Trinity River Basin BBEST
Instream Flow Study

Ecological Overlay for the Trinity River for support of Development of Instream Flow Recommendations for Environmental Flows:

Prepared for:
Trinity River Authority and
Texas Water Development Board

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September 21, 2009

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Executive Summary

This report summarizes available ecological information on the Trinity River and provides an "Ecological Overlay" document for future development of instream flow recommendations for the Trinity River. This summary report includes graphical representations and tabular information revealing key relationships between flow variation and the ecological indicators. This also include a species occurrence matrix indicating, when available, the location of various fish and aquatic species within the basin by river mile, TCEQ waterbody code, HUC code and latitude and longitude. This was developed in coordination with San Jacinto River Authority and other investigators in Texas who are conducting similar studies. Supporting graphical and tabular data are included and attached both in hard copy format and are available in digital format from the Trinity River Authority and/or Texas Water Development Board

Data used in the preparation was extracted from various sources including published peer reviewed articles, agency reports, federal aid progress reports, conference proceedings, and regional, state and federal environmental databases. The focus of this study was on development of ecological information on the occurrence and relationship of instream living resources and hydrology. However, an attempt was made to evaluate the concentrations and fluctuation of important water quality variables (water temperature, conductivity, dissolved oxygen, selected nutrients and suspended solids) in relation to flow. In addition we reviewed pertinent literature and data and generated estimates of downstream loading of suspended solids and nutrients to the lower river and estuary. These loads were evaluated for potential impacts on geomorphology and aquatic life.

We found that historically degraded water quality (anoxia, hypoxia and fish kills) had reduced or eliminated aquatic communities in the upper basin below Dallas Fort Worth. Today although many segments are still listed for violations of dissolved oxygen criteria, fish communities have recovered. One of the primary factors limiting full recovery of riverine/fluvial specialist fish species and reintroduction of highly migratory fishes is the high number of dams and reservoirs in the Trinity River basin which have fragmented the river and reduced connectivity. Based on recent studies the Trinity River watershed was classified as the most fragmented watershed in Texas. In addition, this network of reservoirs affects the ability of the river to transport nutrients and sediment to downstream areas. The cumulative extent of this impact is however unknown. The lowest reservoir on the river, Lake Livingston, has since its construction reduced sediment and nutrient loading to the lower river and/or Galveston Bay. The impacts of sediment reductions are however localized below the dam and do not appear to be affecting Galveston Bay due to the sediment load regeneration below the dam. Nitrogen and phosphorus loads have also been reduced below Lake Livingston in comparison to inputs from the upper watershed. However the phosphorus deficit has slowly been reduced in recent years. The effects of nutrient load reduction are unknown. During the period after dam construction chlorophyll-a levels declined rapidly in Galveston Bay. However, there are few pre-dam data and during this period point source loading sources in the lower basin were also reduced.

Two major products produced from this study include a species occurrence matrix which utilized data compiled from surveys of the literature including agency reports, and summarization of ecological relationships of candidate "focal species" previously suggested by TPWD. These focal species were compared, based on their life history attributes, to other members of the fish community to determine if they can serve as indicator species representing larger ecological fish guilds. Finally using these indicator species generic and specific recommendations on possible instream flow targets and metrics are presented. These data can be used to inform, validate and modify current and future hydrological analysis generated by IHA/HEFR/MBFIT to recommend environmental instream flow regimes for conservation and protection of the ecological health of the river. Although data on other biological communities exist for the Trinity River, there is, based on our literature survey, much more information on the fish communities of the Trinity River basin. This is due in part to their cultural and economic importance as a food and game resource, relative ease of identification, and the longer history of research and monitoring by state agencies and university researchers. Comparatively few long term data sets and studies exist on invertebrate and wildlife resources.

Introduction

This report summarizes available ecological information on the Trinity River and provides an "Ecological Overlay" document for future development of instream flow recommendations for the Trinity River. This summary report includes graphical representations and tabular information revealing key relationships between flow variation and the ecological indicators. This also include a species occurrence matrix indicating, when available, the location of various fish and aquatic species within the basin by river mile, TCEQ waterbody code, HUC code and latitude and longitude. This was developed in coordination with San Jacinto River Authority and other investigators in Texas who are conducting similar studies. Supporting graphical and tabular data are available in digital format from the Trinity River Authority and/or Texas Water Development Board with a copy of the full summary report.

Data used in the preparation was extracted from various sources including published peer reviewed articles, agency reports, federal aid progress reports, conference proceedings, and regional, state and federal environmental databases. The focus of this study was on development of ecological information on the occurrence and relationship of instream living resources and hydrology. However, two related study objectives were also included in the scope of work. This included developing background data on important variables processes needed to understand the influence of changing hydrology on water quality and the physical transport of sediments. Therefore an attempt was made to evaluate the fluctuation of important water quality parameters (water temperature, conductivity, dissolved oxygen, selected nutrients and suspended solids in relation to flow, including loading estimates at selected priority gages. In addition we have provided estimates of downstream loading of nutrients and suspended solids to the estuary from the Trinity River. Two major products produced from this study include a species occurrence matrix which utilized data compiled from surveys of the literature including agency reports, and summarization of ecological relationships of candidate "focal species" previously suggested by TPWD. These focal species were compared, based on their life history attributes, to other members of the fish community to determine if they can serve as indicator species representing larger ecological fish guilds. Finally using these indicator species generic and specific recommendations on possible instream flow regimes is presented. This data can be used to inform current and future hydrological analysis generated by IHA/HEFR/MBFIT to prescribe recommend flow regimes for conservation and protection of the ecological health of the river.

Although other biological data exist on benthic communities and wildlife, by far more information exists on the fish communities of the Trinity River basin. This is due in part to their cultural and economic importance as a fisheries resource and the more extensive history of research and monitoring by state agencies and university researchers. The primary sources of data include fisheries and river fish community studies by Texas Parks and Wildlife Department during the last 40 years and recent investigations by TCEQ and predecessor agencies conducting water quality related permitting studies including receiving water assessments. In addition, EPA and TCEQ have funded additional university studies investigating the effects of water quality on biota. Comparatively few data and studies exist on invertebrate and wildlife resources.

Background

Senate Bill 3 (SB 3), passed by the Texas Legislature in 2007, directed the development of environmental flow recommendations through a regulatory approach using a local stakeholder process and the best available science and culminating in Texas Commission on Environmental Quality (TCEQ) rulemaking. SB 3 directed the use of an environmental flow regime in developing flow standards from the environmental flow recommendations and defined a regime as a schedule of flow quantities that reflects seasonal and yearly fluctuations that typically would vary geographically and that are shown to be adequate to support a sound ecological environment and to maintain the productivity, extent, and persistence of key aquatic habitats. Initial flow recommendations by the local basin and bay expert science teams (BBEST) are to be made without regard to the need for the water for other uses.

The Science Advisory Committee (SAC) has published guidance on using hydrologic data as a method to develop initial instream flow recommendations as part of SB 3 efforts (Science Advisory Committee (SAC) 2009). One of the approaches outlined is the Hydrology-Based Environmental Flow Regime (HEFR) methodology which uses hydrologic data to populate an initial flow regime matrix consisting of monthly/seasonal schedules for subsistence flows, base flows, high flow pulses, and overbank flows. The hydrology-based approach represents a critical component in the collaborative process designed to identify flows needed to maintain a sound ecological environment in Texas Rivers and streams. However, completion of the process requires input from other scientific disciplines including biology, geomorphology, and water quality to ensure that environmental flow recommendations use the best available scientific information, and are adequate to support all processes and functions that maintain a sound ecological environment. This includes flow sufficient to maintain water quality, sediment transport, and provide habitat needs for aquatic life. To facilitate the use of other disciplines to inform, confirm, or modify the hydrology-based initial flow regime matrix, the SAC has produced various guidance documents related to the overlay of biologic, geomorphologic, and water quality information. Some of these have been completed, others are still in preparation.

The primary focus of this report is development of a biological overlay to be used in conjunction with ongoing hydrological based methods. Recently the SAC has produced a draft guidance on development of biological overlay information (Instream Biology Workgroup of the Science Advisory Committee (SAC) 2009). Many of the suggested approaches and recommended procedures in that document are included in this report and are outlined below.

The recommended steps as outlined in draft recommendations include:

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

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

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

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

STEP 5. Evaluate and refine the initial flow matrix

Our study and report provides information needed to immediately complete steps 2 and 3. Furthermore the information provided in this report can be used to assist the BBEST complete the remaining steps.

The SAC draft guidance also provided other general recommendations on use of biological data.

They are paraphrased and listed below.

1. Quantification of biology based flow parameters

The BBEST should examine sources from the literature review, assess them for relevance and identify any statements, data, or graphs that specifically link aspects of the flow regime with biota or key ecological processes. It is important to document key habitat requirements and preferences of target biological species and assemblages.

2. Causal connections based on available data and known relationships

It is recommended that the BBEST portray the flow-ecology relationships and ecological processes in a conceptual model. Conceptual models provide a concise way to portray ecological knowledge and show hypothesized linkages between flow and various aspects of ecosystem health, or a species' dependence upon certain flow conditions to complete a particular life history stage.

3. If there is existing data that links aspects of the flow regime with biological information, this information should be used to parameterize the flow regime analysis, e.g. HEFR

Based on the quantification of flow parameters, development of causal connections and geospatial information, information may be available that specifically links biological information to aspects of the flow regime. Even if specific biological information is not available to inform all decision points in the hydrographic separation, any available information should be used.

4. Subsistence flows should maintain water quality and key habitat considerations

Subsistence flows need to be sufficient to support key habitats and habitat needs for focal species, populations, or guilds of representative flowing-water organisms and adjustments should be made to minimize or avoid loss of key habitats and needs, to the extent possible. Flows should be evaluated and adjusted to ensure water quality parameters (e.g. DO and temperature) are maintained in a suitable range to ensure aquatic life persists/endures.

5. Base flows should be identified that provide suitable and diverse habitat conditions and support the survival, growth, and reproduction of aquatic organisms

To the extent available, information on focal species can be used to confirm and refine base flow estimates. Specifically, quantified flow-ecology relationships discovered in literature reviews can be used directly by comparing statistical (e.g. HEFR-derived) estimates with specific flow requirements. Qualitative life history information and conceptual models of species' life cycles can also be used. A variety of tools can be used to evaluate suitable habitat. Desktop methods can be used where limited information is available.

6. High flow pulses have important roles in maintaining water quality, physical processes, connectivity, and biological processes.

Pulse characteristics (such as the magnitude, timing, duration, and frequency) should be evaluated and refined relative to life history information for focal species, to the extent available. Approaches to address lateral connectivity to oxbows or other riparian habitats include reviewing available life history information, conducting targeted sampling and hydraulic modeling to identify flow levels needed to provide connections.

7. Overbanking flows support geomorphic processes, provide lateral connectivity, and maintain the balance and diversity of riparian areas.

Our study and report provides information needed to immediately evaluate and attain recommendations 1-3 and 5. Furthermore the information provided in this report can be used to assist the BBEST evaluate attainment of the remaining recommendations.

Data summarized in this report will need to be coupled with existing and future information generated by the hydrological analysis of the Trinity River basin. A separate related project conducted concurrently during this study was the hydrological analysis utilizing various tools including IHA, HEFR and/or MBFIT. The primary objective of that study entitled "*Use of Hydrologic Data in the Development of Instream Flow Recommendations for the Environmental Flows*" conducted by Crespo Consulting Services, Inc. was to study the flow regime at specific locations within the Trinity/San Jacinto River Basin (Crespo Consulting Services Inc. 2009). Their study included development of preliminary flow matrices for 8 locations on the Trinity River (along with qualifications about the meaning, limitations, and uses thereof), and recommendations on how these preliminary flows might ultimately be developed into environmental flow recommendations using biological overlay data, supplemental evaluation tools, and improvements in computational methodologies. Part of our effort involved comparing the distribution of biological resources in relation to these hydrological gages (potential control points) for future instream flow recommendations to insure complementary flow and biological data sets exist.

This report contains graphical representations and tabular information revealing key relationships between flow variation and the ecological indicators. Included in this report is a fish and aquatic invertebrate (mussel) species occurrence matrix. This was done in coordination with San Jacinto River Authority to facilitate use of the information by the Trinity and San Jacinto BBEST. The report includes graphical and tabular data including compiled summary biological data in electronic spreadsheet format. This report and analysis is an attempt to provide generic and where possible specific biological criteria that can be used to provide guidance to future hydrological analyses for development of instream flow criteria in the Trinity River.

Methodology

Hydrology Summary

In order to understand the potential biological responses to the hydrology in the basin it is necessary to provide some background on the historical hydrology in the basin. Eight priority USGS gage sites were selected from a list of 119 historical sites by the BBEST instream flow workgroup as potential control points in the Trinity River basin. The primary criteria used included having a sufficiently long period of record, and a strategic location which facilitates characterization of a significant percentage of the basin hydrology. These sites are listed and displayed in Table 1 and Figures 1 and 2. A separate but related project conducted concurrently during this study was the hydrological analysis utilizing various tools including IHA, HEFR and/or MBFIT. The primary objective of that study entitled "*Use of Hydrologic Data in the Development of Instream Flow Recommendations for the Environmental Flows*" conducted by Crespo Consulting Services, Inc. was to study the flow regime at specific locations within the Trinity/San Jacinto River Basin (Crespo Consulting Services Inc. 2009). Their study lays the groundwork for subsequent development of the hydrologic analysis. Their study included the development of preliminary flow matrices for eight priority gage locations (along with qualifications about the meaning, limitations, and uses thereof) on the Trinity River, and recommendations on how these preliminary flows might ultimately be developed into environmental flow recommendations using biological overlay data.

We also provided a very basic summary of the historical hydrology in the basin using the previously identified priority gages as control points. These data and related discussion are not intended to replace the more in-depth analysis provided through the Crespo Consulting report (IHA-HEFR/MBFIT analysis) but instead to provide a general description of long-term patterns in hydrology in the basin within the historical period of record. This may be helpful in understanding the possible relationships between hydrology, water quality, and life history adaptations and requirements of organisms within the river. Daily average discharge data during the period of record through December 2008, was obtained for the eight priority gage sites: (http://nwis.waterdata.usgs.gov/nwis/monthly/?search_site_no=08066500&agency_cd=USGS&referred_module=sw&format=sites_selection_links). Monthly mean daily average flow was generated for all months including periods with missing daily values. In addition, we computed average differences in flow (between adjacent days) as a means of characterizing daily variations in flow and ramping rates. The IHA software package was also used to preprocess and organize the daily mean average daily values and generate daily discharge graphs. The Minitab© software package was used to construct summary graphics.

Table 1. Location of priority gage sites on the Trinity River utilized for hydrological analysis project (Crespo Consulting 2009).

USGS Gage #	Gage Site Description	lat	long	TCEQ Segment #	HUC Code	River Mile	Watershed	Flow Data	
							sq. miles	begin date	end date
08055500	Elm Fork Trinity River near Carrollton, TX	32.96583	-96.94417	0822	12030103	18.2	2459	1907	2008
08049500	West Fork Tiniry River at Grand Prairie, TX	32.76250	-96.99444	0841	12030102	514.6	3065	1926	2008
08057000	Trinity River at Dallas, TX	32.77472	-96.82167	0805	12030105	500.3	6106	1904	2008
08062500	Trinity River near Rosser, TX	32.42639	-96.46278	0805	12030105	451.4	8147	1939	2008
08062700	Trinity River at Trinidad, TX	32.14750	-96.10222	0804	12030105	390.3	8538	1965	2008
08065000	Trinity River near Oakwood, TX	31.64833	-95.78917	0804	12030201	313.4	12833	1924	2008
08065350	Trinity River near Crockett, TX	31.33833	-95.65611	0804	12030201	265.4	13911	1964	2008
08066500	Trinity River @ Romayor, TX	30.42500	-94.85056	0802	12030202	94.3	171186	1925	2008

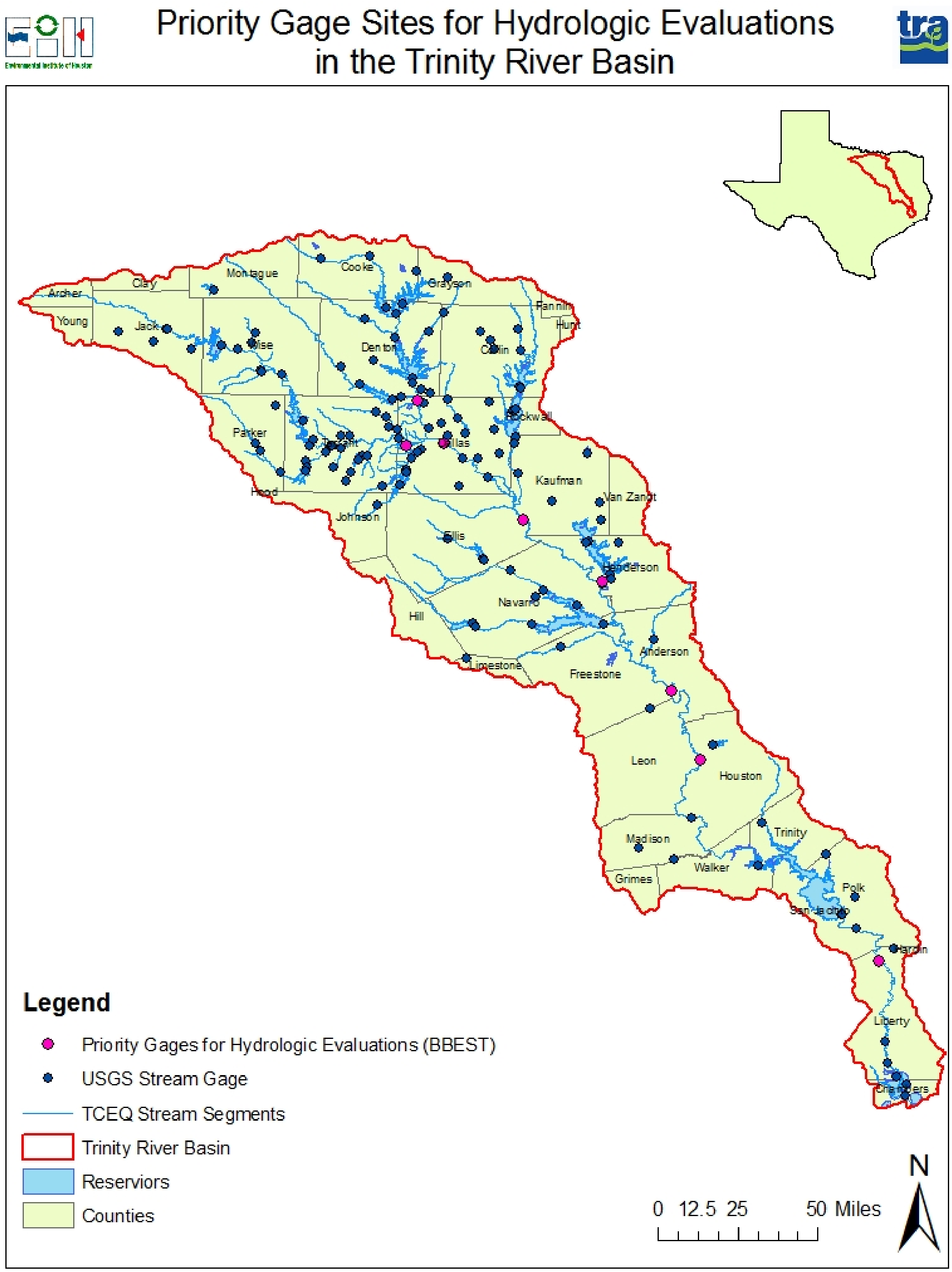


Figure 1. Distribution of USGS gage sites in Trinity River.

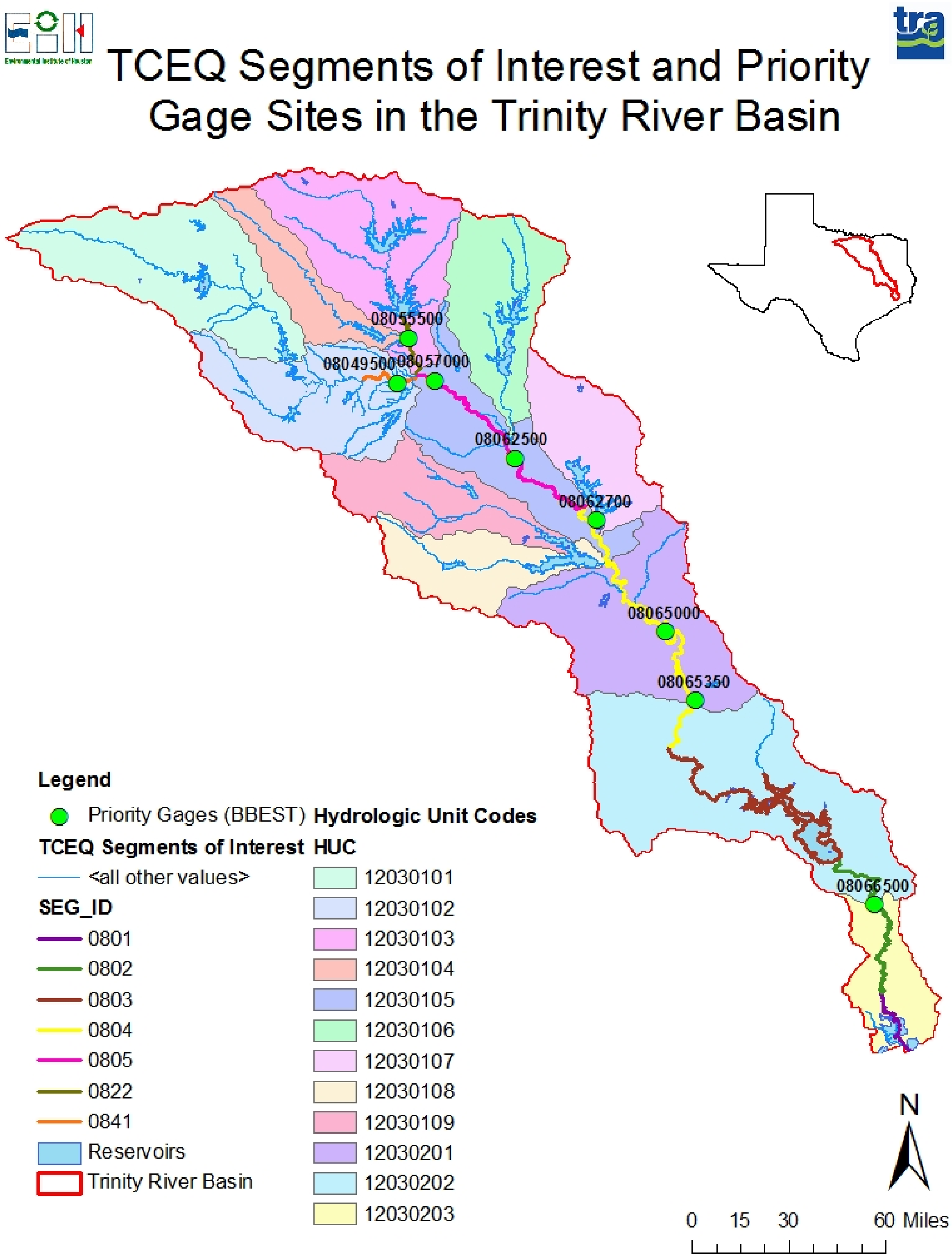


Figure 2. Distribution of USGS priority gage sites in relation to TCEQ segments and hydrologic units of the Trinity River.

Water Quality and Geomorphology

Recent and archived historical digital water quality and hydrology data within the Trinity River basin was compiled from both USGS, TCEQ and the Clear Rivers Program (CRP) partner TRA and are included in the comprehensive database compiled by EIH prior to this project. In order to evaluate the potential relationship between hydrology and water quality we queried several databases including the USGS, Clean Rivers Program and TCEQ surface water quality monitoring database. In order to evaluate the relationship between streamflow and water quality and geomorphology (i.e. sediment transport) we focused our efforts on the eight USGS priority gage sites and associated TCEQ river segments on the Trinity River utilized by the hydrological analysis study (Crespo Consulting Services Inc. 2009)(Figures 1 and 2). The preferred data sets in order of priority include USGS, TCEQ, and Clean Rivers Program (CRP). Data collected by USGS at priority gage sites were specifically targeted for characterization. In all cases we utilized paired water quality data collected near the gage site and upstream of any major downstream tributaries. Water quality data collected by TCEQ and Clean Rivers Program at routine water quality monitoring sites were used to supplement data collected at the USGS gage network to provide broad scale characterizations of selected variables (Figure 3). Since much of the water quality data collected in the state is done for compliance with water quality standards we also provide a list of the current legally defined water body segments in the Trinity River watershed that are used for water quality management (Table 2)(TNRCC 2000).

Graphical plots depicting streamflow, concentrations and loading were constructed when paired water quality and instantaneous flow data were available. We also attempted to develop statistical models of flow versus observed water quality data. In most cases we only plotted data if there was sufficient temporal intensity and coverage. Our decision rule was to only conduct these analyses when at least 10 observations were obtained over a range of flow levels. The period of record was usually shorter then the period of record for only discharge data alone and is reported with each graph. When data was insufficient we did not plot the data. In some cases we evaluated the fit of various statistical models (e.g. linear, log-linear and quadratic) to determine if there were viable predictive models that could be develop predictive discharges loading estimates and key water quality variables that may influence stream productivity and aquatic organisms.

