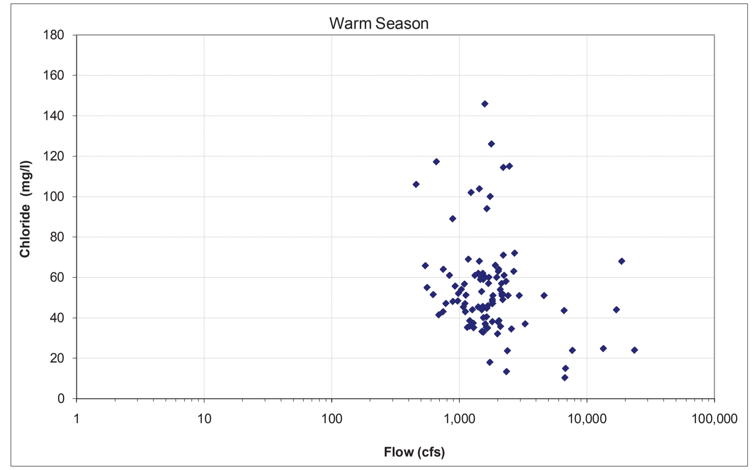
Colorado River at Columbus

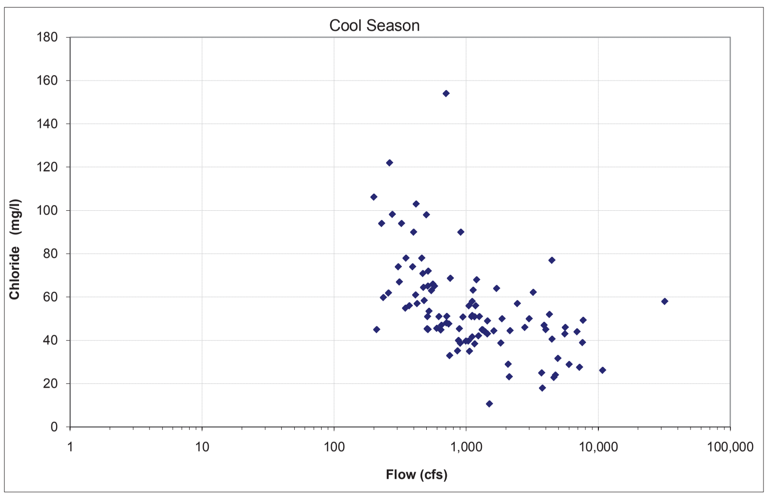
Chloride vs Flow

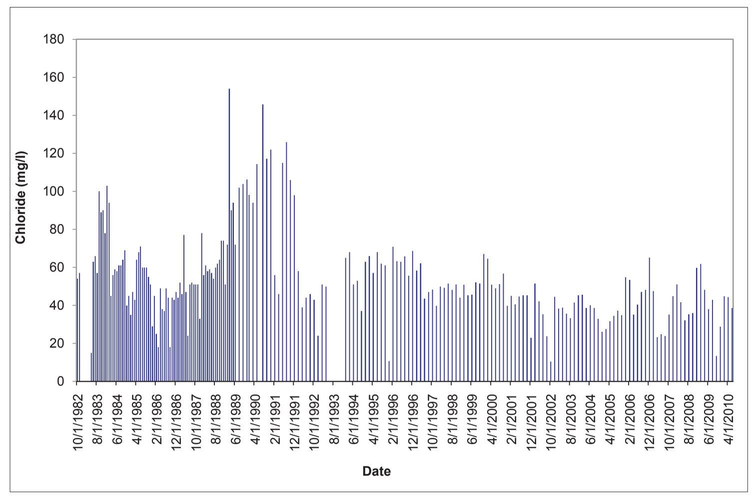
Flow Analysis

Trend Analysis POR: 10/4/1982 thru 6/2/2010









Summary statistics by season for Chloride vs Flow

Season	n	% censored	Minimum	1st Quartile	Median	3rd Quartile	Maximum	IQ Range	Range	Mean	Standard Deviation	Standard Error	± 95% Conf Limit	Skewness	Kurtosis	Normality Check	r^2	t	p
All	198	0.0	10.40	41.53	51.00	62.15	154.00	20.63	143.60	54.54	23.243	1.652	3.238	1.413	3.063	0/2	0.013	-1.786	0.075
Cool	99	0.0	10.70	43.00	50.80	63.60	154.00	20.60	143.30	54.70	22.389	2.250	4.410	1.448	3.789	2/2	0.020	-1.554	0.123
Warm	99	0.0	10.40	39.35	51.00	61.00	145.80	21.65	135.40	54.37	24.180	2.430	4.763	1.403	2.666	2/2	0.007	-0.947	0.346