Target parameters included water temperature, specific conductance, suspended solids, and nutrients (nitrates or nitrate+nitrites, total phosphorus, orthophosphates). For water temperature and dissolved oxygen we segregated the data first into seasonal periods and then analyzed these subsets separately. In some cases data were limited and/or lacking and consequently some analyses were not feasible. Another critical factor that should be noted was the frequency and reason for data collection. Matching flow and water quality data sets collected by USGS were collected at various time frequencies including long term monitoring and storm events. Sampling frequency and timing along with prior environmental conditions (e.g. flood, drought) will influence the levels in nutrients etc. For example levels of pollutants are often highly elevated during the initial rising limb of a storm hydrograph following a dry period than comparable flows levels under sustained stream flow conditions during wet periods. The relationship of these parameters would be expected to vary due to the factors. However, our basic analysis does not separate these groups. Therefore potential relationships between parameters during storm versus sustained flows may be obscured. To separate this it would be necessary to go back and reclassify these data sets and analyze them separately.

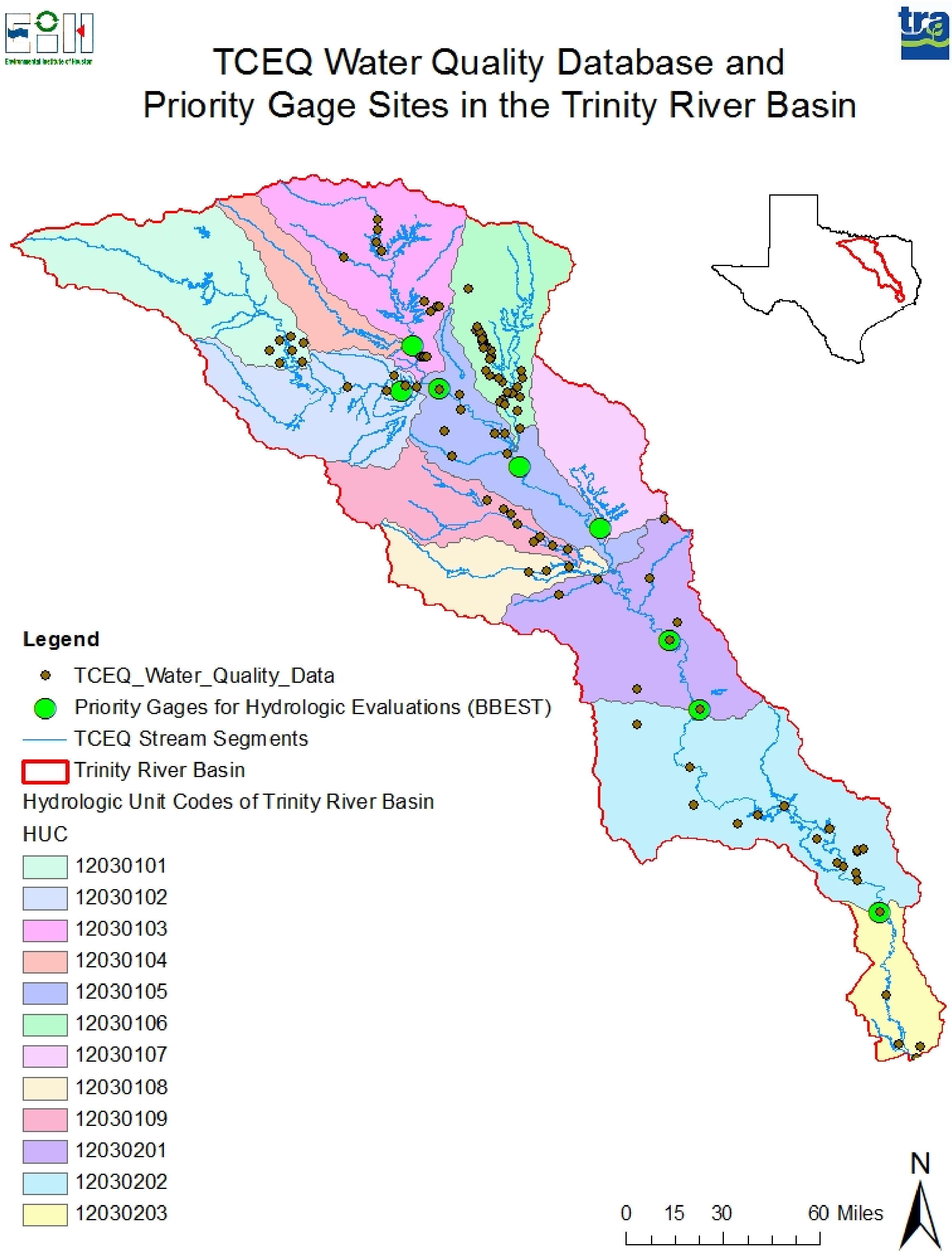


Figure 3. Location of TCEQ/CRP water quality monitoring sites within the Trinity River Basin that were used as data sources.

Table 2. List of legally defined waterbody segments within the Trinity River watershed (TNRCC 2000). Other segments referred to in the text with letter suffixes refer to unclassified tributaries of these main segments.

SEGMENT	DESCRIPTION
0801	Trinity River Tidal - from the confluence with Anahuac Channel in Chambers County to a point 3.1 kilometers (1.9 miles) downstream of US 90 in Liberty County
0802	Trinity River Below Lake Livingston - from a point 3.1 kilometers (1.9 miles) downstream of US 90 in Liberty County to Livingston Dam in Polk/San Jacinto County
0803	Lake Livingston - from Livingston Dam in Polk/San Jacinto County to a point 1.8 kilometers (1.1 miles) upstream of Boggy Creek in Houston/Leon County, up to the normal pool elevation of 131 feet
0804	Trinity River Above Lake Livingston - from a point 1.8 kilometers (1.1 miles) upstream of Boggy Creek in Houston/Leon County to a point immediately upstream of the confluence of the Cedar
0805	Upper Trinity River - from a point immediately upstream of the confluence of the Cedar Creek Reservoir discharge canal in Henderson/Navarro County to a point immediately upstream of the
0806	West Fork Trinity River Below Lake Worth - from a point immediately upstream of the confluence of Village Creek in Tarrant County to Lake Worth Dam in Tarrant County
0807	Lake Worth - from Lake Worth Dam in Tarrant County to a point 4.0 kilometers (2.5 miles) downstream of Eagle Mountain Dam in Tarrant County, up to the normal pool elevation of 594.3 feet
0808	West Fork Trinity River Below Eagle Mountain Reservoir - from a point 4.0 kilometers (2.5 miles) downstream of Eagle Mountain Dam in Tarrant County to Eagle Mountain Dam in Tarrant County
0809	Eagle Mountain Reservoir - from Eagle Mountain Dam in Tarrant County to a point 0.6 kilometer (0.4 mile) downstream of the confluence of Oates Branch in Wise County up to the normal pool
0810	West Fork Trinity River Below Bridgeport Reservoir - from a point 0.6 kilometer (0.4 mile) downstream of the confluence of Oates Branch in Wise County to Bridgeport Dam in Wise County
0811	Bridgeport Reservoir - from Bridgeport Dam in Wise County to a point immediately upstream of the confluence of Bear Hollow in Jack County, up to the normal pool elevation of 836 feet (impounds
0812	West Fork Trinity River Above Bridgeport Reservoir - from a point immediately upstream of the confluence of Bear Hollow in Jack County to SH 79 in Archer County
0813	Houston County Lake - from Houston County Dam in Houston County up to the normal pool
0814	Chambers Creek Above Richland-Chambers Reservoir - from a point 4.0 kilometers (2.5 miles) downstream of Tupelo Branch in Navarro County to the confluence of North Fork Chambers Creek
0815	Bardwell Reservoir - from Bardwell Dam in Ellis County up to the normal pool elevation of 421 feet
0816	Lake Waxahachie - from South Prong Dam in Ellis County up to the normal pool elevation of 531.5
0817	Navarro Mills Lake - from Navarro Mills Dam in Navarro County up to the normal pool elevation of
0818	Cedar Creek Reservoir - from Joe B. Hoggsett Dam in Henderson County up to the normal pool
0819	East Fork Trinity River - from the confluence with the Trinity River in Kaufman County to Rockwall-
0820	Lake Ray Hubbard - from Rockwall-Forney Dam in Kaufman County to Lavon Dam in Collin County, up to the normal pool elevation of 435.5 feet (impounds East Fork Trinity River)
0821	Lavon Lake - from Lavon Dam in Collin County up to the normal pool elevation of 492 feet
0822	Elm Fork Trinity River Below Lewisville Lake - from the confluence with the West Fork Trinity River in Dallas County to Lewisville Dam in Denton County
0823	Lewisville Lake - from Lewisville Dam in Denton County to a point 200 meters (220 yards) upstream of FM 428 in Denton County, up to the normal pool elevation of 522 feet (impounds Elm Fork Trinity
0824	Elm Fork Trinity River Above Ray Roberts Lake - from a point 9.5 kilometers (5.9 miles) downstream of the confluence of Pecan Creek in Cooke County to US 82 in Montague County
0825	Denton Creek - from the confluence with the Elm Fork Trinity River in Dallas County to Grapevine
0826	Grapevine Lake - from Grapevine Dam in Tarrant County up to the normal pool elevation of 535 feet
0827	White Rock Lake - from White Rock Dam in Dallas County up to the normal pool elevation of 458
0828	Lake Arlington - from Arlington Dam in Tarrant County up to the normal pool elevation of 550 feet

Source: (TNRCC 2000).

We also provided estimates of draft 7Q2 estimates obtained from TCEQ for selected USGS gage sites in the basin. We also reviewed the most current TCEQ 303d list of impaired water bodies to determine the causes and extent of impairment within the basin and potential influences on aquatic biota (Texas Commission on Environmental Quality (TCEQ) 2009). Using available data and previous published literature we also provide estimated loads of nutrients and solids to Galveston Bay by utilizing data at the most downstream gage, Trinity River at Rotator (08066500). We have also provided citations in our EndNote® databases on pertinent water quality and geomorphological studies, and in some cases associated data in Excel Spreadsheets and/or Access databases for future analyses. Where appropriate we have cited data extracted data and estimates from these reports. We attempted to compile stream cross-sectional data from known USGS gage sites but were only able to obtain a few from the agency since most of this information is not digital.

Focal Species Matrix

Prior to the August 2009 BBEST meeting, the Texas Parks and Wildlife Department (TPWD) was contacted and asked to provide a preliminary list of "focal" species that should be considered during development of the ecological overlay analysis and report. The focal species included selected finfish and unionid mussels. Some of these recommended species were presented at the Trinity/San Jacinto BBASC meeting in July 2009 (Botros 2009). One of the critical exercises we would conduct is a comparison of the distribution of important species with the distribution of priority gages. Hopefully there would be considerable overlap so that information obtained from the biological analysis could be used with hydrological data collected in the same section of river. Upon receipt we cross referenced these recommended species against our existing Trinity watershed fish species matrix that we had previously developed (Table 3).

The species matrix was initially developed using data compiled from a comprehensive literature review of fisheries and aquatic surveys historically conducted or sponsored by various agencies including EPA, USGS, FWS, TPWD, TCEQ, TRA, and university researchers. Data was obtained from various resources including electronic literature databases, peer reviewed articles, and gray literature (agency reports). In some cases this involved directly contacting regional fisheries and aquatic biologists directly. They would sometimes need to make copies of the original reports and send them to us. This included old Federal Aid Progress (Dingell-Johnson) Reports. The responding biologists knew our primary study emphasis was riverine fish populations. Consequently, it is possible that some reservoir fisheries investigations conducted by TPWD during the mid-1970s through mid-1980s were under reported.

Recent synthesis studies on the distribution and status of Texas freshwater fishes conducted by Dr. Tim Bonner at Texas State University and Dr. Dean Hendrickson from the University of Texas have also generated lists of species found in the Trinity River Basin. The data on occurrences on the Trinity Basin compiled by Dr. Bonner was extracted from his web page: http://www.bio.txstate.edu/~tbonner/txfishes/Trinity.htm. Dr. Hendrickson provided a draft copy of his compilation of Trinity River fish species from the ("Fishes of Texas Project database, Texas Natural History Collections, University of Texas at Austin (http://www.utexas.edu/tmm/tnhc/)"). This was provided to us on August 13, 2009 on an Excel spreadsheet. His data was compiled by various institutions and researchers who contributed data to the project. This included voucher specimens. The list of data donor institutions is maintained on their website.

Table 3. List of fish species previously observed or collected in the Trinity River basin.

SPECIES	COMMON NAME	FAMILY	STATUS	OUR STUDY	BONNNER Web Site	Hendrick Study	Shared	Trophic	Tolerance	BALON Reprod Guild	TPWD Spp Concern	Hubbs Status
Agonostomus monticola	mountain mullet	Mugilidae			1	1	2	O	N	CAT		
Alosa chrysochloris	skipjack herring	Clupeidae	ANA	1	1	1	3	P	N	A14		
Ambloplites rupestris	rock bass	Centrarchidae		1			1	P	I	B22		
Ameiurus nebulosus	brown bullhead	Ictaluridae	??	1			1	O	N	B27		
Ameiurus melas	black bullhead	Ictaluridae		1	1	1	3	O	T	B27		
Ameiurus natalis	yellow bullhead	Ictaluridae		1	1	1	3	O	N	B27		
Amia calva	bowfin	Amiidae		1	1	1	3	P	T	B25		
Ammocrypta vivax	scaly sand darter	Percidae		1	1	1	3	IF	N	A16		
Anguilla rostrata	American eel	Anguillidae		1	1	1	3	P	N	CAT		SC
Aphredoderus sayanus	pirate perch	Aphredoderidae		1	1	1	3	IF	N	C14		
Aplondinotus grunniens	freshwater drum	Sciaenidae		1	1	1	3	IF	T	A11	TR	
Astyanax mexicanus	Mexican tetra	Characidae		1	1	1	3	IF	N	A11		
Atractosteus spatula	alligator gar	Lepisosteidae		1	1	1	3	P	T	A15	TR	SC
Campostoma anomalum	central stoneroller	Cyprinidae		1	1	1	3	H	N	A23		
Carassius auratus	goldfish	Cyprinidae	(I)	1	1	1	3	O	T	A15		
Carpiodes carpio	river carpsucker	Catostomidae		1	1	1	3	O	T	A12		
Centrarchus macropterus	flier	Centrarchidae		1	1	1	3	IF	N	B23		
Cichlasoma cyanoguttatum	Rio Grande cichlid	Cichlidae			1	1	2	IF	N	B23		
Ctenopharyngodon idella	grass carp	Cyprinidae	(I)		1		1	H	T	A11		
Cycleptus elongatus	blue sucker	Catostomidae			1		1	IF	I	A12		T
Cyprinella lutrensis	red shiner	Cyprinidae		1	1	1	3	IF	T	A24		
Cyprinella venusta	blacktail shiner	Cyprinidae		1	1	1	3	IF	N	A24		
Cyprinodon rubrofluviatilis	Red River pupfish	Cyprinodontidae				1	1	O	T	B23		
Cyprinodon variegatus	sheepshead minnow	Cyprinodontidae		1	1	1	3	O	T	B23		
Cyprinus carpio	common carp	Cyprinidae	(I)	1	1	1	3	O	T	A14		
Dionda argentosa	Manatial roundnose minnow	Cyprinidae				1	1	O	I	A13		
Dionda episcopa	roundnose minnow	Cyprinidae				1	1	O	I	A13		
Dorosoma cepedianum	gizzard shad	Clupeidae		1	1	1	3	O	T	A12		
Dorosoma petenense	threadfin shad	Clupeidae		1	1	1	3	O	N	A15		
Elassoma zonatum	banded pygmy sunfish	Elassomatidae		1	1	1	3	IF	N	B14		
Erimyzon oblongus	creek chubsucker	Catostomidae		1	1	1	3	O	N	A12	**SJR**	T
Erimyzon sucetta	lake chubsucker	Catostomidae		1	1	1	3	O	N	A14		
Esox americanus	redfin pickerel	Esocidae		1	1	1	3	P	N	A15		
Esox niger	chain pickerel	Esocidae		1			1	P	N	A15		
Etheostoma artesiae	redspot darter	Percidae		1			1	IF	N	B14		
Etheostoma chlorosomum	bluntnose darter	Percidae		1	1	1	3	IF	N	B14		
Etheostoma fusiforme	swamp darter	Percidae				1	1	IF	N	B14		
Etheostoma gracile	slough darter	Percidae		1	1	1	3	IF	N	B14		
Etheostoma histrio	harlequin darter	Percidae		1	1		2	IF	N	B14		
Etheostoma lepidum	greenthroat darter	Percidae		1		1	2	IF	I	B14		
Etheostoma nigrum	johny darter	Percidae				1	1	IF	N	B27		
Etheostoma parvipinne	goldstripe darter	Percidae				1	1	IF	I	B14		
Etheostoma proeliare	cypress darter	Percidae		1	1	1	3	IF	I	B14		
Etheostoma spectabile	orangethroat darter	Percidae		1	1	1	3	IF	N	A23		
Fundulus blairae	western starhead topminnow	Fundulidae			1	1	2	IF	N	A14		
Fundulus chrysotus	golden topminnow	Fundulidae		1	1	1	3	IF	N	A14		
Fundulus cingulatus	Banded topminnow	Fundulidae				1	1	IF	N	A23		
Fundulus diaphanus	banded killifish	Fundulidae		1			1	IF	N	A15		
Fundulus dispar	starhead topminnow	Fundulidae		1		1	2	IF	N	A14		
Fundulus notatus	blackstripe topminnow	Fundulidae		1	1	1	3	IF	N	A15		
Fundulus nottii	bayou topminnow	Fundulidae				1	1	IF	N	A14		
Fundulus olivaceus	blackspotted topminnow	Fundulidae		1	1	1	3	IF	I	A13		
Fundulus zebrinus	plains killifish	Fundulidae			1	1	2	IF	T	A14		
Gambusia affinis	western mosquitofish	Poeciliidae		1	1	1	3	IF	N	C21		
Gambusia geiseri	largespring gambusia	Poeciliidae				1	1	IF	N	C21		
Gambusia speciosa	Tex-Mex gambusia	Poeciliidae				1	1	IF	N	C21		
Hybognathus nuchalis	Mississippi silvery minnow	Cyprinidae		1	1	1	3	O	T	A12		
Hybognathus placitus	plains minnow	Cyprinidae		1	1		2	O	T	A11		
Hybopsis amnis	pallid shiner	Cyprinidae			1	1	2	IF	N	A11	**SJR**	
Ichthyomyzon castaneus	chestnut lamprey	Petromyzontidae		1			1	P	I	A23		
Ichthyomyzon gagei	southern brook lamprey	Petromyzontidae		1	1	1	3	None	I	A23		
Ictalurus furcatus	blue catfish	Ictaluridae		1	1	1	3	P	N	B27	TR	
Ictalurus punctatus	channel catfish	Ictaluridae		1	1	1	3	O	T	B27		
Ictiobus bubalus	smallmouth buffalo	Catostomidae		1	1	1	3	O	N	A12		
Ictiobus cyprinellus	bigmouth buffalo	Catostomidae	?	1			1	IF	T	A12		
Ictiobus niger	black buffalo	Catostomidae		1	1		2	O	N	A12		
Labidesthes sicculus	brook silverside	Atherinopsidae		1	1	1	3	IF	I	A14		
Lepisosteus oculatus	spotted gar	Lepisosteidae		1	1	1	3	P	T	A15		
Lepisosteus osseus	longnose gar	Lepisosteidae		1	1	1	3	P	T	A14	SJR	
Lepisosteus platostomus	shortnose gar	Lepisosteidae		1		1	2	P	T	A15		
Lepomis auritus	redbreast sunfish	Centrarchidae	(I)	1	1	1	3	IF	N	B22		
Lepomis cyanellus	green sunfish	Centrarchidae		1	1	1	3	P	T	B22		
Lepomis gulosus	warmouth	Centrarchidae		1	1	1	3	P	T	B23		
Lepomis humilis	orangespotted sunfish	Centrarchidae		1	1	1	3	IF	N	B23		

Table 3. Continued

SPECIES	COMMON NAME	FAMILY	STATUS	OUR STUDY	BONNNER Web Site	Hendrick Study	Shared	Trophic	Tolerance	BALON Reprod Guild	TPWD Spp Concern	Hubbs Status
Lepomis macrochirus	bluegill	Centrarchidae		1	1	1	**3**	IF	T	B22		
Lepomis marginatus	dollar sunfish	Centrarchidae		1	1	1	**3**	IF	N	B22		
Lepomis megalotis	longear sunfish	Centrarchidae		1	1	1	**3**	IF	N	B22	TR	
Lepomis microlophus	redear sunfish	Centrarchidae		1	1	1	**3**	IF	N	B22		
Lepomis miniatus	redspotted sunfish.	Centrarchidae		1	1	1	**3**	IF	N	B22		
Lepomis symmetricus	bantam sunfish	Centrarchidae		1	1	1	**3**	IF	N	B22		
Luxilus chrysocephalus	striped shiner	Cyprinidae		1		1	**2**	IF	N	A13		
Lythrurus fumeus	ribbon shiner	Cyprinidae		1	1	1	**3**	IF	N	A13	**SJR**	
Lythrurus umbratilis	redfin shiner	Cyprinidae		1	1	1	**3**	IF	N	A13		
Macrhybopsis hyostoma	shoal chub	Cyprinidae			1		**1**	IF	N	A11		
Membras martinica	rough silverside	Atherinopsidae			1	1	**2**	IF	N	A14		
Menidia beryllina	inland silverside	Atherinopsidae		1	1	1	**3**	IF	N	A14		
Menidia peninsulae	tidewater silverside	Atherinopsidae		1			**1**	IF	N	A14		
Micropterus dolomieui	smallmouth bass	Centrarchidae		1		1	**2**	P	I	B22		
Micropterus punctulatus	spotted bass	Centrarchidae		1	1	1	**3**	P	N	B22		
Micropterus salmoides	largemouth bass	Centrarchidae		1	1	1	**3**	P	N	B22	TR	
Minytrema melanops	spotted sucker	Catostomidae		1	1	1	**3**	IF	N	A12		
Morone americana	white perch	Moronidae				1	**1**	P	N	A14		
Morone chrysops	white bass	Moronidae		1	1	1	**3**	P	N	A14	TR	
Morone mississippiensis	yellow bass	Moronidae		1	1	1	**3**	P	N	A14		
Morone saxatilis	striped bass	Moronidae	(I)	1	1	1	**3**	P	N	A14		
Moxostoma congestum	gray redhorse	Catostomidae		1		1	**2**	IF	N	A13		
Moxostoma poecilurum	blacktail redhorse	Catostomidae		1	1	1	**3**	IF	N	A13	SJR	
Notemigonus crysoleucas	golden shiner	Cyprinidae		1	1	1	**3**	IF	T	A15		
Notropis amabilis	Texas shiner	Cyprinidae		1		1	**2**	IF	N	A11		
Notropis atherinoides	emerald shiner	Cyprinidae		1	1	1	**3**	IF	N	A11		
Notropis atrocaudalis	blackspot shiner	Cyprinidae		1	1	1	**3**	IF	N	A11	TR&SJR	SC
Notropis blennius	ghost shiner	Cyprinidae		1	1		**2**	IF	N	A12		
Notropis buchanani	ghost shiner	Cyprinidae		1		1	**2**	IF	N	A12		
Notropis chalybaeus	ironcolor shiner	Cyprinidae		1		1	**2**	IF	I	A12		SC
Notropis chrosomus	rainbow shiner	Cyprinidae	**?**	1			**1**	IF	N	A12		
Notropis jemezanus	Rio Grande shiner	Cyprinidae				1	**1**	IF	N	A11		
Notropis potteri	chub shiner	Cyprinidae			1	1	**2**	IF	N	A12		SC
Notropis sabinae	Sabine shiner	Cyprinidae		1	1		**2**	IF	N	A12		SC
Notropis shumardi	silverband shiner	Cyprinidae		1	1	1	**3**	IF	N	A12	TR	SC
Notropis stramineus	sand shiner	Cyprinidae		1	1	1	**3**	IF	N	A12		
Notropis texanus	weed shiner	Cyprinidae		1	1	1	**3**	IF	N	A15		
Notropis volucellus	mimic shiner	Cyprinidae		1	1	1	**3**	IF	I	A15		
Noturus gyrinus	tadpole madtom	Ictaluridae		1	1	1	**3**	IF	I	B27		
Noturus nocturnus	freckled madtom	Ictaluridae		1	1	1	**3**	IF	I	B27	SJR	
Oncorhynchus mykiss	rainbow trout	Salmonidae			1	1	**2**	IF	I	A23		
Opsopoeodus emiliae	pugnose minnow	Cyprinidae		1	1	1	**3**	IF	N	B27		
Oreochromis aureus	blue tilapia	Cichlidae	(I)	1		1	**2**	O	T	B13		
Percina caprodes	logperch	Percidae		1		1	**2**	IF	I	A23		
Percina carbonaria	Texas logperch	Percidae	?	1			**1**	IF	I	A23		
Percina macrolepida	bigscale logperch	Percidae		1	1	1	**3**	IF	I	A23		
Percina sciera	dusky darter	Percidae		1	1	1	**3**	IF	I	A23	TR	
Percina shumardi	river darter	Percidae			1		**1**	IF	I	A23		
Phenacobius mirabilis	suckermouth minnow	Cyprinidae		1	1	1	**3**	IF	N	A12		
Pimephales notatus	bluntnose minnow	Cyprinidae		1			**1**	IF	N	B27		
Pimephales promelas	fathead minnow	Cyprinidae		1	1	1	**3**	O	T	B27		
Pimephales vigilax	bullhead minnow	Cyprinidae		1	1	1	**3**	IF	N	B27		
Poecilia latipinna	sailfin molly	Poeciliidae		1	1	1	**3**	O	T	C21		
Polyodon spathula	paddlefish	Polyodontidae		1	1		**2**	O	I	A12	TR	T
Pomoxis annularis	white crappie	Centrarchidae		1	1	1	**3**	P	N	B25		
Pomoxis nigromaculatus	black crappie	Centrarchidae		1	1	1	**3**	P	N	B25		
Pygocentrus nattereri	red piranha	Characidae	(I)			1	**1**	P	N	B14		
Pylodictis olivaris	flathead catfish	Ictaluridae		1	1	1	**3**	P	N	B27	SJR	
Sander vitreus	walleye	Percidae		1			**1**	P	N	A12		
Semotilus atromaculatus	creek chub	Cyprinidae		1	1	1	**3**	P	N	A23		

Explanation for various codes used in Table 3 provided in Table 4. Yellow highlighted rows are for original focal species identified by TPWD and presented at BBEST meeting in August 2009. List compiled from EIH Trinity River fish database, (Bonner 2009), and (Hendrickson 2009; Hendrickson et al. 2008)

All of the data compiled by these various efforts including ours should be considered works in progress since the accuracy of taxonomic identifications and locality data is constantly being reviewed and updated. Dr. Hendrickson agreed to provide his data with the provision that specific collection locations not be revealed. In addition to utilizing data from fishery investigations and aquatic surveys we also reviewed information on the distribution of freshwater fishes from several compilations of freshwater fish distribution within United States and Texas including online electronic databases (e.g. FishBase) (Conner and Suttkus 1986; Froese and Pauly 2000; Hubbs et al. 2008; Lee et al. 1980). The final resulting species matrix list represents the most recent comprehensive compilation of the occurrence of freshwater fish species within the Trinity River basin. We believe our approach is was very thorough and consistent with other large scale efforts to compile comprehensive assessment of freshwater fish species distributions conducted across the world. For example, the author recently attended a technical session, *Symposium 11: Mapping Distributions of North American Freshwater Fishes* which was held at the 2009 national annual meeting of the American Fisheries Society (http://www.fisheries.org/afs09/docs/talks.pdf). At the panel discussion part of the session the moderator reported that the primary databases and literature searched during these large national compilations consisted of state museum collections, state agency collections and published sources such as the *Atlas of North American Freshwater Fishes*, regional fish guides and FishBase (Lee et al. 1980). Our study followed this investigation approach as well.

To facilitate construction of meaningful species guilds we classified species based on published literature into their respective trophic levels, water quality tolerance, and reproductive behavior and early life history classifications (Tables 3 and 4) (Balon 1975; Balon 1981; Linam and Kleinsasser 1998; Simon 1999a). If data were lacking for a species we would utilize information from taxonomically related species that shares similar life history traits.

After compiling the list of fish species, including focal species, and their associated attributes a multivariate cluster analysis technique (Wards algorithm, squared Euclidean distance) was used to classify species (observations) based on shared characteristics. These traits were estimated using indicator variables generated from the suite of life history traits including reproductive behaviour, trophic level and tolerance levels was conducted (Linam and Kleinsasser 1998; Romesburg 1990; Simon 1999a). This process produced a multivariate dendrogram which depicts the similarity of species and species groups based on shared life history attributes. After examination of the output we then classified fish species with highest group affinities into community “guilds”. These guilds, which represent species assemblages with similar life history traits were subsequently examined to determine if at least one candidate “focal” species was present in every guild. Membership in a guild would suggest that the focal species exhibits life history characteristics similar to other members of the group. Furthermore this focal species could theoretically be used as an indicator for that assemblage.

Table 4. Biological codes used in tables 3 and 5.

Guild	Name	Description
A	**Non Guarders**	
A1	**Open Sustratum Spawner**	
A11	Pelagophils	bouyant eggs, open spawners
A12	Lithopelagophils	rock, gravel spawners, pelagic free larvae
A13	Lithophils	rock gravel spawners, benthic larvae
A14	Phytolithophils	nonobligatory plant spawners, benthic larvae
A15	Phytophils	obligatory plant spawners, benthic larvae
A16	Psammophils	sand spawners, benthic larvae
A2	**Brood Hiders**	
A23	Lithophils	rock and gravel spawners, deposit eggs in redd or gravel, not guarded
A24	Speleophils	Cave spawning species, large adhesive eggs
B	**Guarders**	
B1	**Substratum choosers**	**female picks egg deposition site**
B13	Lithophils	rock spawning, adhesive eggs, pelagic larvae
B14	Phytophils	plant spawning, adhesive eggs, pelagic larvae
B2	**Nest Spawners**	**Nests built and guarded**
B22	Polyphils	misc substrate and material nesters
B23	Lithophils	rock and gravel nesters
B24	Ariadnophils	Glue making nesters
B25	Polyphils	plant material nesters
B27	Speleophils	hole nesters
C	**Bearers**	
C1	**External Bearers**	
C13	Mouth Brooders	e.g. tilapia
C14	Gill chamber brooders	e.g. Gill chamber brooders
C2	**Internal Bearers**	
C24	Viviparious	e.g. Viviparous C24

Trophic	**Description**	
IF	Invertivore	
P	Piscivore	
O	Omnivore	
H	Herbivore	
Water Quality Tolerance		
I	intoleranct	
N	neutral or unknown	
T	tolerant	
MISC CODES		
I	introduced	
CAT	Catadromous	
ANA	Anadromous	
TR	Trinity River	
SJR	San Jacinto River	
?	Questionable sighting	
Conservation Status		
SC	Species of concern	
T	Threatened	
E	Endangered	

(Balon 1975; Balon 1981; Hubbs et al. 2008; Linam and Kleinsasser 1998; Simon 1999a)
* Note Balon Level 1 classification used (e.g. A1, A2…C2) for further analysis.

Several published and electronic syntheses on the life history requirements of the candidate focal species were also reviewed (Bonner 2009; Carlander 1969; Carlander 1977; Carlander 1997; Edwards 1997; Froese and Pauly 2000; Graham 1999; Hamilton and Nelson 1984; Hubert et al. 1984; Kuehne and Barbour 1983; Lee et al. 1980; Page 1983; Stuber et al. 1982; Warren 2009; Wilson and McKinley 2004). This additional level of review was conducted to evaluate and identify possible relationships between varying stream discharge and associated variables (e.g. dissolved oxygen, velocity, depth, ramping rates) and local population viability of the focal fish species.. For example, low stream velocities caused by decreased stream flow may result in deposition of fine silt particles on gravel beds which might lead to poor larval recruitment in nest building fishes. In addition, reduction of flooding and overbank flows can result in reduced connectivity with adjacent oxbow lakes and riparian areas and large woody debris recruitment (NRC (National Research Council) 2005).

Fish are highly mobile freshwater fauna that are dependent on healthy populations of invertebrate prey and/or plant material for food, and require cover and habitat provided by wetland/riparian emergent plants and submerged vegetation. Consequently they integrate the effects of stressors, including hydrological alteration, on lower trophic levels. Therefore we feel that they are excellent integrators of stressors, including changes in hydrology, within the watershed (Simon 1999b). Most fish have comparatively longer life spans than invertebrates. Fish are relatively easy to identify in comparison to invertebrates and are a valuable resource easily identified by the public. Although benthic invertebrates can provide excellent information on local conditions, long-term data is generally lacking and identification is often difficult without extensive taxonomic training. This has contributed to the lower amount if information on aquatic invertebrates. Although taxonomy is not as challenging there is a general lack of long-term monitoring data on other aquatic organisms as well. However, there are potentially numerous aquatic or semi-aquatic species (e.g. turtles, beaver, river otter, kingfisher, osprey, and amphibians) that are found in the Trinity River basin that are likely effected by changes in hydrology Sufficient flows are likely needed to maintain their unique habitats (e.g. floodplain forests) and associated forage food base.

Information on other aquatic and riparian species were also compiled, reviewed and cataloged by geographic location (lat, long, TCEQ water code and river mile) for potential future analysis (Figures 4 and 5). In addition, the locations of these studies and recorded sightings or collections were input into the EndNote®, Access and ArcGIS databases. This included aquatic invertebrates, and vertebrates. Data on these groups were generally much more limited than for fish. As previously mentioned TPWD provided us with a list of various invertebrate species of concern for their agency including bivalves (Family Unionidae – mussels) and one crustacean (Table 5). Freshwater mussels represent a unique assemblage of organisms since many species have become endangered at the state or federal levels in areas where streams or lakes have experienced rapid changes in flows and/or water levels. For example, dewatering practices that have been historically used for nuisance vegetation control have often led to local extirpation (Howells 2009). Many of these mussels have documented larval parasitic glochidia stages that utilize various host fish species found in the Trinity River. These larvae attach to the body of the fish or gills until they metamorphose into benthic juveniles. Hence, reductions in the numbers of their host fish species can indirectly and negatively impact mussels. Therefore their population viability in many cases is tied to the viability of their host fish populations. The Texas Parks and Wildlife Department has designated no harvest mussel sanctuary areas in the State.

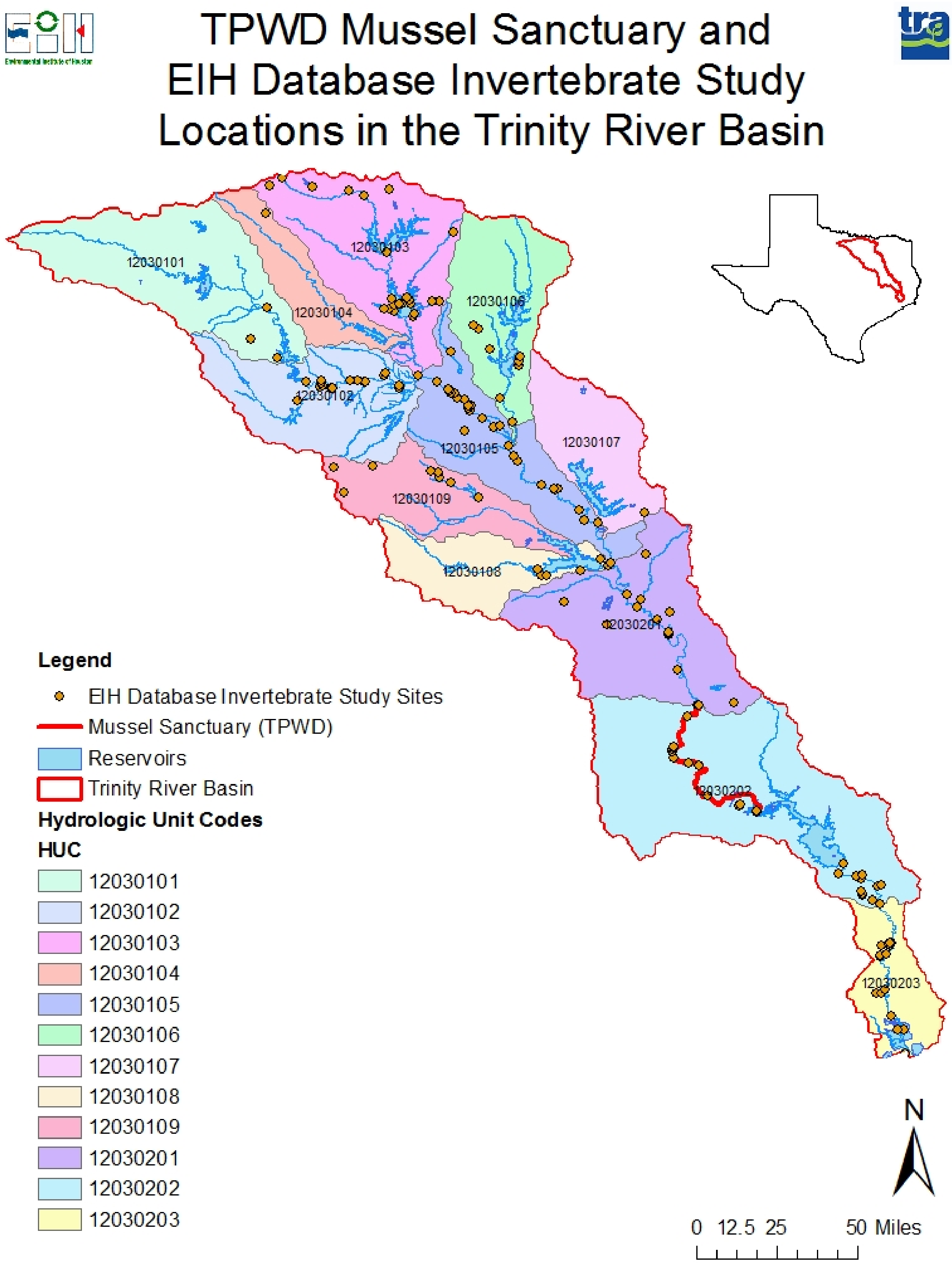


Figure 4. Location of historical invertebrate collection and study sites and TPWD mussel sanctuary within the Trinity River Basin that were used as data sources.

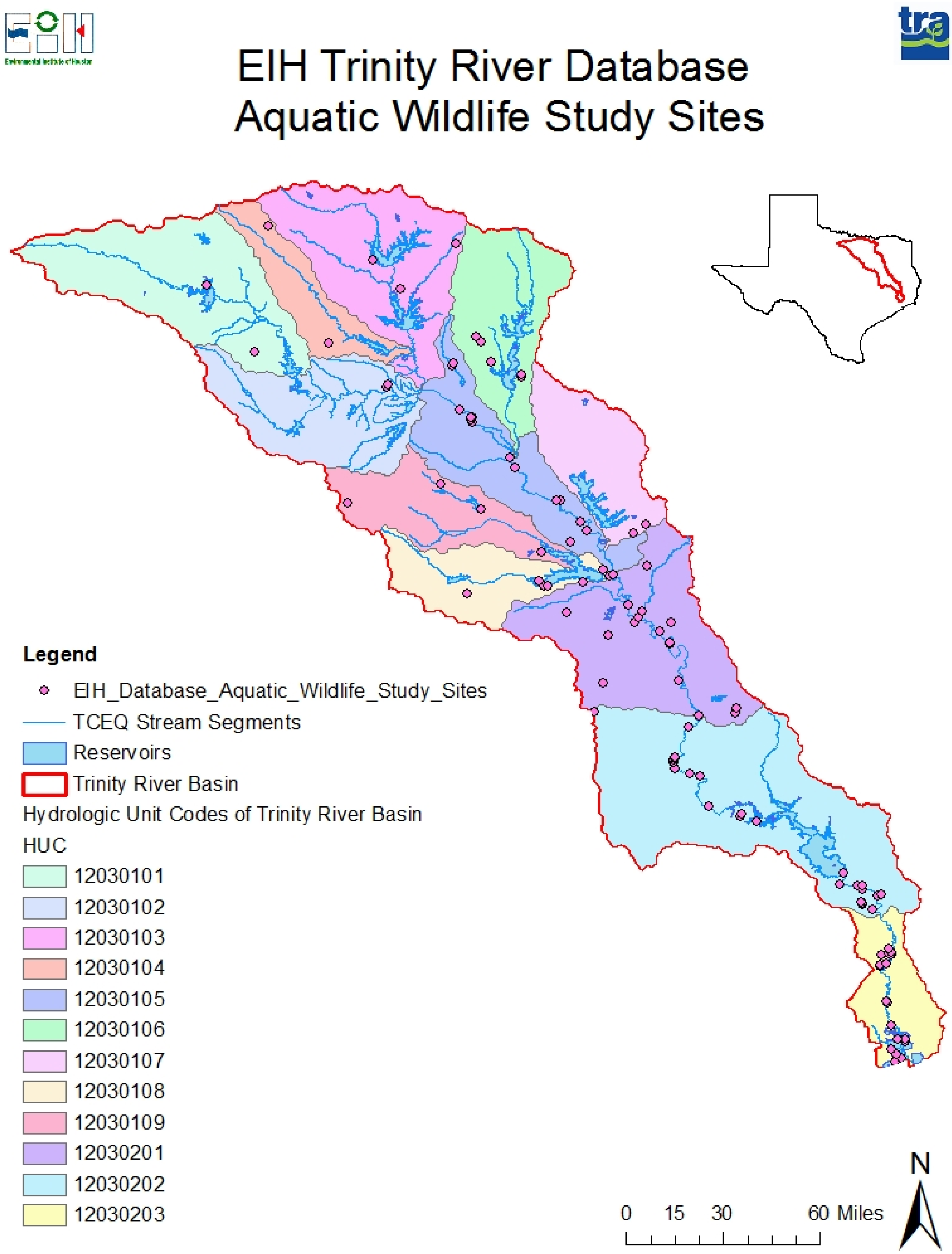


Figure 5. Location of historical aquatic non-fish vertebrate collection and study sites within the Trinity River Basin.

Table 5. Candidate focal invertebrate species in the Trinity River. TWAP SC listings highlighted in yellow.

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

Table 5. Continued.

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

Sources: Pers. Comm. Clint Robertson TPWD; Marsha May TPWD Texas Mussel Watch; (Bender et al. 2005; Howells 2009; Howells et al. 1996) X = Recent Occurrences (within last 30 years); Status: TWAP-SC = Species of Concern, TPWD Texas Wildlife Action Plan 2005 1 = State Rank (S1) – Critically imperiled, extremely rare, very vulnerable to extirpation, 5 or fewer occurrences 2 = State Rank (S2) – Imperiled in state, vulnerable to extirpation, 6 to 20 occurrences 3 = Proposed for Federal Listing

A sanctuary has been designated on the Trinity River along Houston, Leon, Madison, and Trinity, Walker counties at its upper boundary at the intersection with State Highway and at the lower boundary with the State Highway 19 (Figure 4). TPWD also suggested including *Macrobrachium ohione*, river prawn, which undergoes spawning migrations to estuaries and may be effected by instream flow conditions (Bauer and Delahoussaye 2008). Aquatic invertebrates are considered excellent sentinel organisms due to their limited mobility and in some cases sensitivity to variations in flow regimes and water quality (Barbour et al. 1999; Rosenberg and Resh 1993). However, with the exception of freshwater mussels, information on the distribution and long-term trends in these populations are very limited (Howells 2009; Howells et al. 1996).

Although not mentioned by the TPWD biologists who were consulted, there are several other invertebrate and vertebrate species of concern listed in their Texas Wildlife Action Plan that may occur within the Trinity River basin (Bender et al. 2005). These additional species are listed in Table 6. With the exception of Blue sucker *Cycleptus elongates* and Creek chubsucker *Erimyzon oblongus* all the listed species were designated species of concern. Blue sucker and Creek chubsucker are on the state threatened species list.

The State of Texas has in recent years moved to protect some species of turtles due to concerns with excessive commercial harvesting. (TPWD (Texas Parks and Wildlife) 2008). River turtles are currently potentially sensitive to changes in river hydrology. Most river turtles live in higher order systems often characterized by high flows (Moll and Moll 2004). Many species nest on sand banks and are therefore potentially sensitive to unexpected flood flows. Alligator snapping turtle is the only state threatened species of reptiles or amphibians in the piney woods ecosystem that is likely to be found in the Trinity River basin (Bender et al. 2005).

Table 6. List of aquatic species identified in the Texas Comprehensive Wildlife Conservation Strategy that are found in the Trinity River basin but not originally nominated by TPWD biologists.

Species	Status	Known Host	Spawning Season	Stressor Notes
MacNeeses crayfish *Fallicamberus macneesei*	SC	NA	Spawning usually in September (early fall), egg release normally in April (spring)	Defined as vulnerable by AFS due to narrow range and sensitivity to pollution, habitat change and modified flow regimes, only found close to coastal areas within 50 miles
Steigmans Crayfish *Procambarus steigmani*	SC	NA	Spawning usually in September (early fall), egg release normally in April (spring)	According to AFS this species is in imminent danger of extinction or extirpation throughout large portion of range. Found in the extreme northern portion of the Trinity Basin, lives in higher elevation riparian prairie
Bigclaw River Shrimp *Macrobrachium carcinus*	SC	NA	Probably carry eggs in March to September.	Dams limit upstream migration of juveniles. Adults migrate to freshwater and release hatched larvae.
Creeper Mussel *Stophitus undulatus*	SC	Largemouth bass, creek chub, green sunfish	July to April and May; may not need fish host	Found many sites, but rare not seen in state of Texas since 1992, rated stable by AFS.
Texas emerald dragonfly *Somatochlora margarita*	SC	NA	Very little known about biology or larval habitat.	Limited in Texas to a few counties adjacent to the Trinity River and E. Texas. Endemic to two states in the United States (Louisiana and Texas). The species currently is known from six counties in these two states. This species has a restricted range (currently only seven locations are known).
Fishes				
American eel *Anguilla rostrata*	SC	NA	Jan to August in mid-Atlantic - Catadromous	Dams impede upstream movement of juveniles
Blue sucker *Cycleptus elongatus*	ST	NA	Late April to May	Abundance of *Cycleptus elongatus* has been decreased by impoundment, pollution, and reduced water flows in those systems in which it occurs.
Creek chubsucker *Erimyzon oblongus*	ST	NA	March to May	Not listed by AFS.
Sabine shiner *Notropis sabinae*	SC	NA	May to December	*N. sabinae* was designated a species of conservation concern in Texas and Louisiana by U.S. Forest Service Region 8 and U.S. Fish and Wildlife Service Region 2, and as a species of special concern in Mississippi

Sources: (Abbott 2006; Bender et al. 2005; Bonner 2009; Hobbs III 2001; Howells 2009; Howells et al. 1996; Jelks et al. 2008; Johnson and Johnson 2008; Kondratieff 2000; Taylor et al. 2007) X = Recent Occurrences (within last 30 years); Status: TWAP-SC = Species of Concern, TPWD Texas Wildlife Action Plan 2005 1 = State Rank (S1) – Critically imperiled, extremely rare, very vulnerable to extirpation, 5 or fewer occurrences 2 = State Rank (S2) – Imperiled in state, vulnerable to extirpation, 6 to 20 occurrences 3 = Proposed for Federal Listing

Results

Hydrology Summary

Graphical summaries of the hydrology at each priority USGS gage site were used to illustrate seasonal and annual trends. One very obvious trend that was observed is the decline in average daily flows at the USGS Elm Fork gage after 1951 (Figure 6). The initial decline occurred during the drought of record, but flows never did substantially increase after this period (Estaville and Earl 2008). This is probably due to the construction and filling of Lake Grapevine Lake and Lake Lewisville reservoirs which are located less than 5 miles upstream of this gage and were first impounded in 1952 and 1954 respectively (Richard Browning TRA – personal communication)(Farquhar and McDonald 1991; Gandara and Jones 1995)(Table 7). Seasonally the lowest average stream discharge occurs during the months of August through October with little variation (Figures 7-9). Largest daily fluctuations and overall variability of flows occurs during the months of January through June (Figures 8 and 9). Highest average daily flows also generally occur during these months (Figure 7).

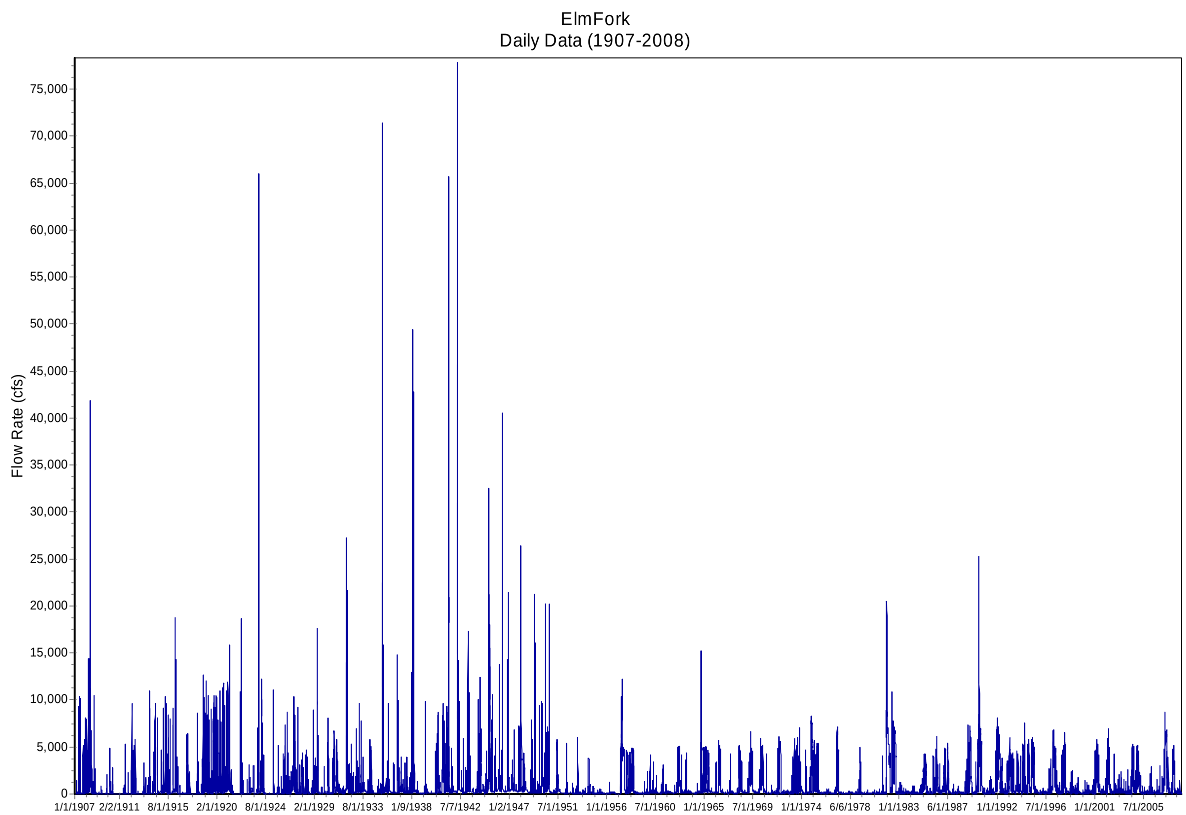


Figure 6. Average daily flows recorded at the USGS Elm Fork Trinity River near Carrollton (08055500) gage from 1907 to 2008.

Table 7. List of reservoirs and associated characteristics within the Trinity River Basin.

Name	1st impndmnt (yr)	mi^2 total watershed	mi^2 uncontr watershed	Elev normal pool	Acres normal pool	Ac-Ft normal pool	Depth mean (ft) normal pool	Elev. strmbd @ dam	Evap net 40-65 ave in/y	Evap net 50-56 ave in/y	Own/Oper	Yield,mgd	Flood Control, AF
JACKSBORO	1950	25.7	25.7	1015.4	142.5	2129	14.9	975	43	56	Jacksboro	0.4665	
LOST CREEK	1990	29.2	3.5	1009.5	367	11961	32.6	925	43	56	Jacksboro	1.03588	
BRIDGEPORT	1932	1111	1082	836	12900	374836	29.1	750	42	55	TRWD		
AMON G. CARTER	1956	106	106	920	1848	28589	15.5	865	41	53	Bowie	2.32	
EAGLE MOUNTAIN	1934	1970	753	649	6480	177520	27.4	589	42	53	TRWD	69.5	
WORTH	1914	2064	94	594.3	3560	37775	10.6	555	42	52	Fort Worth		
WEATHERFORD	1957	109	109	896	1158	18714	16.2	850	44	55	Weatherford	1.96	
BENBROOK	1952	429	320	694	3635	85648	23.6	617	43	53	COE	6.07	170350
CLEAR FORK	1882	518	89	533	43	259	6	524	41	52	Fort Worth	2	
NUTT DAM	1910	2615	33	520	96	673	7	510	41	52	TU	1	
ARLINGTON	1957	143	143	550	1939	38785	20	489	40	50	Arlington	5.35	
JOE POOL	1986	232	232	522	7470	176900	23.7	456	38	48	COE	14.2	127100
MOUNTAIN CREEK	1937	295	63	457	2710	22840	8.4	420	38	47	TU	13.4	
KIOWA	1968	16.4	16.4	700	560	7000	12.5	670	33	46	L Kiowa Inc		
RAY ROBERTS	1986	692	676	632.5	29350	799600	27.2	524	35	46	COE		265000
LEWISVILLE	1954	1660	968	522	29170	571926	19.6	435	36	47	COE	165	314806
GRAPEVINE	1952	695	695	535	7380	181100	24.5	451	38	49	COE	20.6	244400
CARROLLTON	1912	2459	104	433.71	89	666	7.5	418	37	48	Dallas		
NORTH	1957	3	3	510	800	17000	21.2	448	37	48	TU	0.4	
CALIFORNIA CROSSING	1912	2530	68	418	180	990	5.5	410	36	47	Dallas		
FRAZIER	1928	2580	50	408	72	434	6	397	36	46	Dallas	18.1	
WHITE ROCK	1910	100	100	458	1088	9004	8.3	458	35	43	Dallas		
LAVON	1953	770	770	492	21400	456500	21.3	433	31	40	COE	92.9	291700
RAY HUBBARD	1968	1074	304	435.5	21683	413526	19.1	387	32	40	Dallas	50.4	
NEW TERRELL	1955	14	14	504	849	8594	10.1	480	28	35	Terrell	0.7	
FOREST GROVE	1980	53	53	359	1502	20038	13.3	325	24	31	TU	1.6	
CEDAR CREEK	1965	1007	940	322	32623	637180	19.5	248	26	34	TRWD	156	
TRINIDAD	1925	1.2	1.2	284.5	740	7450	10.1	265	23	31	TU	2.1	
NAVARRO MILLS	1963	320	320	424.5	5070	56960	11.2	375.3	32	43	COE	14.7	149240
ALVARADO	1965	15.3	15.3	691.8	503	4757	9.5	668	39	49	Alvarado	0.7	
WAXAHACHIE	1956	30	30	531.5	690	10779	19.6	479	35	47	ECWCID	2.4	
BARDWELL	1965	178	148	421	3138	46472	14.8	377.6	33	43	COE	9.8	79600
HALBERT	1921	12	12	368	603	6033	10	330	29	39	Corsicana	0.5	
RICHLAND-CHAMBERS	1987	1957	1432	315	41356	1136600	27.5	235	27	35	TRWD	187	
WORTHAM	1952	1.5	1.5	416	42	252	6	400	28	39	Wortham		
FAIRFIELD	1969	34	34	310	2159	44169	20.5	248	25	32	TU	6.9	
HOUSTON COUNTY	1966	44	44	260	1330	17665	13.3	215	15	27	HCWCID	10	
LIVINGSTON	1969	16616	6764	131	83277	1741867	20.9	59.6	12	22	TRA	1120	
WALLISVILLE	1998	17584	968	1	0	0	0	-18	11	19	COE	80	
ANAHUAC	1914	199	199	5	5300	35300	6.7	-2	11	19	CLCND	21.7	

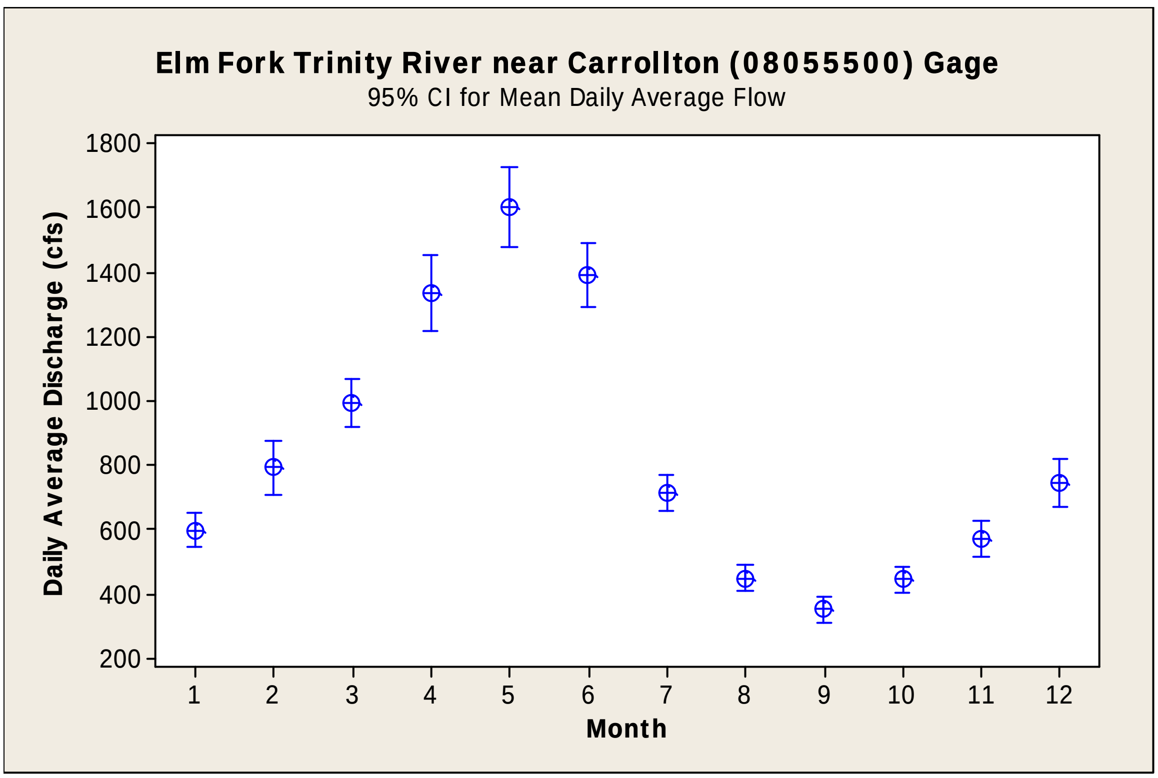


Figure 7. Monthly mean and 95% confidence intervals for daily average flows recorded at the USGS Elm Fork Trinity near Carrollton, (08055500) gage from 1907 through 2008.

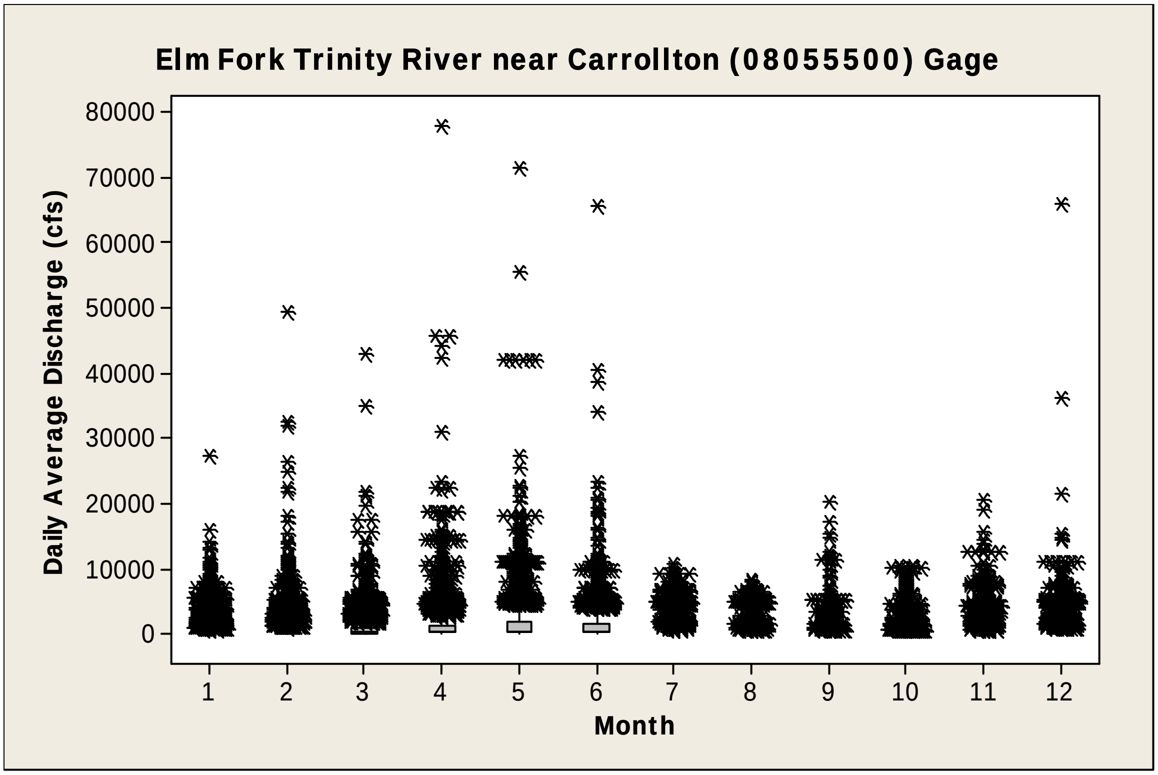


Figure 8. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average flows recorded at the USGS Elm Fork Trinity near Carrollton, (08055500) gage from 1907 through 2008.

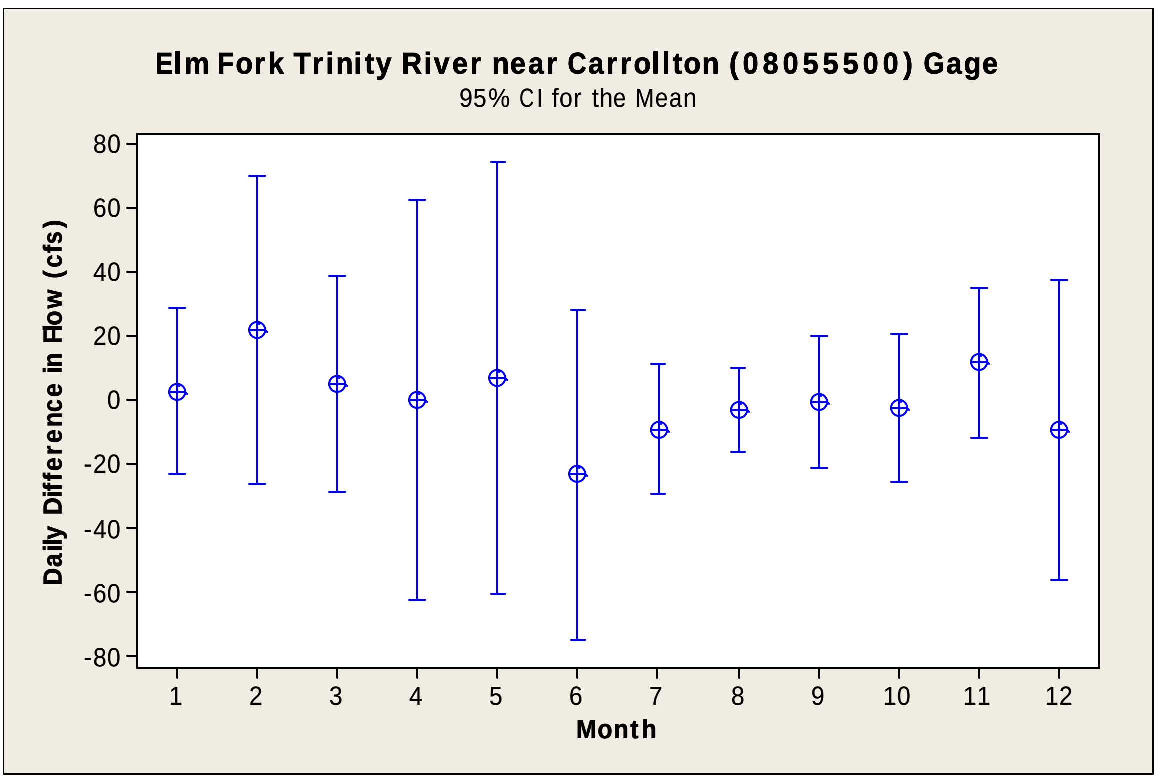


Figure 9. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the Elm Fork Trinity River near Carrollton (08055500) gage from 1907 through 2008.

The remaining priority gages, although exhibiting different absolute levels in flow and differences in flow variation, generally followed the same seasonal patterns exhibited by the Elm Fork gage. As expected, stream flow generally increased as you move downstream. Throughout the basin seasonally the lowest average stream discharges occur during the months of July through October with associated reductions in daily and short-term flow variability (Figures 10-37). In contrast, average daily flow rates are elevated and exhibit the largest daily and short-term fluctuations during the months of March through May or June (Figures 10-37). During these periods stream velocities would generally increase and the probability of overbank (flood) flows would increase. In addition, sediment transport capacity would also increase. These patterns in average daily flow and flow variability can effect instream habitat components (e.g. depth, cover, and velocity), larval drift, nesting behavior, and availability of riparian habitat (e.g. overbank flooding, and connectivity to oxbow lakes and associated wetlands. In addition, increased river flows in the spring months have a higher capacity for downstream sediment and nutrient transport including deposition in estuaries. This has major implications for fluvial processes including bank erosion, channel stability and pollutant transport. Preliminary estimates of draft 7Q2 values for selected gages in each major segment of the Trinity River are provided in Table 7. These were obtained from TCEQ water quality standards staff in September 2009 and are subject to change.

Trinity River hydrology has to varying degrees been influenced by the construction of dams and reservoirs. In addition, these structures and associated reservoirs generally trap sediments and increase residence times which can effect nutrient processing in addition to attenuating flood pulses depending on dam operations (Collier et al. 2000; Yeager 1993). Although the magnitude and frequency of some components of the river’s hydrology have likely changed due to dam construction, water diversions, and increased urban and wastewater loading, many of the remaining local fauna have most likely evolved or retained life history traits that allow them to persist under these conditions. Later when we discuss the important biological resources we will try to identify key life history traits that may be important for dealing with these seasonal patterns in flow and flow variability and related water quality and geomorphological processes. Based on our limited analysis we did not see any large shift in hydrology post dam construction at the other gage sites in comparison to the Elm Fork site. However, we did not conduct a detailed hydrological analysis but rather provide broad spatial and temporal patterns in hydrology that may affect water quality, sediment transport and instream habitat.

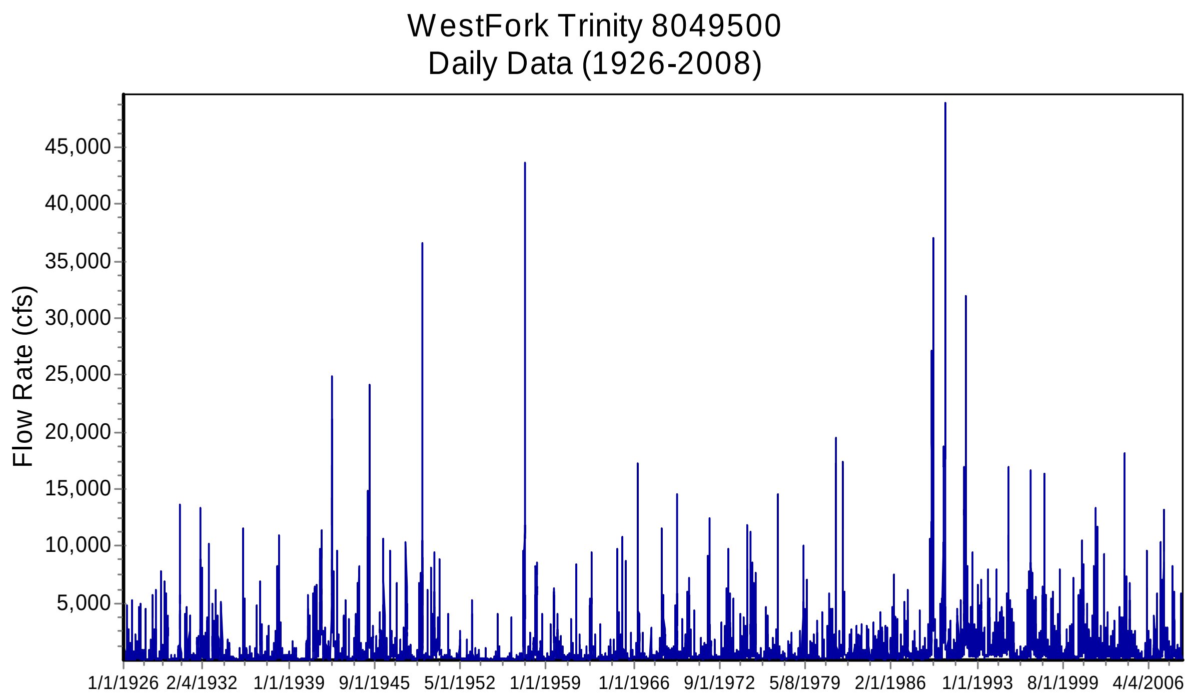


Figure 10. Average daily flows recorded at the USGS West Fork Trinity River (08049500) gage from 1926 through 2008).

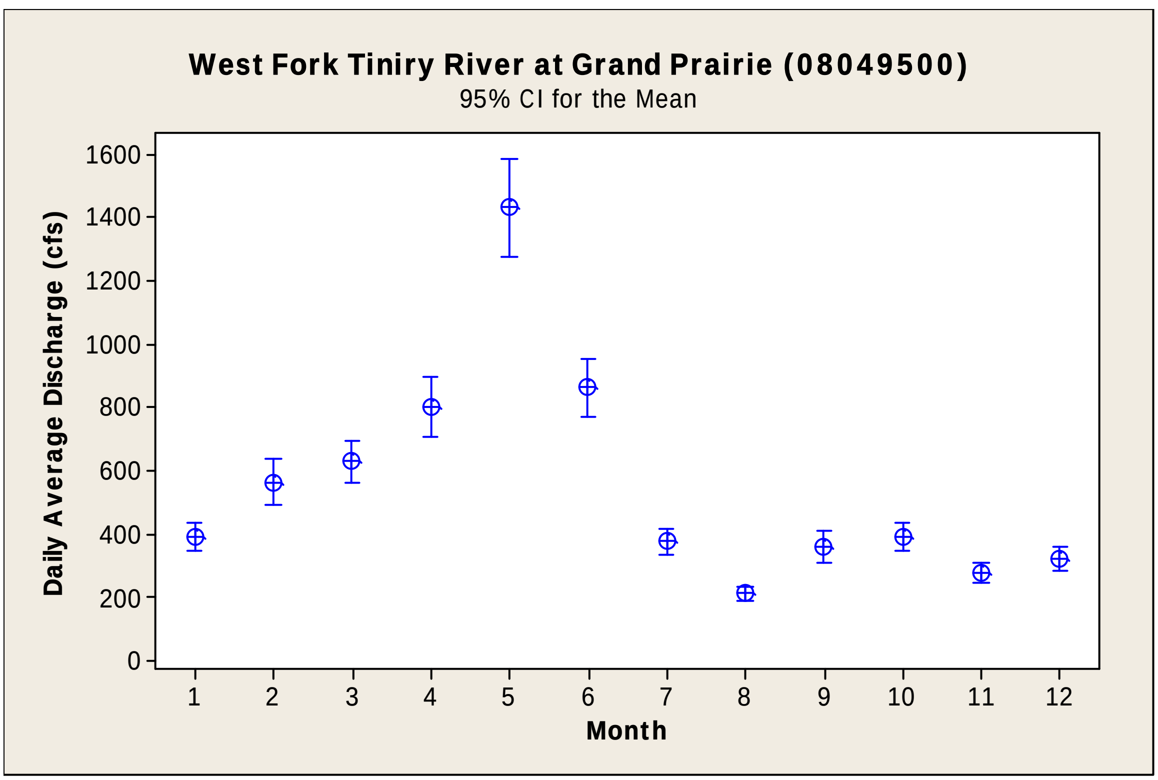


Figure 11. Monthly mean and 95% confidence intervals for daily average flow recorded at the USGS West Fork Trinity River at Grand Prairie (08049500) gage from 1926 through 2008.

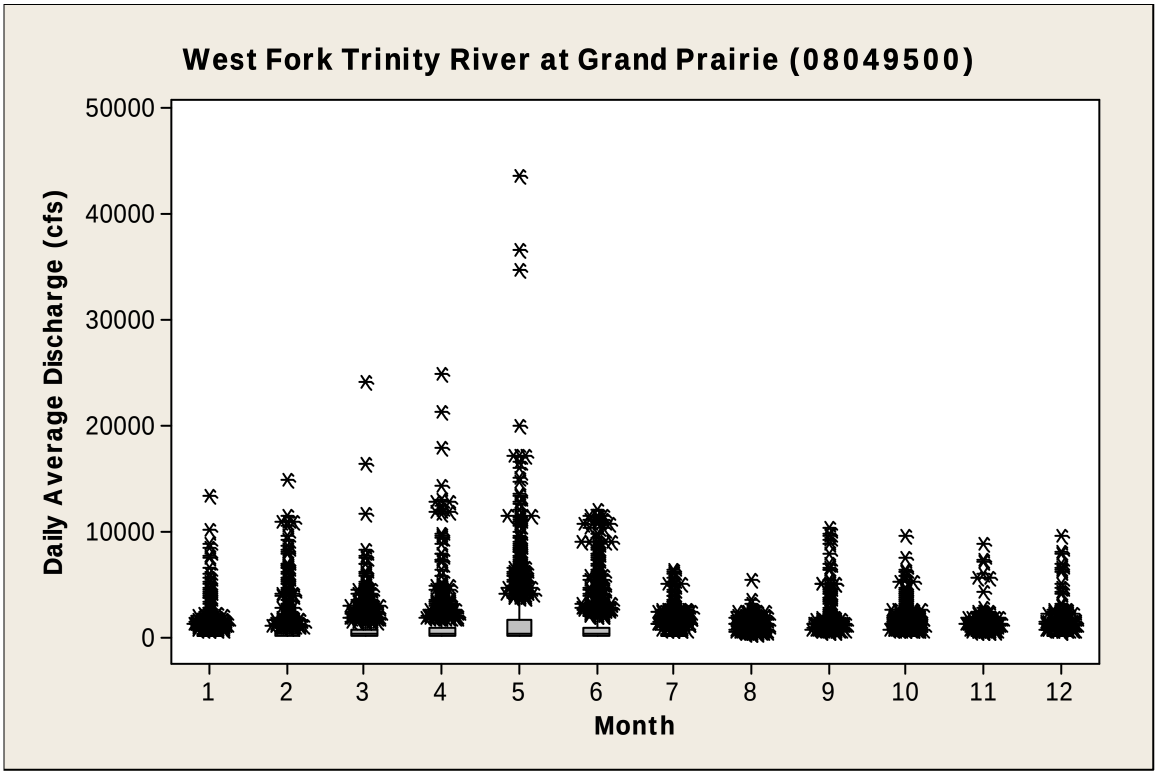


Figure 12. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average flows recorded at the USGS Elm Fork Trinity near Carrollton (08055500) gage from 1907 through 2008.

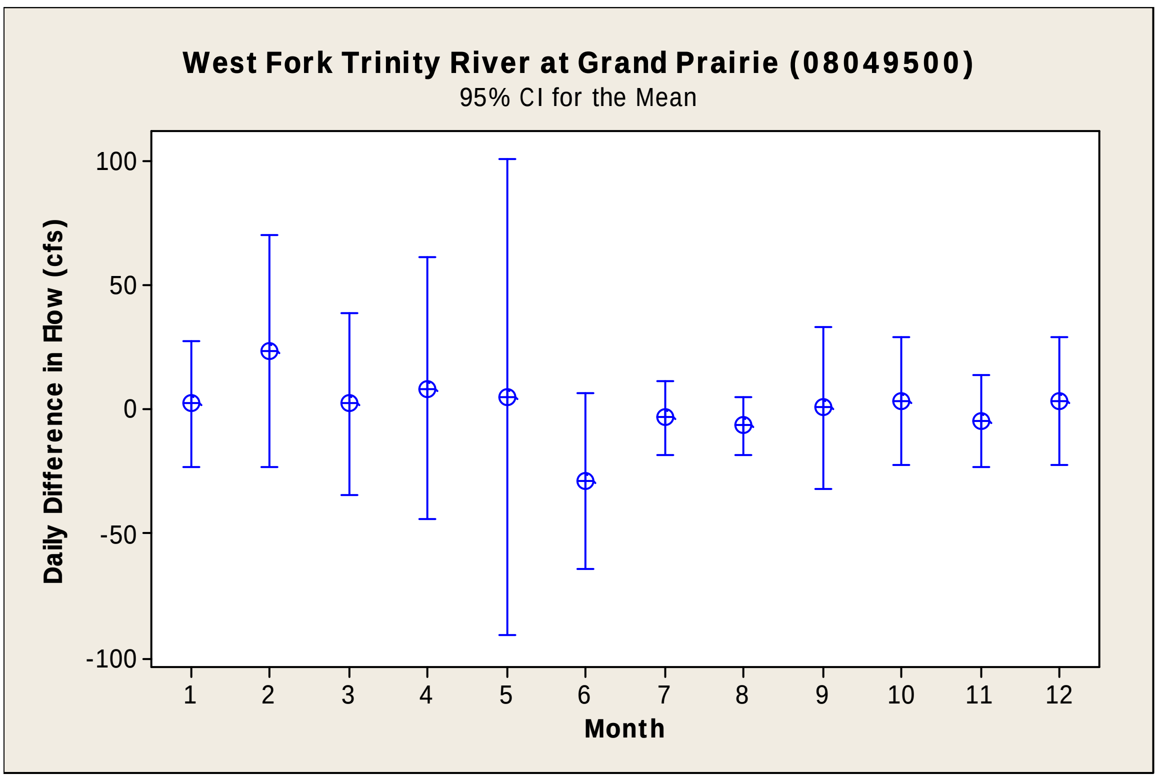


Figure 13. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the West Fork Trinity River at Grand Prairie (08049500) gage from 1926 through 2008.

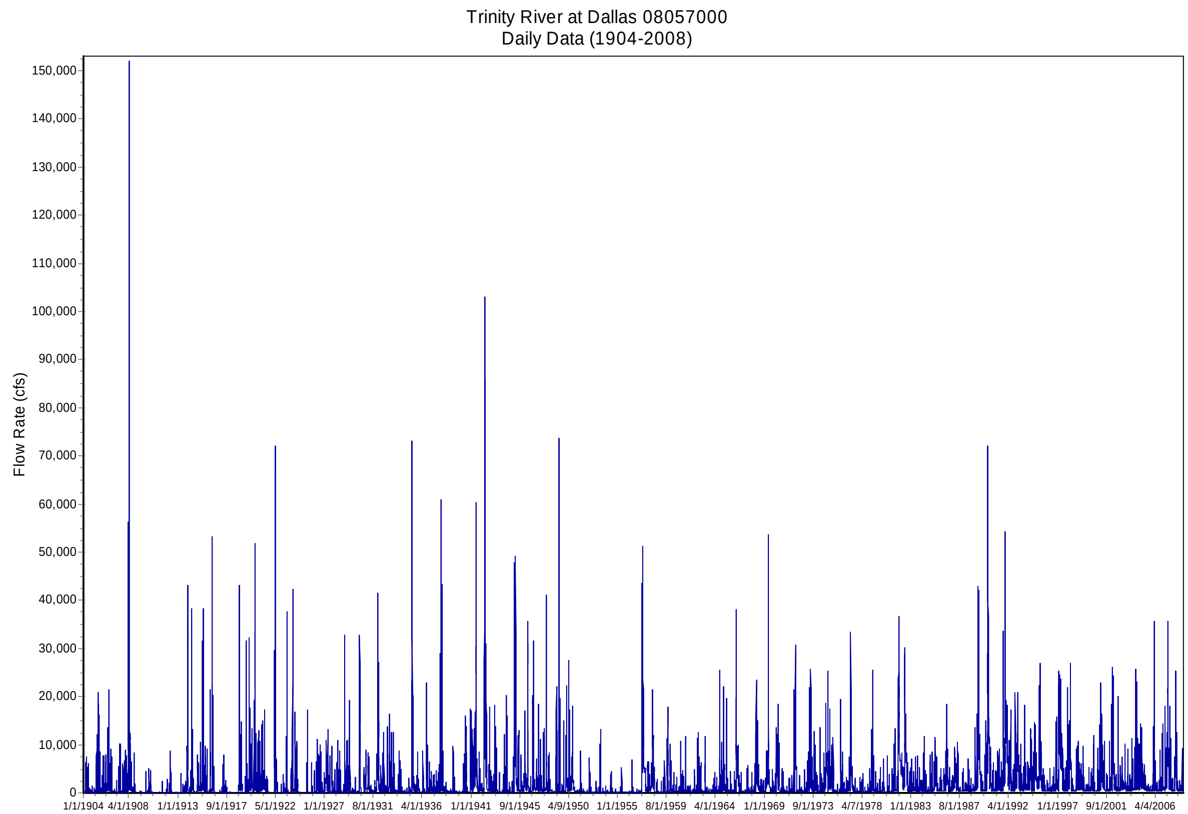


Figure 14. Average daily flows recorded at the USGS Trinity River at Dallas (08057000) gage from 1904 through 2008.

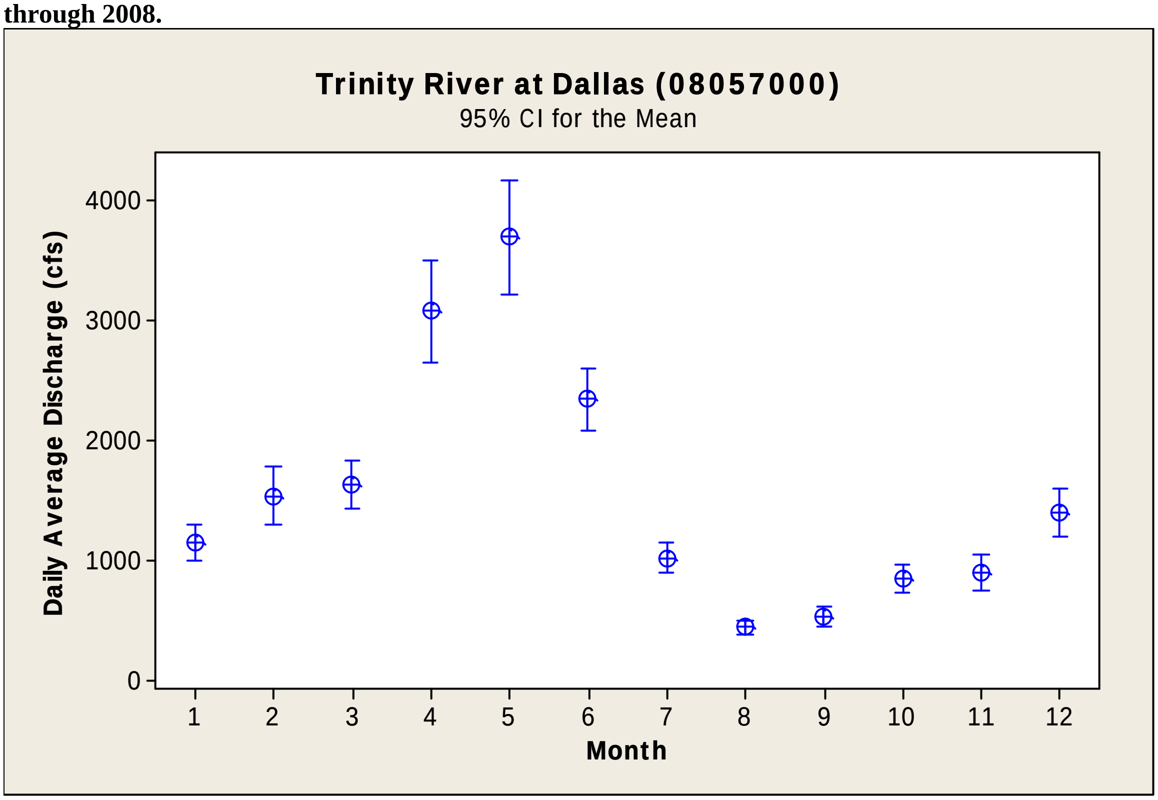


Figure 15. Monthly mean and 95% confidence intervals for daily average flow recorded at the USGS Trinity River at Dallas (08057000) gage from 1904 through 2008.

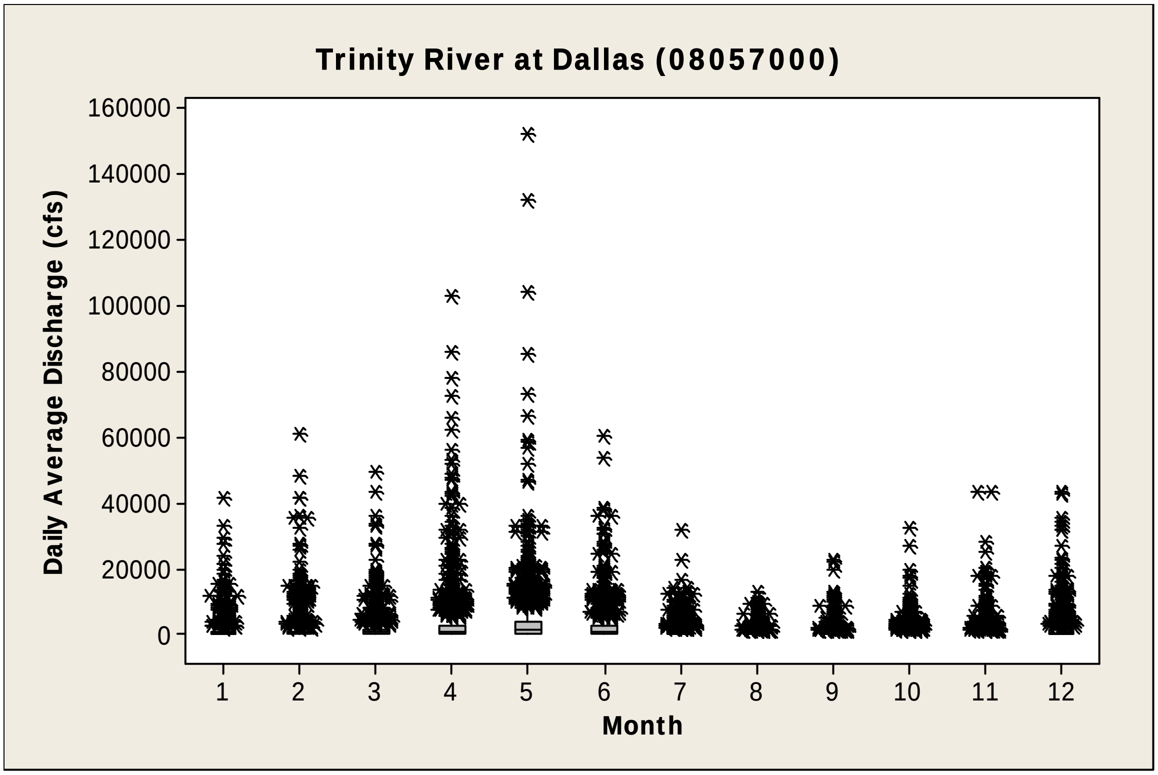


Figure 16. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average flows recorded at the USGS Elm Fork Trinity near Carrollton (08055500) gage from 1907 through 2008.

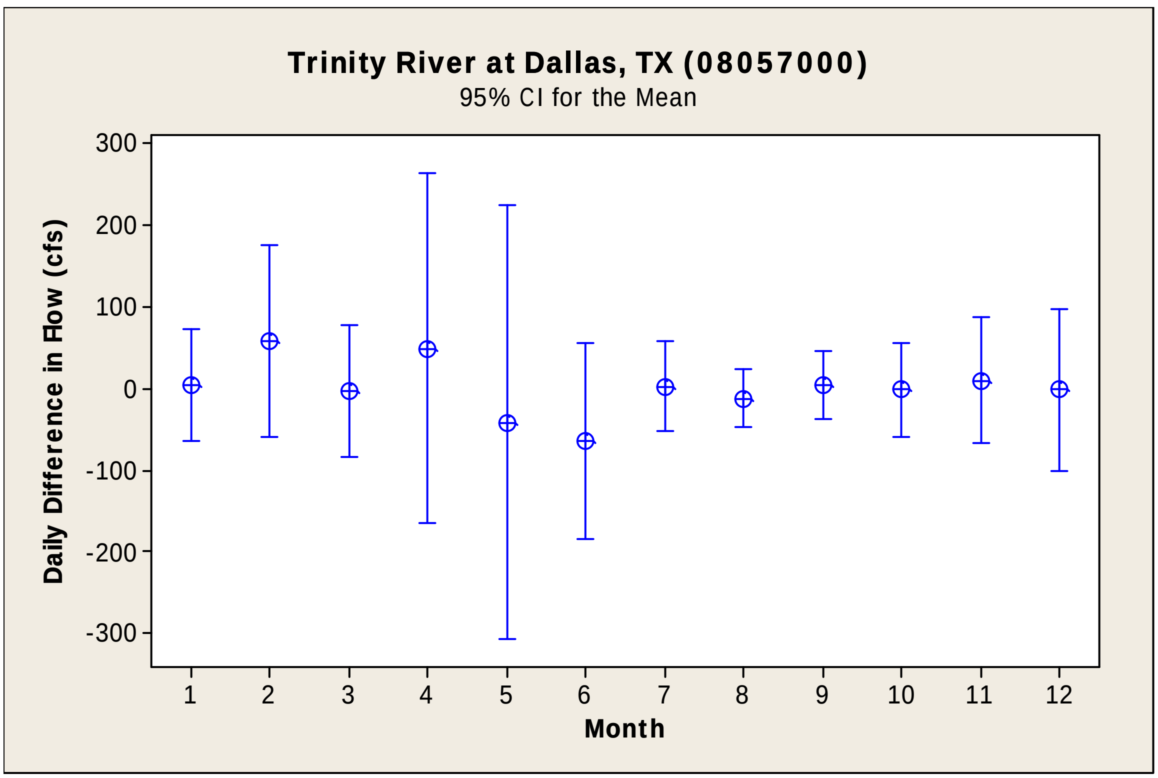


Figure 17. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the USGS Trinity River at Dallas (08057000) gage from 1904 through 2008.

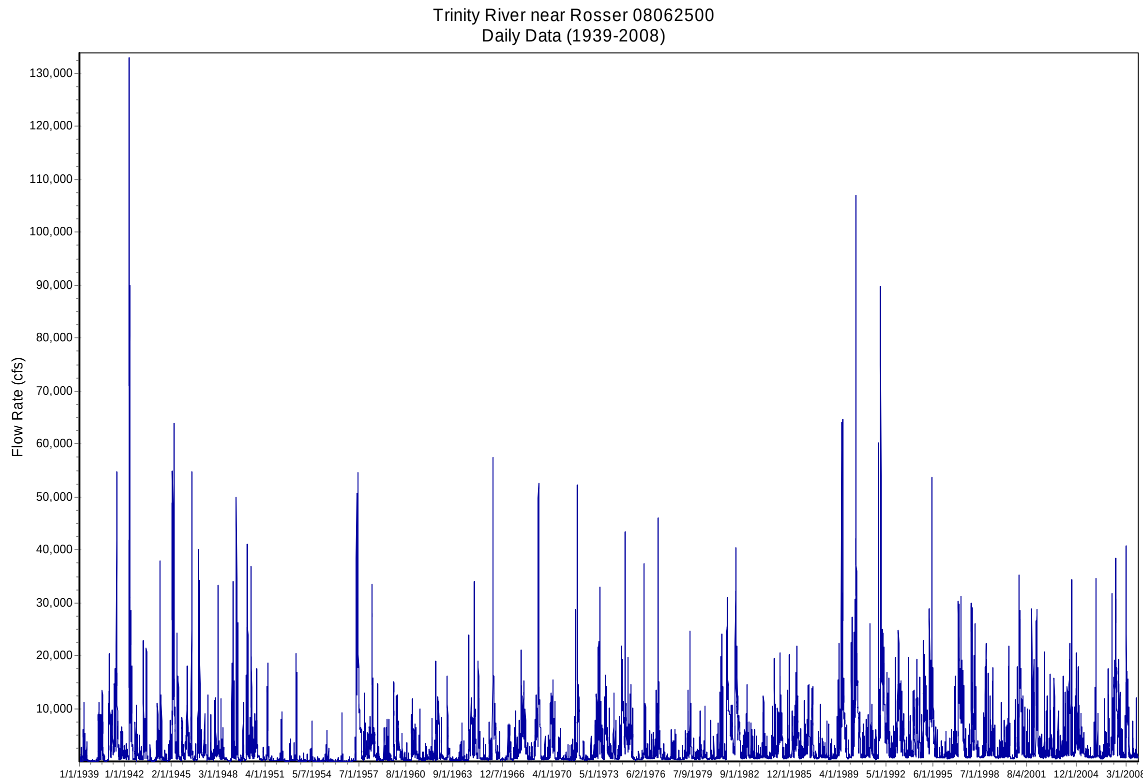


Figure 18. Average daily flows recorded at the USGS Trinity River at Rosser (08062500) gage from 1939 through 2008.

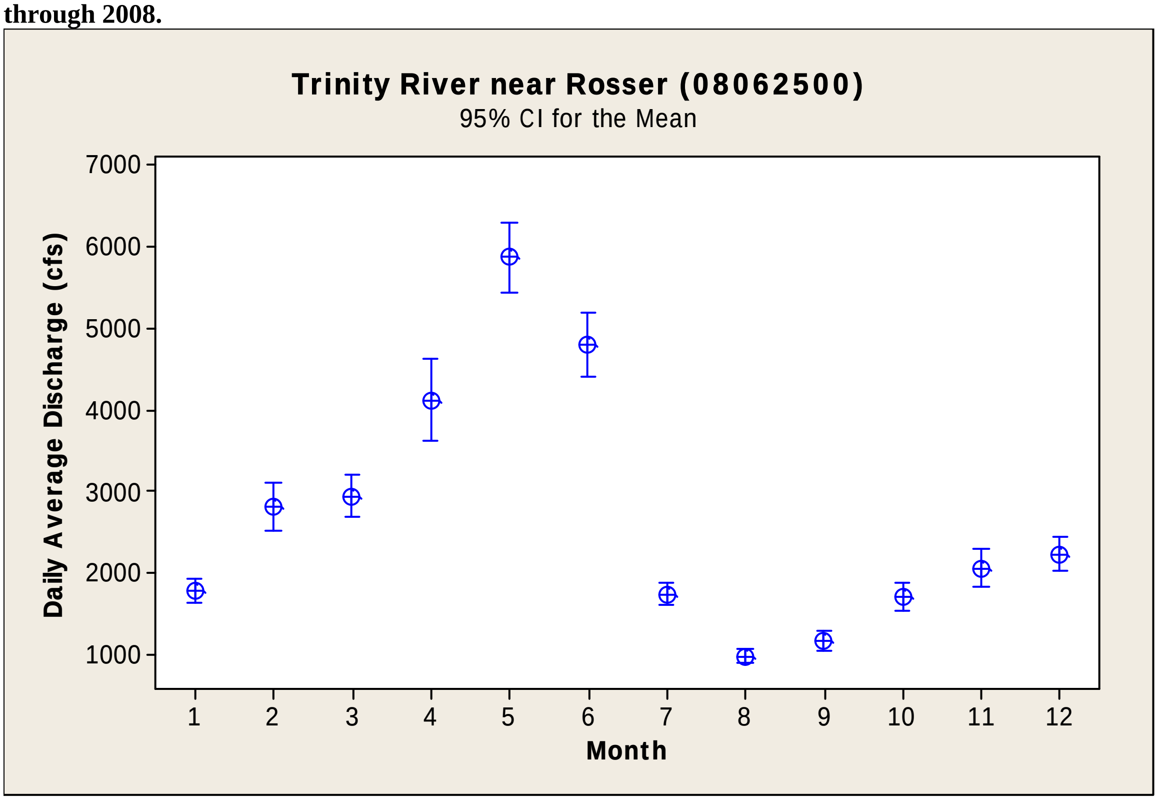


Figure 19. Monthly mean and 95% confidence intervals for daily average flow recorded at the USGS Trinity River at Rosser (08062500) gage from 1939 through 2008.

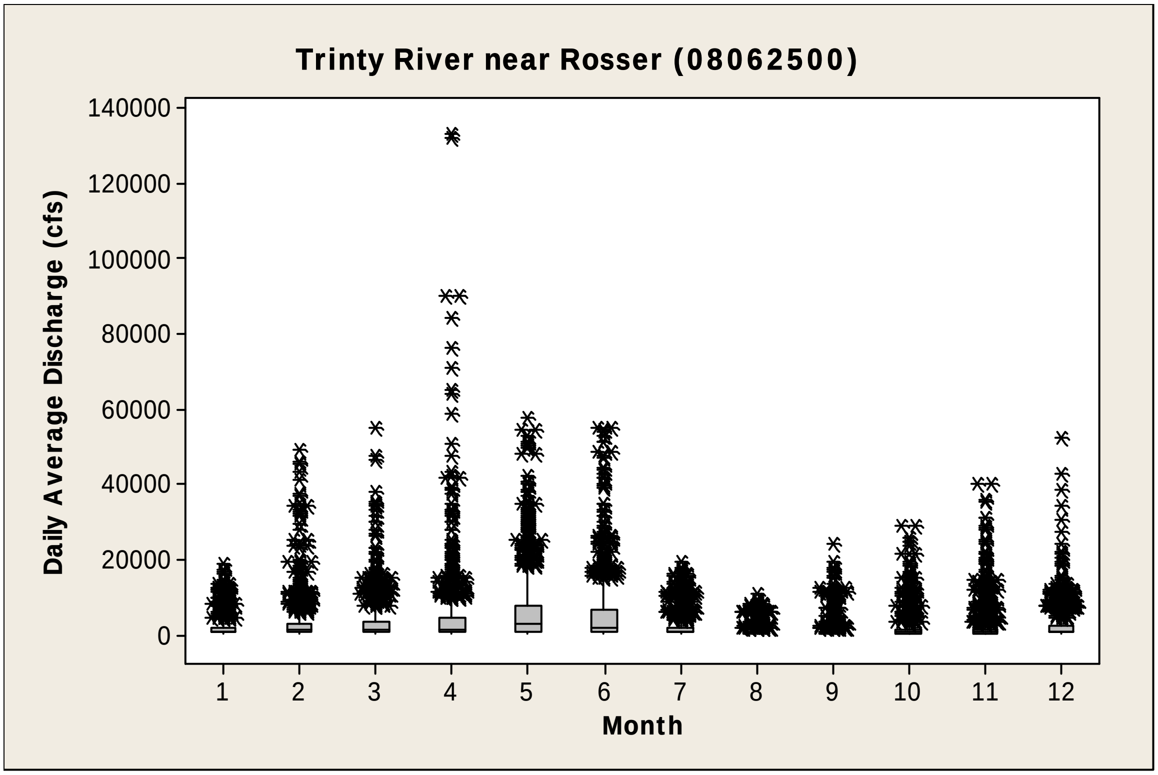


Figure 20. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average flows recorded at the USGS Trinity near Rosser (08062500) gage from 1939 through 2008.

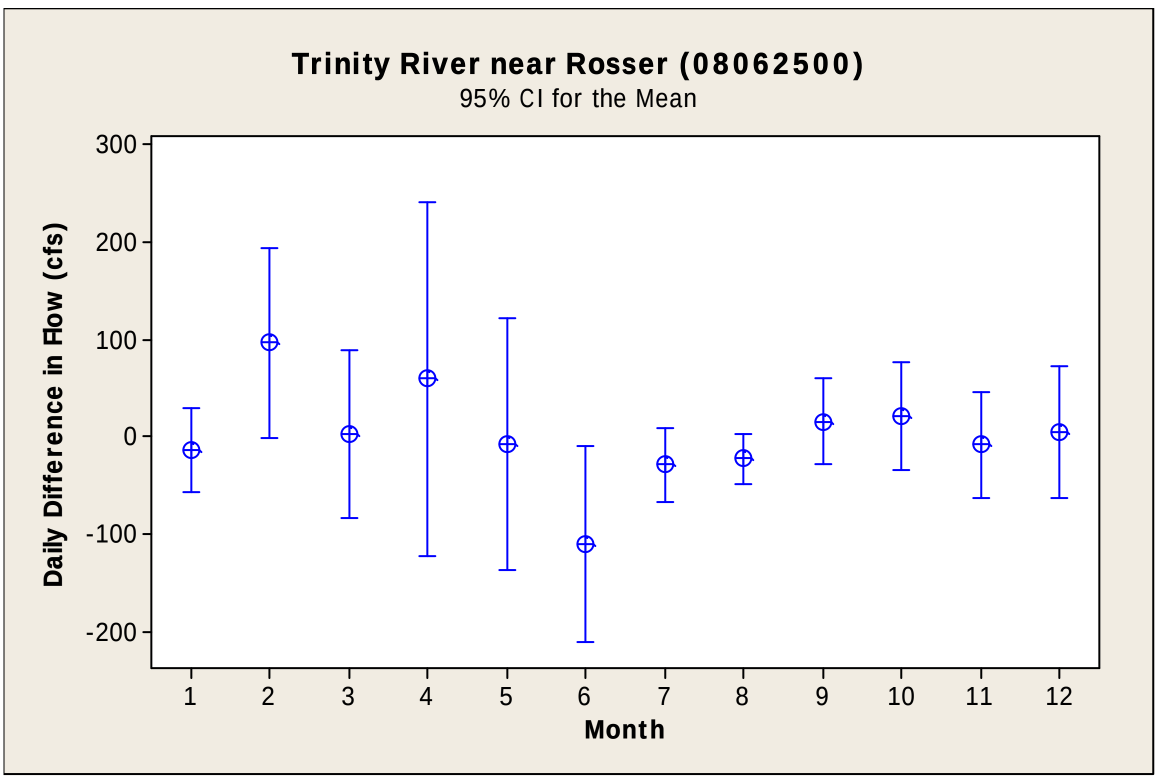


Figure 21. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the USGS Trinity River near Rosser (08062500) gage from 1939 through 2008.

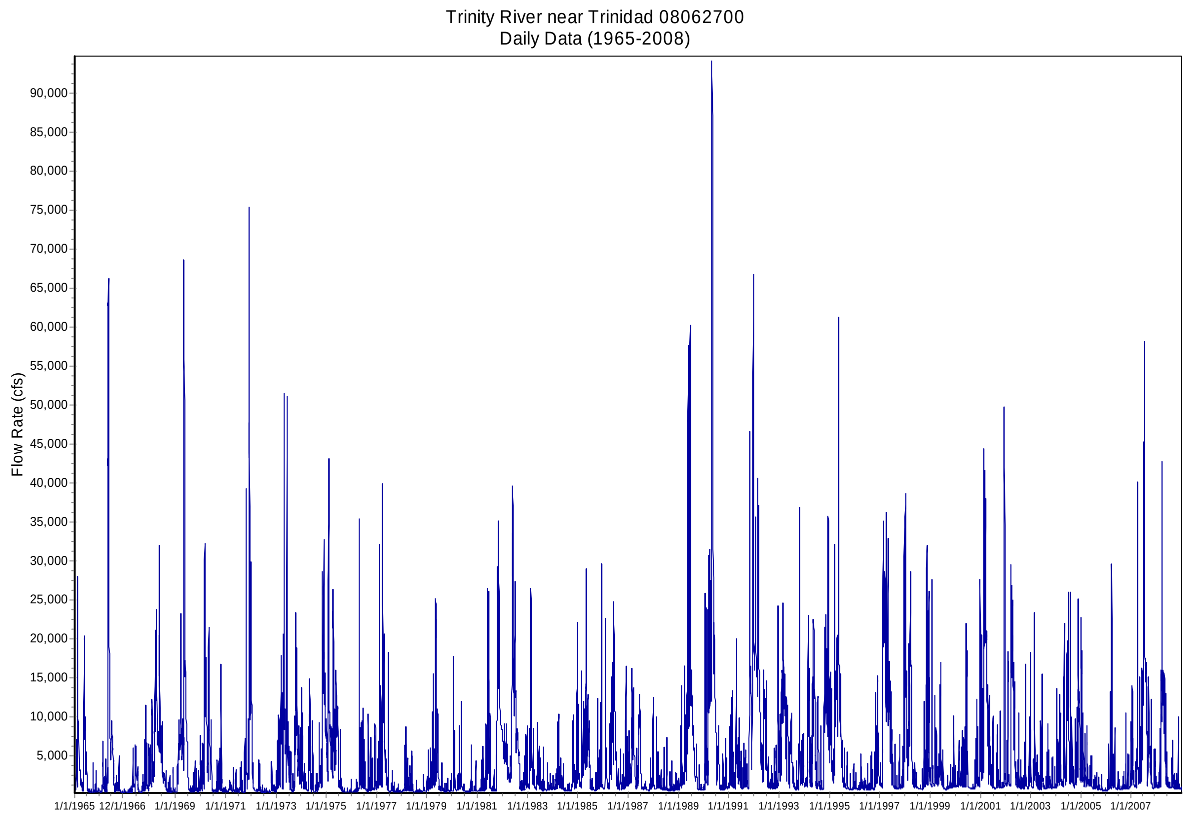


Figure 22. Average daily flows recorded at the USGS Trinity River near Trinidad (08062700) gage from 1965 through 2008.

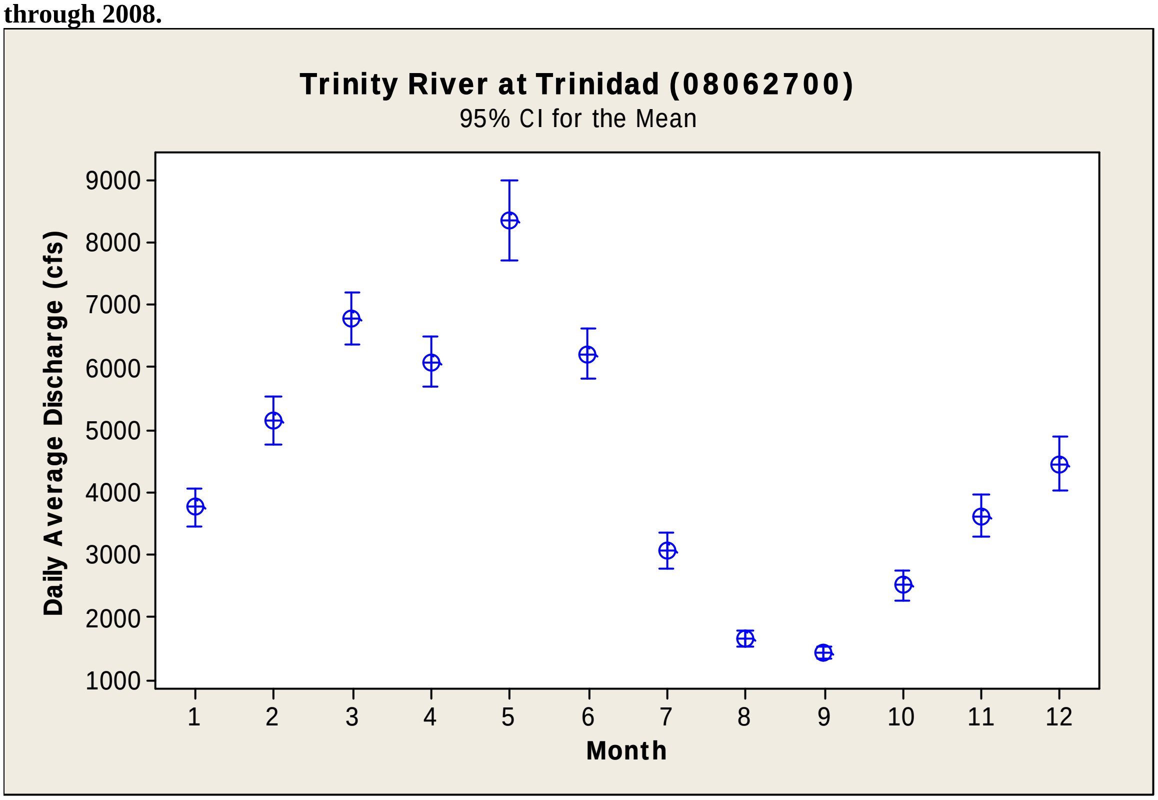


Figure 23. Monthly mean and 95% confidence intervals for daily average flow recorded at the USGS Trinity River at Trinidad (08062700) gage from 1965 through 2008.

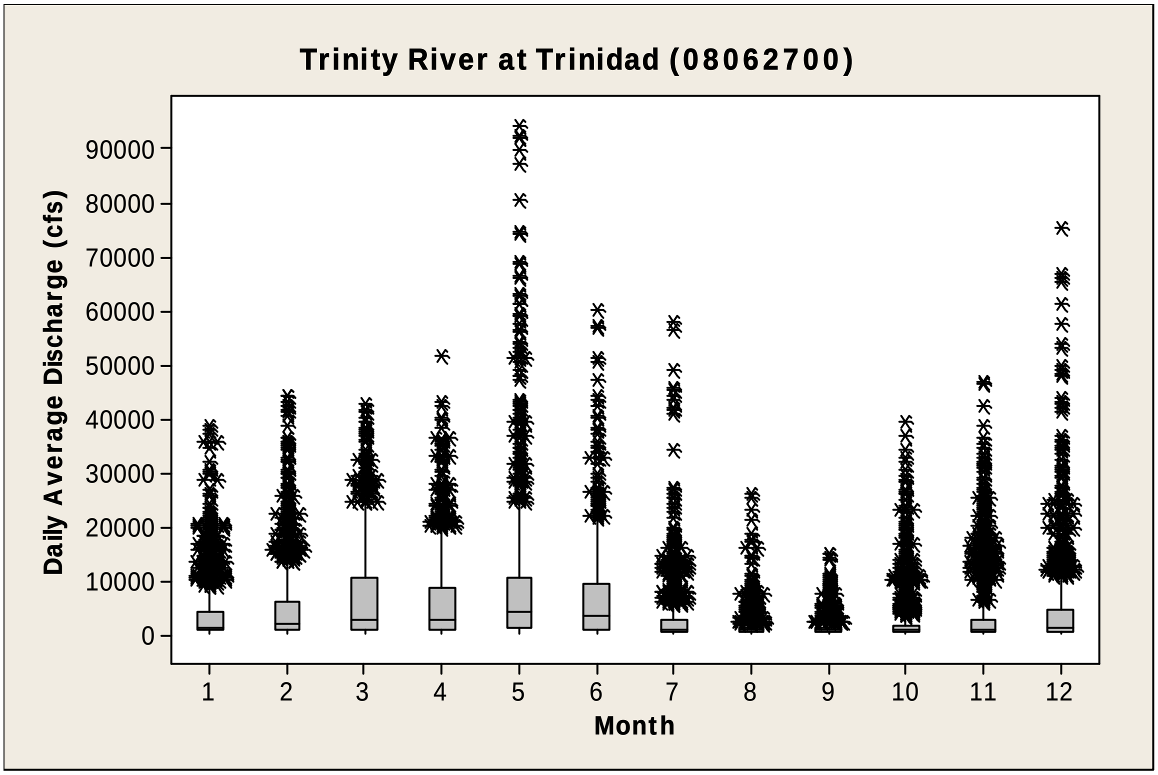


Figure 24. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average flows recorded at the USGS Trinity near Rosser (08062500) gage from 1939 through 2008.

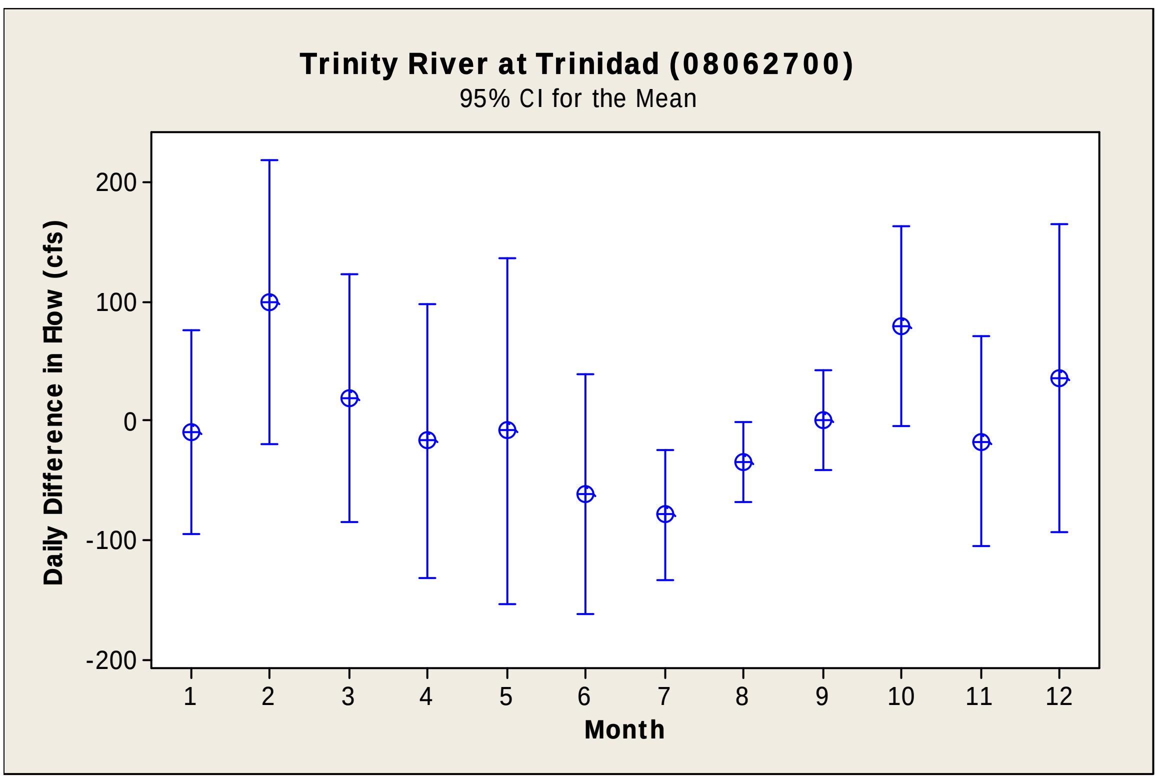


Figure 25. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the USGS Trinity River at Trinidad (08062700) gage from 1965 through 2008.

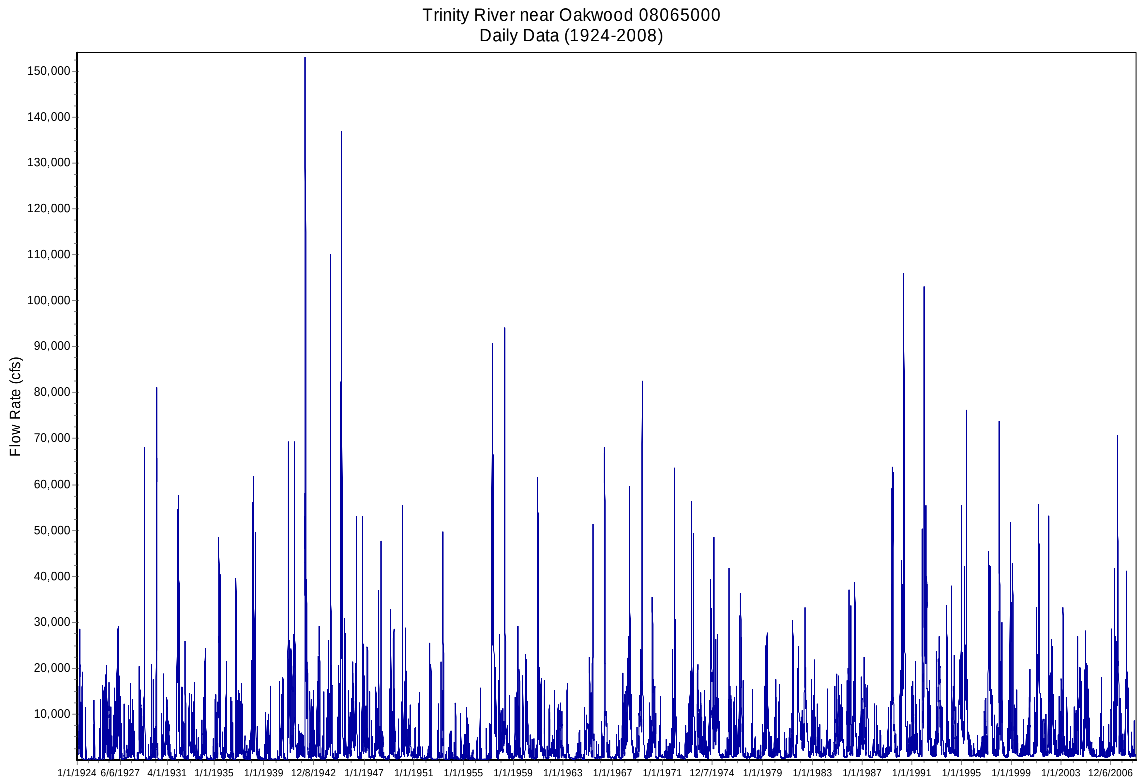


Figure 26. Average daily flows recorded at the USGS Trinity River near Oakwood (08065000) gage from 1924 through 2008.

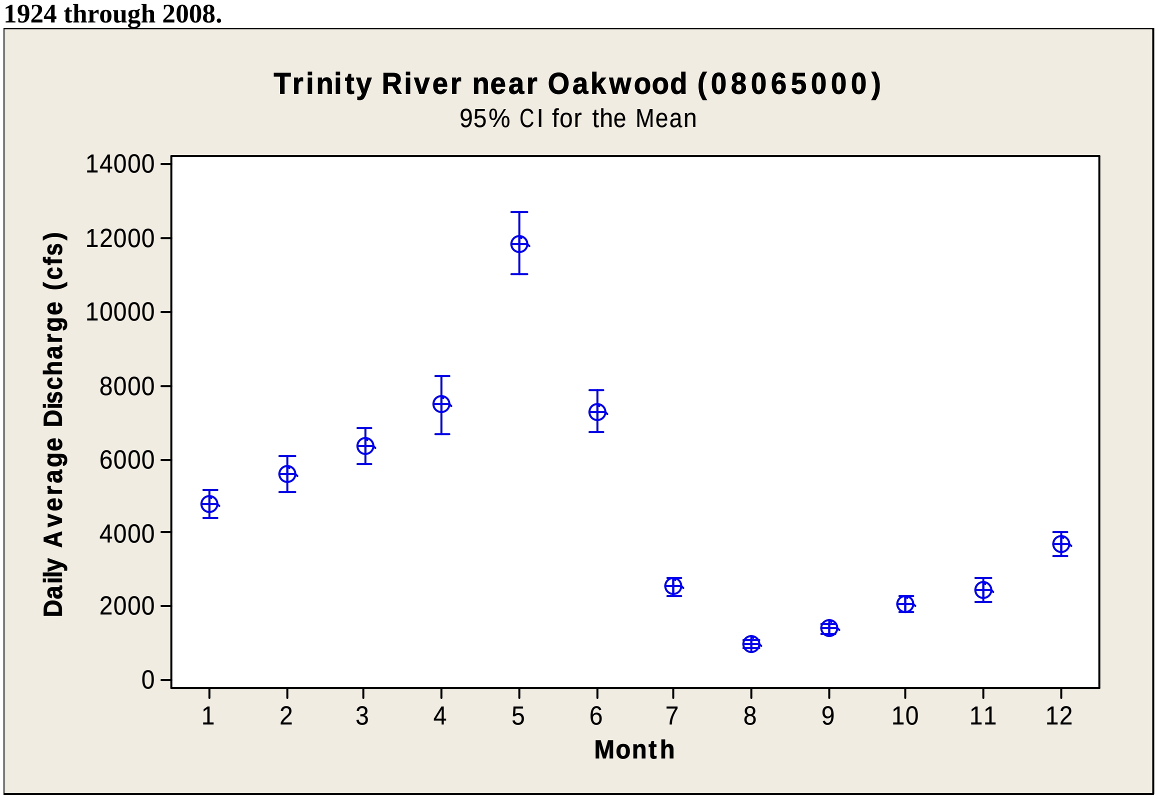


Figure 27. Monthly mean and 95% confidence intervals for daily average flow recorded at the USGS Trinity River near Oakwood (08065000) gage from 1924 through 2008.

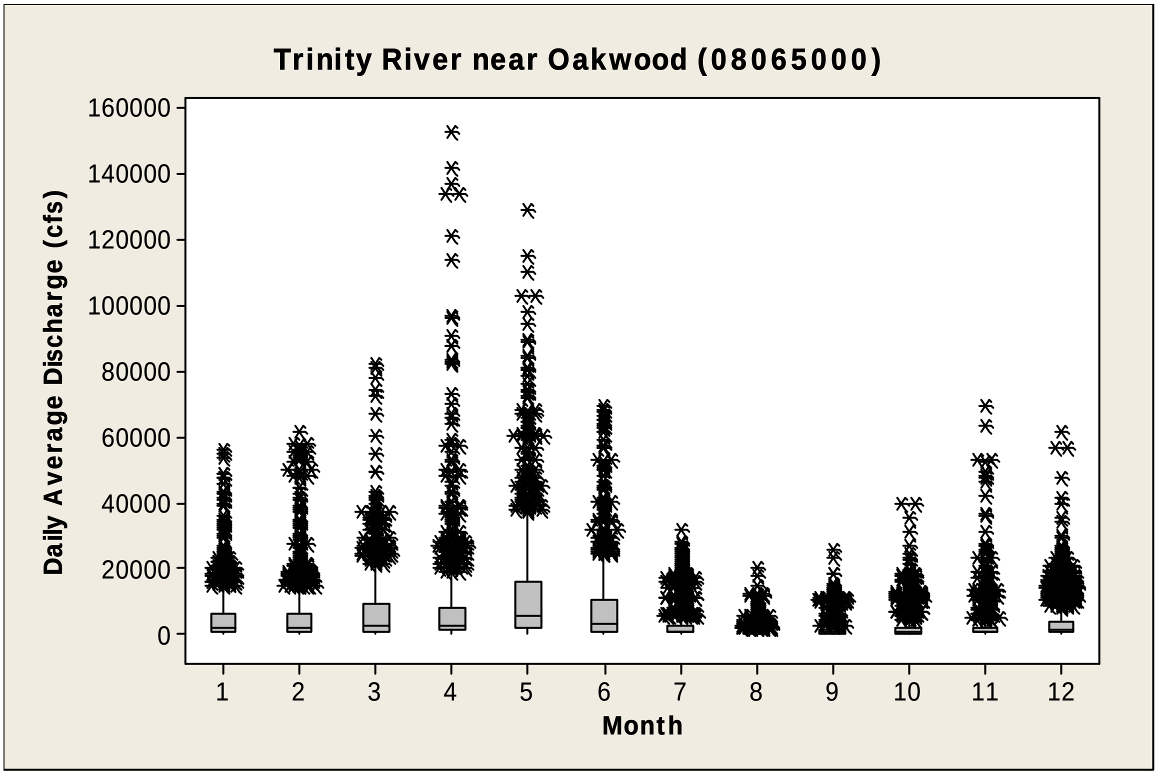


Figure 28. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average flows recorded at the USGS Trinity near Oakwood (08065000) gage from 1924 through 2008.

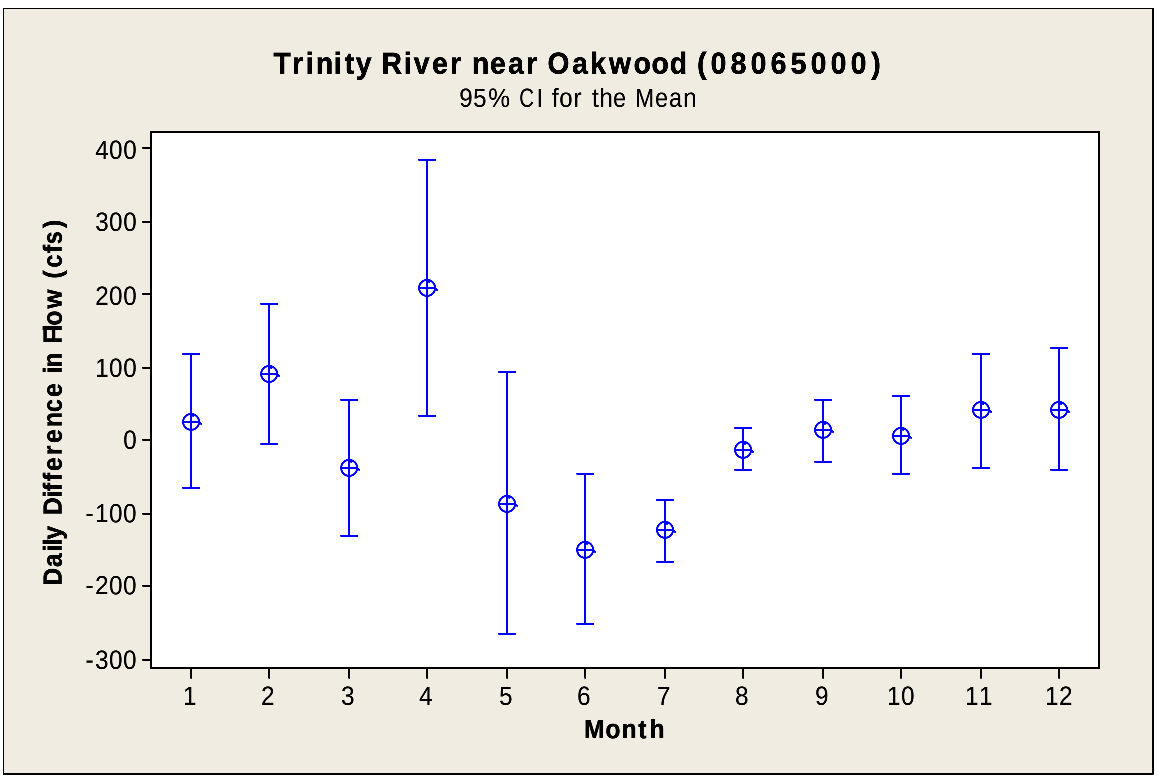


Figure 29. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the USGS Trinity River at Oakwood (08065000) gage from 1924 through 2008.

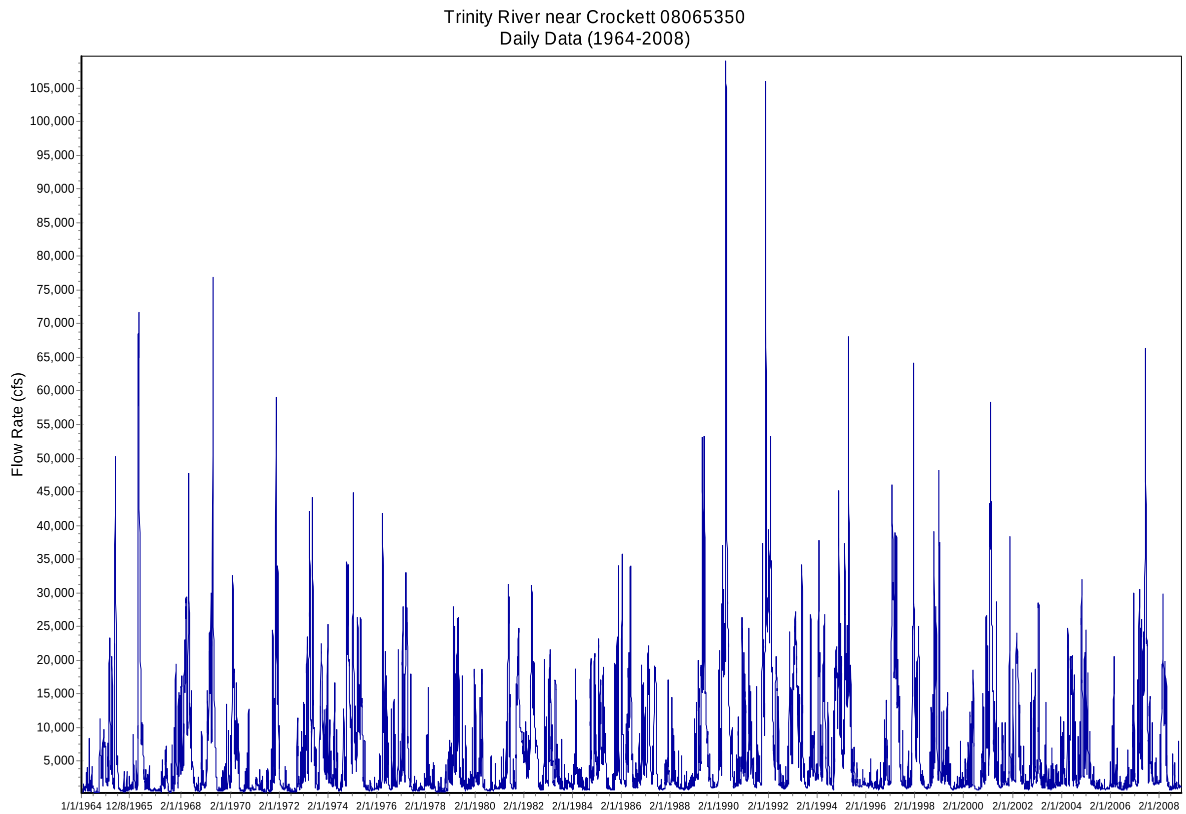


Figure 30. Average daily flows recorded at the USGS Trinity River near Crockett (08065350) gage from 1964 through 2008.

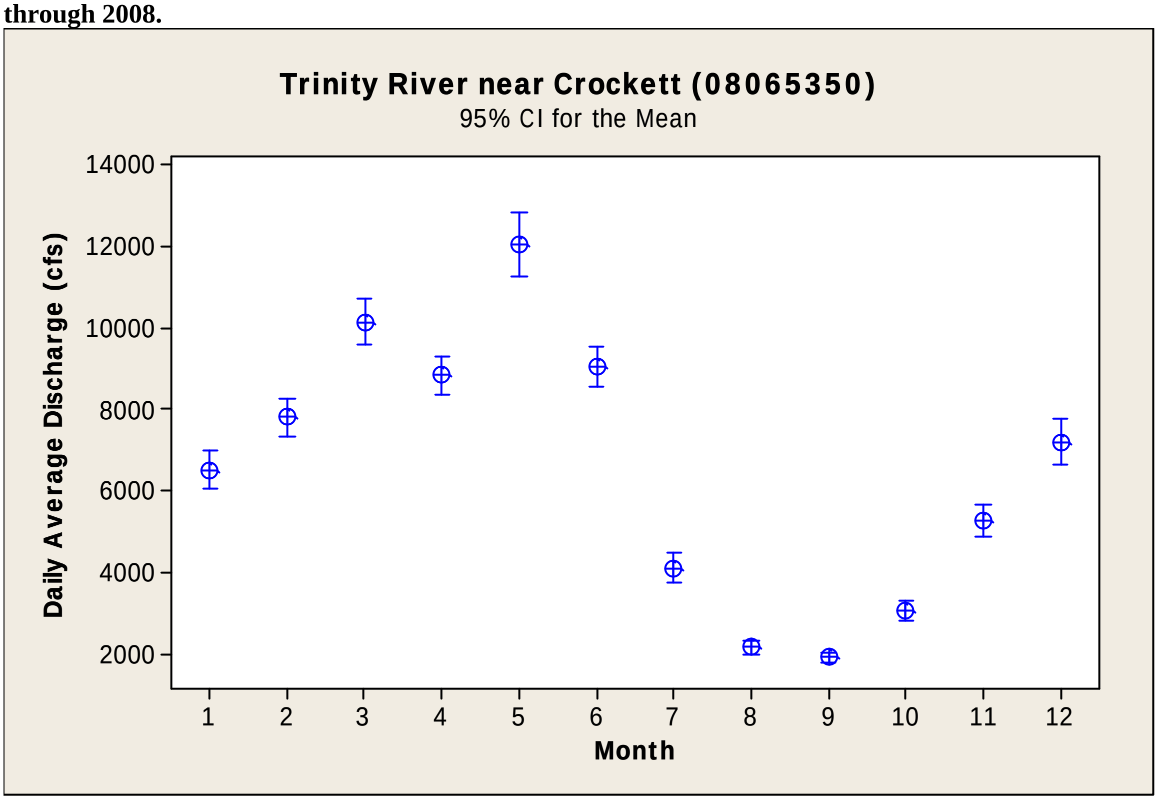


Figure 31. Monthly mean and 95% confidence intervals for daily average flow recorded at the USGS Trinity River near Crockett (08065350) gage from 1964 through 2008.

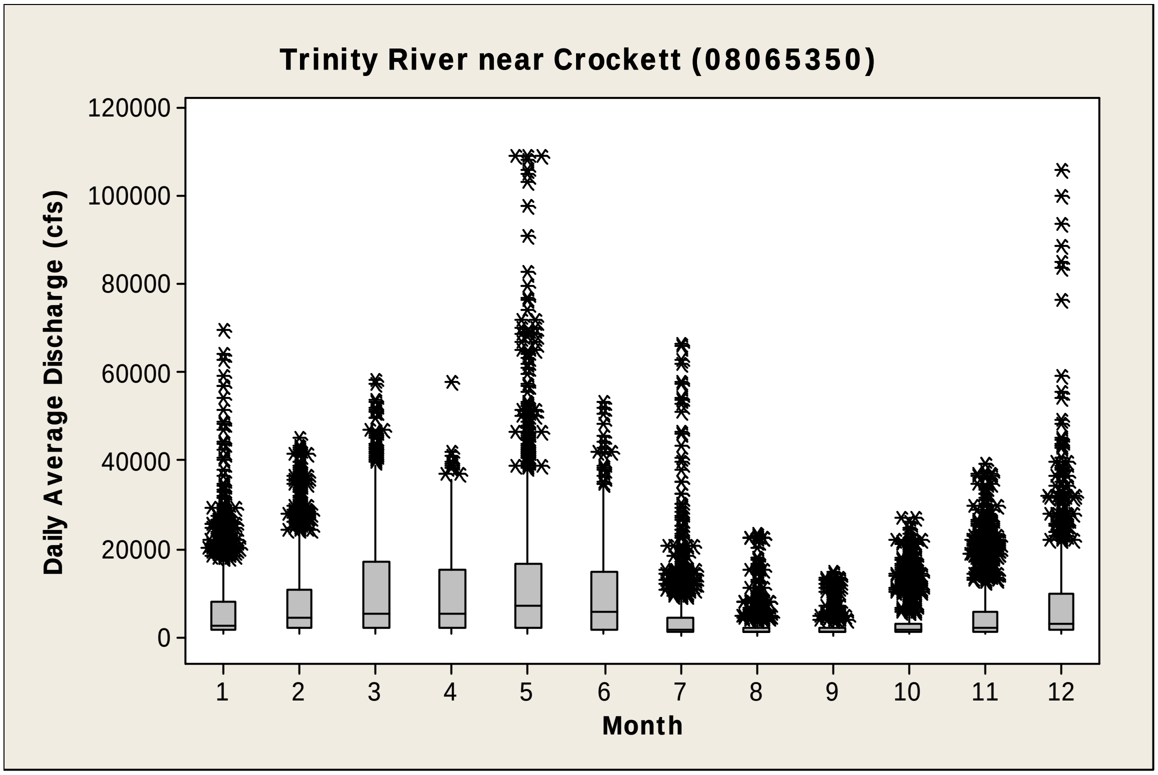


Figure 32. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average.

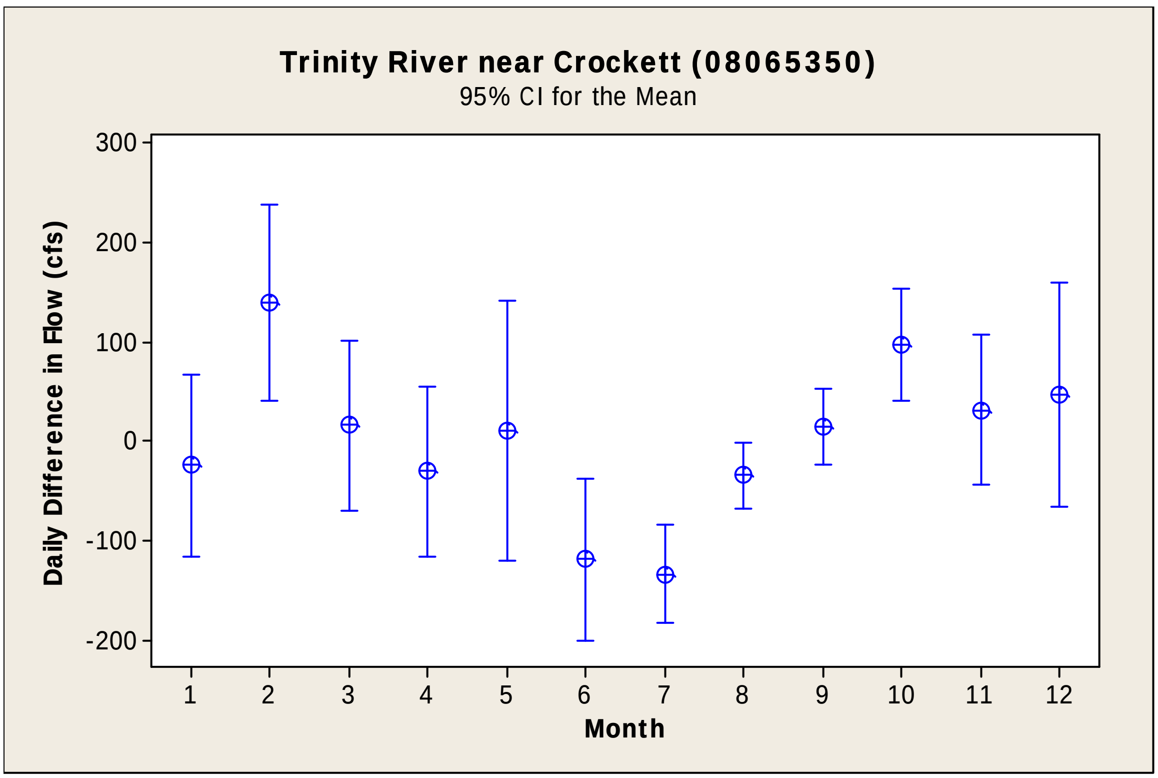


Figure 33. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the USGS Trinity River near Crockett (08065350) gage from 1964 through 2008.

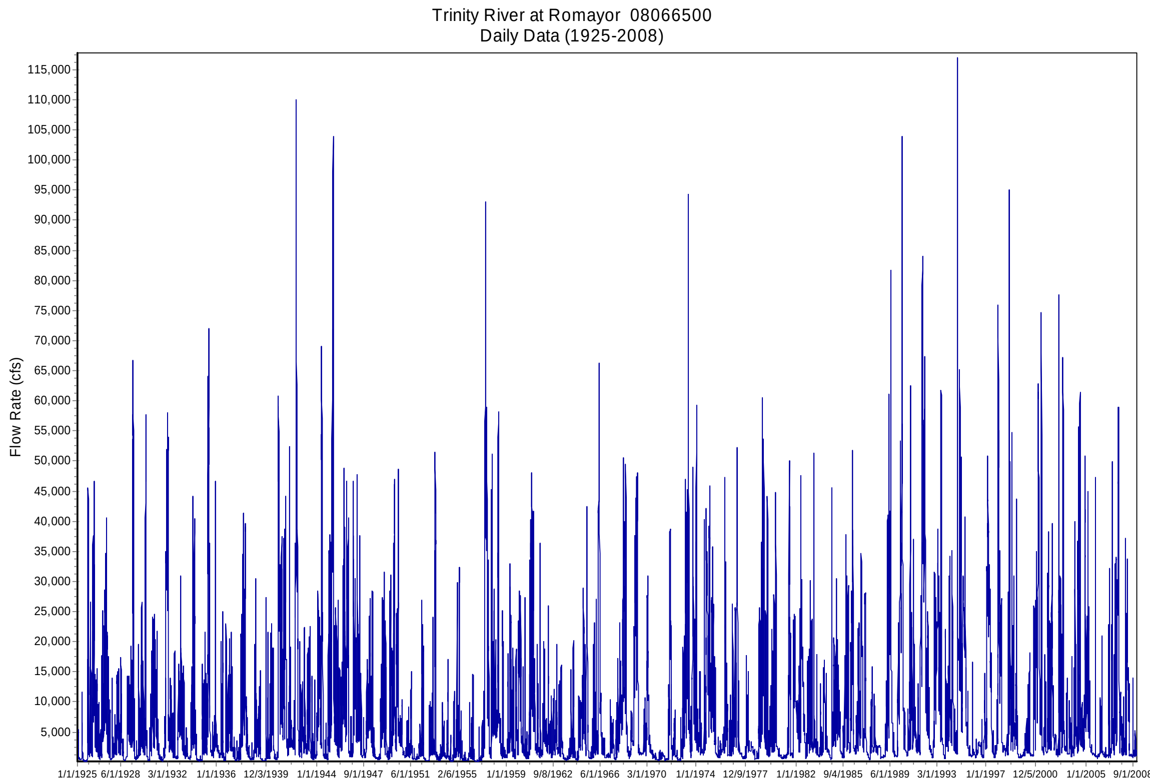


Figure 34. Average daily flows recorded at the USGS Trinity River at Romayor (08066500) gage from 1925 through 2008.

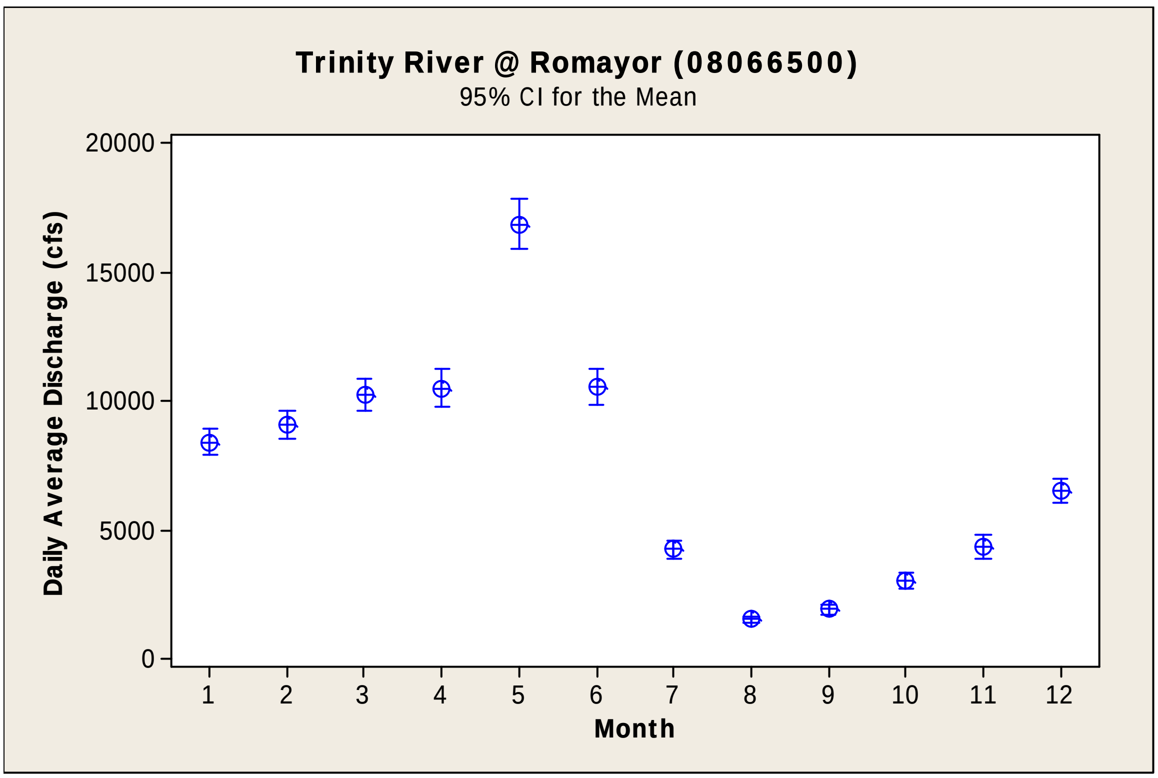


Figure 35. Monthly mean and 95% confidence intervals for daily average flow recorded at the USGS Trinity River at Romayor (08066500) gage from 1925 through 2008.

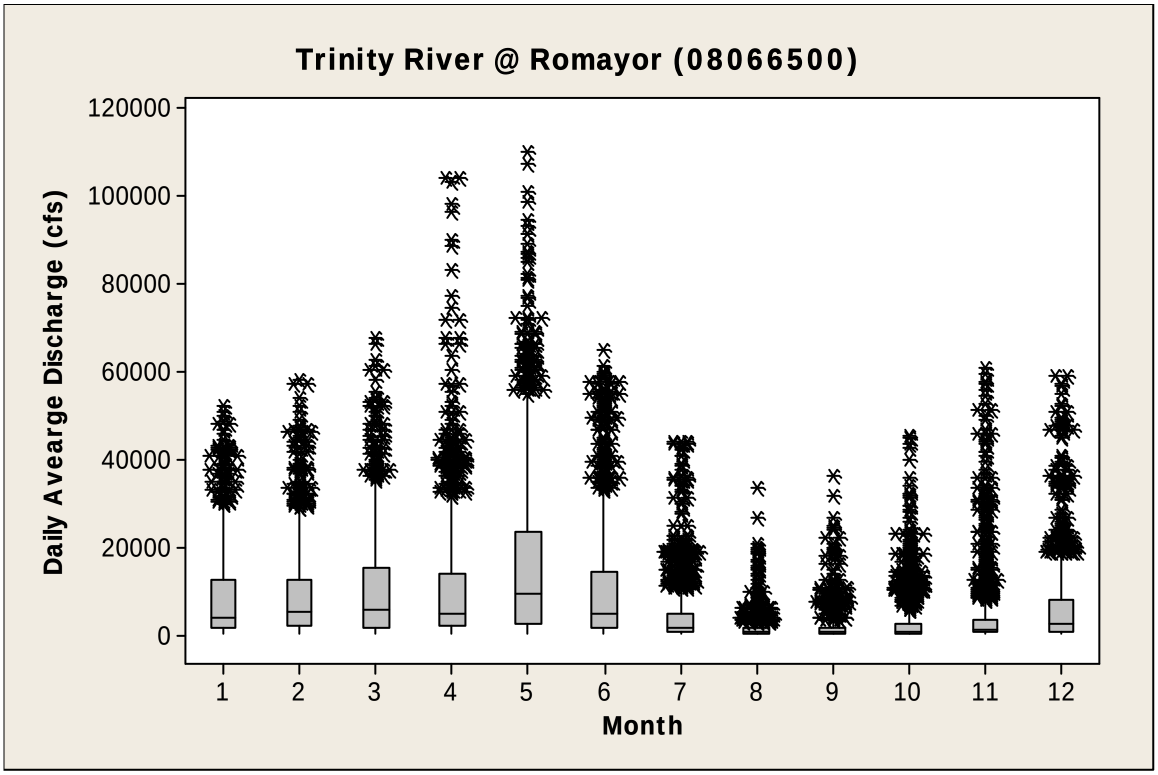


Figure 36. Monthly median, interquartile range (boxes), extended range (1.5 X quartile = line) and outliers (*) for daily average.

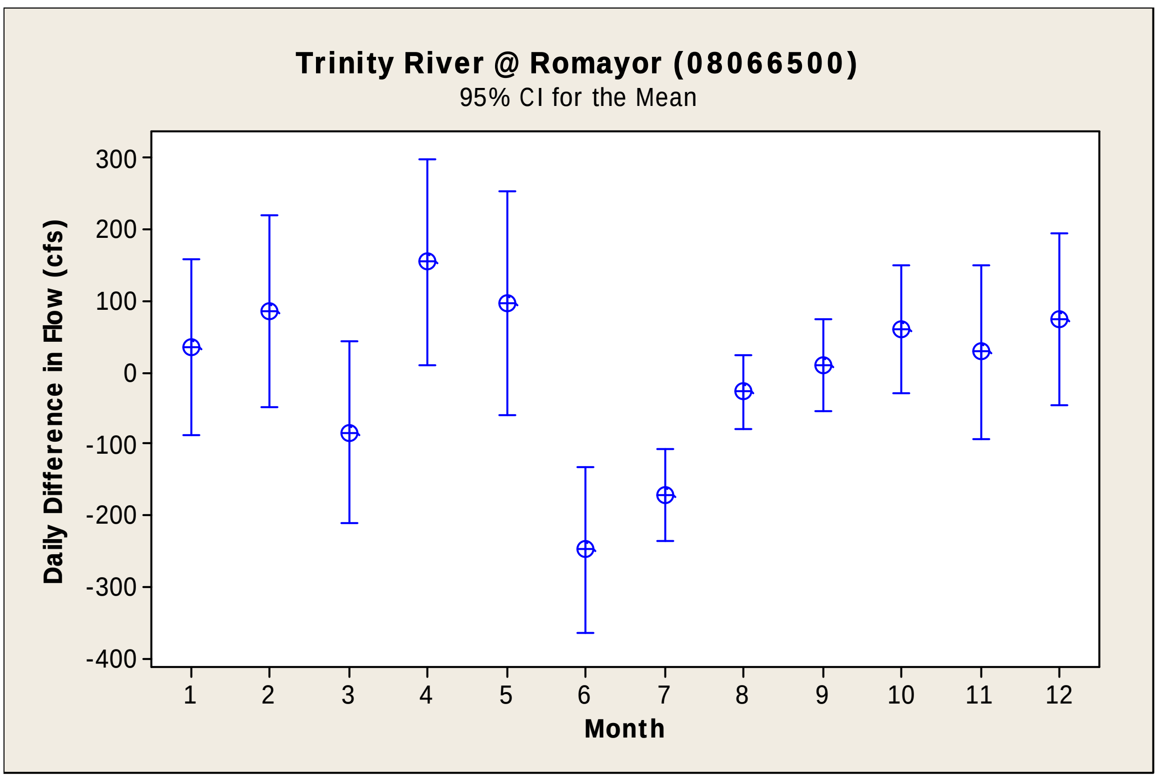


Figure 37. Monthly mean and 95% confidence intervals for daily difference in average daily flows between successive dates recorded at the USGS Trinity River at Romayor (08066500) gage from 1925 through 2008.

Table 8. Preliminary list of 7Q2 estimates for various gage sites in the Trinity River Basin obtained form TCEQ in September 2009. Cell in yellow highlight are priority gage sites.

Gage	GageID	Start_Year	End_Year	7Q2	County_1	County_2	Stream_Name	Discontin	Gaps	Below_res	Dist_res	Res_ name	Res_date	Segment#
08066250	254	1979	2007	728	POLK	SAN JACINTO	TRINITY R			Y	11.9	LIVINGSTON RESERVOIR	6/26/69	0802
08066500	257	1979	2007	775	LIBERTY		TRINITY R			Y	34.9	LIVINGSTON RESERVOIR	6/26/69	0802
08065500	244	1960	1970	510	MADISON	HOUSTON	TRINITY R	Y		Y	147.8	RICHLAND CHAMBERS RESERVOIR	12/88	0803
08062700	224	1982	2007	722	HENDERSON	NAVARRO	TRINITY R			Y	101.4	LAKE RAY HUBBARD	3/22/78	0804
08065000	241	1982	2007	759	ANDERSON	FREESTONE	TRINITY R			Y	64.8	RICHLAND CHAMBERS RESERVOIR	12/88	0804
08065350	243	1981	2007	833	LEON	HOUSTON	TRINITY R			Y	112.8	RICHLAND CHAMBERS RESERVOIR	12/88	0804
08057000	197	1989	2007	396	DALLAS		TRINITY R			Y	39.3	LAKE ARLINGTON	3/31/57	0805
08057410	202	1975	2007	503	DALLAS		TRINITY R		Y	Y	47.8	LAKE ARLINGTON	3/31/57	0805
08057448	204	1998	2002	662	DALLAS		TRINITY R	Y		Y	60.4	LAKE ARLINGTON	3/31/57	0805
08062500	222	1982	2007	678	KAUFMAN	ELLIS	TRINITY R			Y	41.2	LAKE RAY HUBBARD	3/22/78	0805
08048000	159	1979	2007	12	TARRANT		TRINITY R, W FK			Y	12	BENBROOK LAKE	9/29/52	0806
08048543	163	1979	2007	13	TARRANT		TRINITY R, W FK			Y	19.2	BENBROOK LAKE	9/29/52	0806
08043100	148	1985	1989	1.6	WISE		TRINITY R, W FK	Y		Y	2.9	BRIDGEPORT RESERVOIR	1972	0810
08044500	150	1979	2007	7	WISE		TRINITY R, W FK			Y	25	BRIDGEPORT RESERVOIR	1972	0810
08042800	147	1979	2007	0	JACK		TRINITY R, W FK			N				0812
08064100	238	1984	2007	0.04	NAVARRO		CHAMBERS CR			Y	10.6	BARDWELL LAKE	3/27/66	0814
08061750	216	2003	2007	25	KAUFMAN		TRINITY R, E FK			Y	1.9	LAKE RAY HUBBARD	3/22/78	0819
08061970	218	1989	1992	33	DALLAS		TRINITY R, E FK	Y		Y	10	LAKE RAY HUBBARD	3/22/78	0819
08061980	219	1989	1996	63	DALLAS		TRINITY R, E FK	Y	Y	Y	13	LAKE RAY HUBBARD	3/22/78	0819

Table 8. Continued.

Gage	GageID	Start_Year	End_Year	7Q2	County_1	County_2	Stream_Name	Discontin	Gaps	Below_res	Dist_res	Res_ name	Res_date	Segment#
08062000	221	1993	2007	64	KAUFMAN		TRINITY R, E FK			Y	21.7	LAKE RAY HUBBARD	3/22/78	0819
08061000	213	1960	1989	0	COLLIN		TRINITY R, E FK	Y		Y	0.7	LAVON LAKE	10/53	0820
08053000	189	1979	2007	61	DENTON		TRINITY R, ELM FK			Y	1.9	LAKE LEWISVILLE	8/55	0822
08055500	194	1979	2007	15	DALLAS		TRINITY R, ELM FK			Y	11.9	LAKE LEWISVILLE	8/55	0822
08050300	177	1960	1973	0.01	COOKE		TRINITY R, ELM FK	Y		N				0824
08050400	178	1998	2007	0.03	COOKE		TRINITY R, ELM FK			N				0824
08050410	179	1988	1998	4.3	COOKE		TRINITY R, ELM FK	Y		N				0824
08055000	193	1966	2007	11	DENTON		DENTON CR		Y	Y	5.6	GRAPEVINE LAKE	7/3/52	0825
08047000	156	1979	2007	1.6	TARRANT		TRINITY R, CLEAR FK			Y	1.5	BENBROOK LAKE	9/29/52	0829
08047500	158	1979	2007	4.4	TARRANT		TRINITY R, CLEAR FK			Y	10	BENBROOK LAKE	9/29/52	0829
08045850	152	1980	2005	0.2	PARKER		TRINITY R, CLEAR FK	Y	Y	Y	2.8	LAKE WEATHERFORD	1957	0831
08046000	153	1960	1975	0	PARKER		TRINITY R, CLEAR FK	Y		Y	15	LAKE WEATHERFORD	1957	0831
08046020	154	1989	1996	9.8	TARRANT		TRINITY R, CLEAR FK	Y		Y	19	LAKE WEATHERFORD	1957	0831
08064550	779	1994	2008	5	FREESTONE		RICHLAND CR			Y	0	RICHLAND CHAMBERS RESERVOIR	12/88	0835
08063500	232	1960	1988	0	NAVARRO		RICHLAND CR	Y		Y	30	NAVARRO MILLS LAKE	9/19/63	0836
08063100	230	1979	2007	0.01	NAVARRO		RICHLAND CR			Y	1.7	NAVARRO MILLS LAKE	9/19/63	0837
08051100	778	1988	2008	2	DENTON		TRINITY R, ELM FK			Y	0	LAKE RAY ROBERTS	6/30/87	0839
08051130	183	1986	1992	0.04	DENTON		TRINITY R, ELM FK	Y		Y	0.1	LAKE RAY ROBERTS	6/30/87	0839
08049500	170	1979	2007	140	DALLAS		TRINITY R, W FK			Y	25	LAKE ARLINGTON	3/31/57	0841

Water Quality and Geomorphological Factors

Historical Data

Based on their most recent assessment the TCEQ identified 37 impaired waterbody segments within the Trinity watershed (Texas Commission on Environmental Quality (TCEQ) 2009). The majority (29) of these segments were listed exclusively for not meeting contact recreational use criteria that is exceeding numerical indicator bacteria criteria (Table 9). Only five segments were listed as not supporting aquatic life uses, primarily due to not meeting dissolved oxygen criteria. These segments located in the upper watershed include Cotton Bayou, Catfish Creek, West Fork Trinity River and Clear Fork Trinity River (Table 9). Four stream segments were also listed for not meeting general use criteria (e.g. chlorides, sulfate, TDS and pH). These data suggest that the majority of majority of the Trinity River basin is meeting aquatic life use numerical water quality criteria and aquatic life uses. Prior to 1990's water quality was severely impaired in the upper portions of the Trinity River basin, downstream of Dallas and Fort Worth, due to inadequate wastewater treatment (Arnold 1989; Dickson et al. 1991; Lamb 1961; Leifeste and Hughes 1967). The resulting anoxia or hypoxia created areas devoid of life and/or later caused periodic fish kills following storm events, commonly referred to as the "black rise"(Davis 1987; Davis and Bastian 1988). Since the early 1990's dissolved oxygen levels have improved and seldom drop below 4.0 mg/l based on data collected during routine monitoring conducted by TCEQ and partner agencies (Figures 38 and 39). Dissolved oxygen concentrations in most portions of the Trinity River now appear to be meeting aquatic life use criteria (Figure 40 and 41). Median values within the basin during 1968 through 2008 appear to fluctuate between 5 and 10 mg/l, although there are occasional periods when levels have dropped below 2.0 mg/l.

Table 9. Current 303d listed impaired water bodies within the Trinity River Basin and concerns.

Segment	Description	Extent	Status	Year Listed	Concern	Human Health	Aquatic Life	General
0801C	Cotton Bayou	portions	unclassified	2006	low oxygen		X	
0803	Lake Livingston	portions	classified	2006-2008	sulfate, pH			X
0804G	Catfish Creek	entire	unclassified	2006	low oxgyen, imparied benthos		X	
0805	Upper Trinity River	portions	classified	1996-2002	bacteria, PCB in tissue	X		
0806	W. Fork Trinity River Below Lake Worth	portions	classified	1996	PCB in tissue	X		
0806D	Marine Creek	portions	unclassified	2006	bactera	X		
0806E	Sycamore Creek	portions	unclassified	2006	bacteria	X		
0810	West Fork Trinity R. below Bridgeport Reservoir	portions	classified	1998	bacteria	X		
0810A	Big Sandy Creek	portions	unclassified	2006	bacteria	X		
0810B	Garrett Creek	portions	unclassified	2006	bacteria	X		
0810C	Martin Branch	portions	unclassified	2006	bacteria	X		
0810D	Salt Creek	portions	unclassified	2006	bacteria	X		
0812	West Fork Trinity R. above Bridgeport Res.	portions	classified	1998	chloride, low oxygen, TDS,	X	X	X
0818	Cedar Creek Reservoir	portions	classified	2002	pH			X
0819	E. Fork Trinity River	entire	classified	2008	sulfate, TDS, chloride			X
0820C	Muddy Creek	entire	unclassified	2002	bacteria	X		
0822	Elm Fork T. River below Lewisville	portions	classified	2006	bacteria	X		
0822A	Cottonwood Branch	portions	unclassified	2006	bacteria	X		
0822B	Grapevine Creek	portions	unclassified	2006	bacteria	X		
0829	Clear Fork Trinity River below Benbrook L.	portions	classified	1996	PCBs in tissue	X		

Table 9. Continued.

0831	Clear Fork Trinity River below Lake Weatherford	portions	classified	1996	low oxygen		X	
0833	Clear Fork Trinity River above Lake Weatherford	portions	classified	1996	low oxygen		X	
0838C	Walnut Creek	portions	unclassified	2006	bacteria	X		
0841	Lower West Fork Trinity River	portions	classified	1996	bacteria, PCB in tissue	X		
0841B	Bear Creek	entire	unclassified	2006	bacteria	X		
0841C	Arbor Creek	entire	unclassified	2006	bacteria	X		
0841D	Big Bear Creek	entire	unclassified	2006	bacteria	X		
0841E	Copart Branch Mountain Creek	entire	unclassified	2006	bacteria	X		
0841F	Cottonwood Creek	entire	unclassified	2006	bacteria	X		
0814G	Dalworth Creek	entire	unclassified	2006	bacteria	X		
0814H	Delaware Creek	entire	unclassified	2006	bacteria	X		
0814J	Estelle Creek	entire	unclassified	2006	bacteria	X		
0841K	Fish Creek	entire	unclassified	2006	bacteria	X		
0841M	Kee Branch	entire	unclassified	2006	bacteria	X		
0841N	Kirby Creek	entire	unclassified	2006	bacteria	X		
0814S	Vilbig Lakes	portions	unclassified	2006	bacteria	X		
0814U	West Irving Creek	portions	unclassified	2006	bacteria	X		
Total						**30**	**5**	**4**

Source: (Texas Commission on Environmental Quality (TCEQ) 2009)

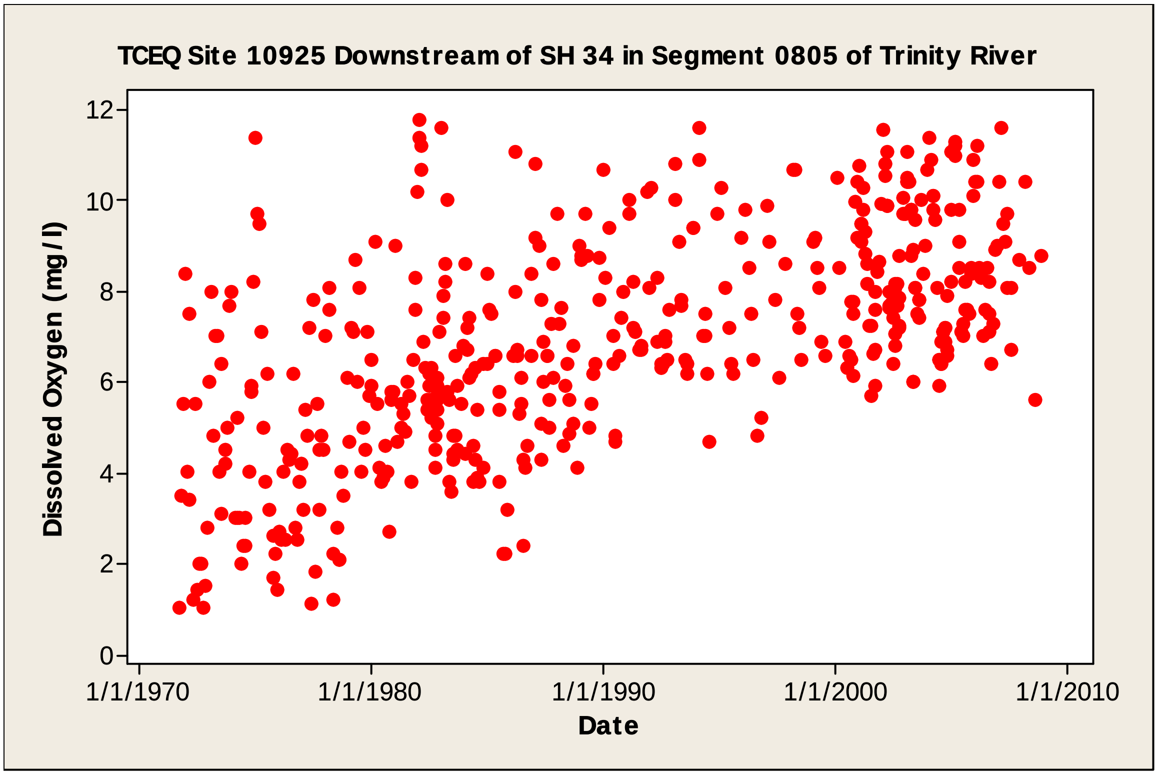


Figure 38. Trends in dissolved oxygen measured at the TCEQ monitoring site 10925 located downstream of SH 34 in segment 0805 of the Trinity River from 1971 through 2008.

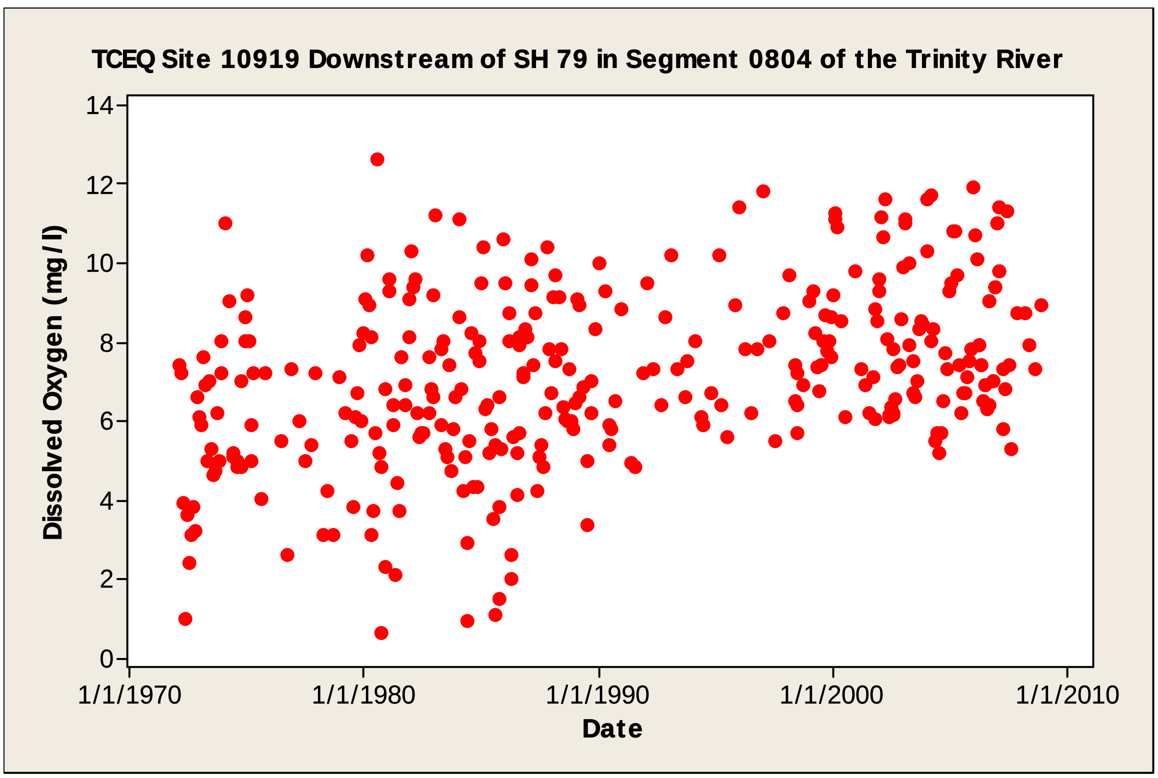


Figure 39. Trends in dissolved oxygen measured at the TCEQ monitoring site 10925 downstream of SH 79 in segment 0804 of the Trinity River from 1972 through 2008.

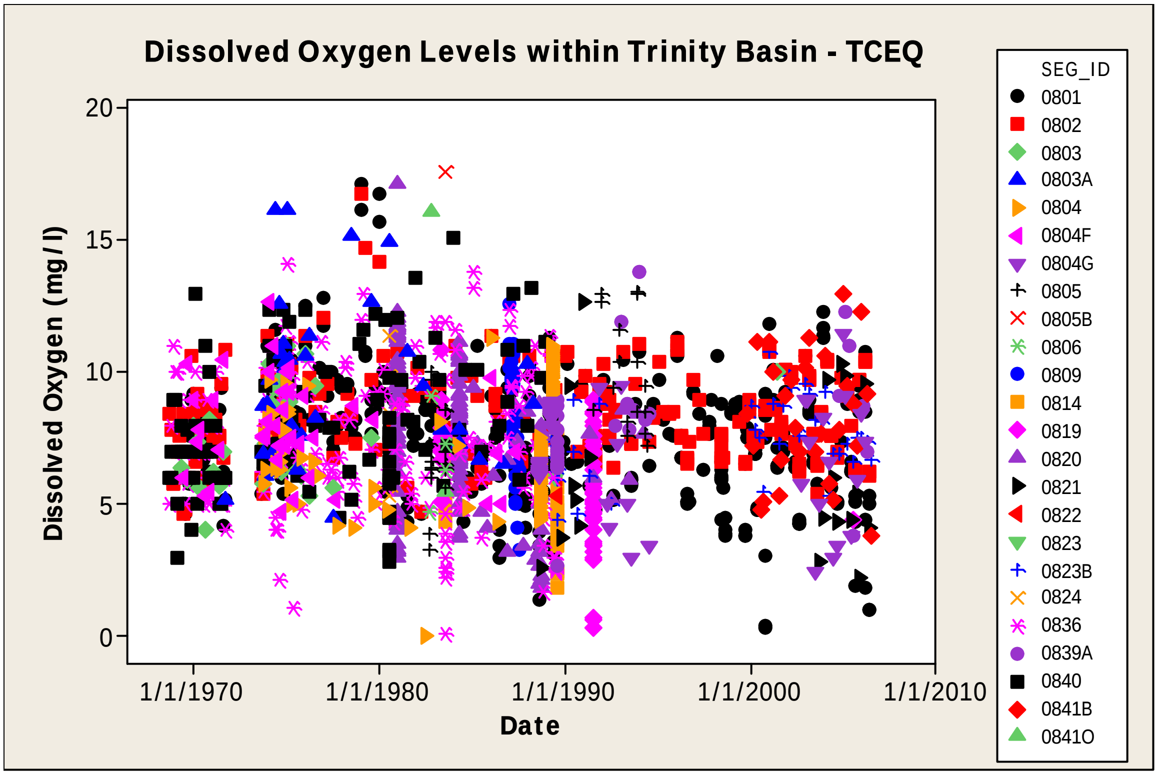


Figure 40. Long terms trends in dissolved oxygen measured at various sites in the all segments of the Trinity River basin based on historical data extracted TCEQ SWQM database from 1968 through 2006, n= 1894.

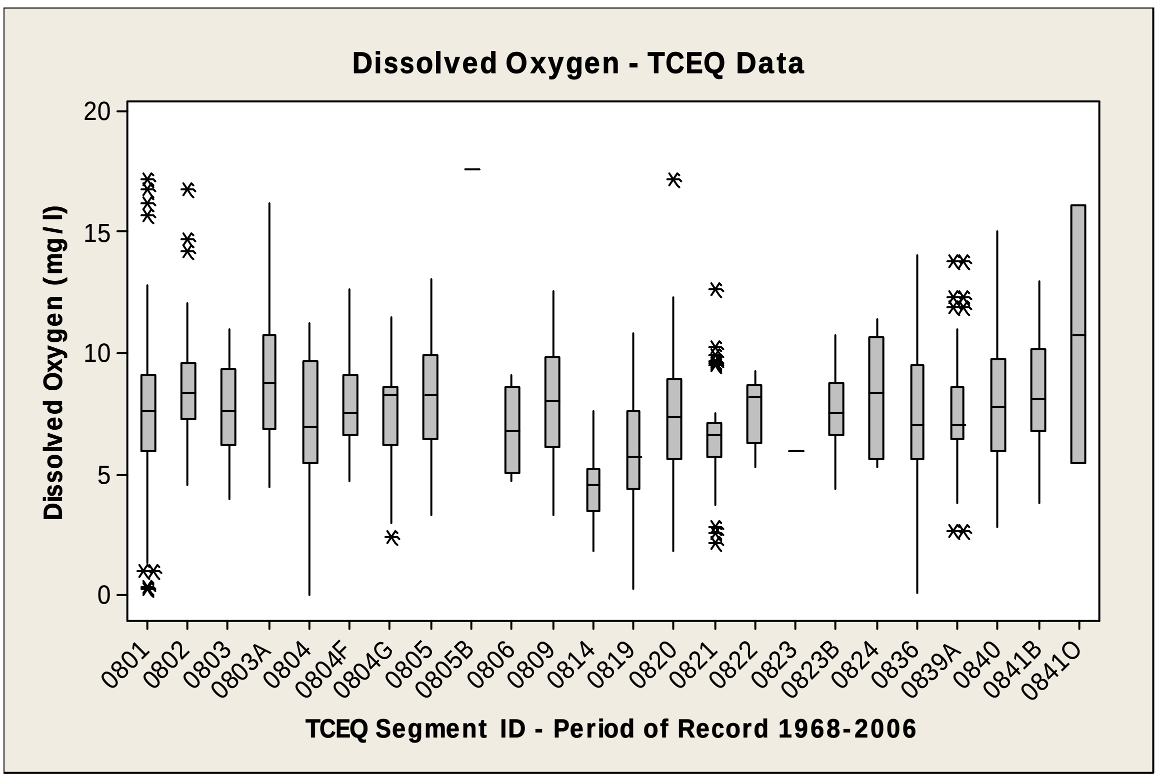


Figure 41. Long term spatial trends in dissolved oxygen measured at various sites within each segment of the Trinity River basin based on historical data extracted TCEQ SWQM database from 1968 through 2006, n= 1894.

Using historical USGS data we prepared a series of graphs depicting possible relationships between instantaneous flow and selected variables including water temperature, specific conductance (uS), total suspended sediments (TSS), total nitrogen (N) and total phosphorus (P) data at priority gage sites (Figures 42- 124). In many cases one or more variables were not collected at the site during the same time. In addition, we also utilized data compiled at the Romayor (08066500) site to estimate loading of selected constituents including TSS, N and P to Galveston Bay. The variables investigated included total nitrogen and phosphorus (Figure 122-123). Finally we utilized historical TCEQ data to evaluate long-term spatial trends in total suspended solids (Figures 127-128). Suspended solids loading was also estimated at the Trinity River near Oakwood gage (08065000) since it was one of the few gages that contained sufficient long-term data to estimate sediment loading at various flows. At some gage sites little data was available for the parameters of interests. In some cases there was insufficient data for selected parameters for a subset of the priority gages. In these cases graphical depictions between discharge and that parameter is not depicted. Again, for flow versus water quality relationships we only utilized data where paired instantaneous and water quality data were present. In some cases paired daily average daily flow and grab samples results for a particular chemical or physical trait were available. However, we did not utilize these for development of predictive relationships due to different time scales that the data parameters integrate.

Specific conductance was the only water quality parameter collected at a sufficient frequency at the at the Elm Fork Trinity gage (080555500) (Figure 42). Specific conductance did not exhibit a strong relationship with flow. In contrast several water quality parameters including water temperature, dissolved oxygen, specific conductance, total nitrogen, ammonia, nitrate and nitrite nitrogen, phosphates, orthophosphate, and phosphorous were measured at a sufficient intensity at the West Fork Trinity to evaluate effects of stream flow on their concentration (Figures 42-57). Water temperature during all seasons was depressed at higher flows (Figures 42-45). The strongest response occurred during the summer months (Figure 42). Flows above 3000 cfs generally resulted in water temperatures below 26 C, whereas at low flows temperatures ranged between 33 and 27 C. Over the period of record dissolved oxygen also increased slightly at higher flows (Figures 47 to 50). During the spring through fall dissolved oxygen levels were seldom below 6.0 mg/l at flows above 2000 cfs. During the winter dissolved oxygen seldom dropped below 8.0 mg/l whenever flows were above 1000 cfs. Highest variability and highest frequency of hypoxia and anoxia usually occurred at flows below 500 cfs. Specific conductance declined as flows decreased and was generally depressed below 400 uS above 2000 cfs (Figure 48). Nutrient concentrations generally peaked at 200 to 1000 cfs and then declined with increasing flows (Figures 52-58). This pattern is likely due to increased loading occurring during the ascending limb of flood events with subsequent dilution at higher flows.

Winter water temperature varied little flow, however higher flows during other months generally resulted in declining water temperatures at the Rosser gage (08062500)(Figures 60-62). This relationship was strongest during the summer months (Figure 62). Dissolved oxygen exhibited similar seasonal responses to increasing flows with greatest increases occurring in the summer months (Figures 63 to 65). Dissolved oxygen levels at the Rosser gage were seldom below 4.0 mg/l when flows were above 5000 to 6000 cfs. Specific conductance was depressed at higher flows and was seldom above 400 uS at flows greater than 5000 cfs. Nutrient levels at Rosser varied considerably at lower flows (<2500 cfs) but generally declined above 5000 cfs (Figures 68-74). Elevated levels of nutrients below 2000 cfs are likely due to storm events causing temporary increases in their levels as they are washed out into the watershed.

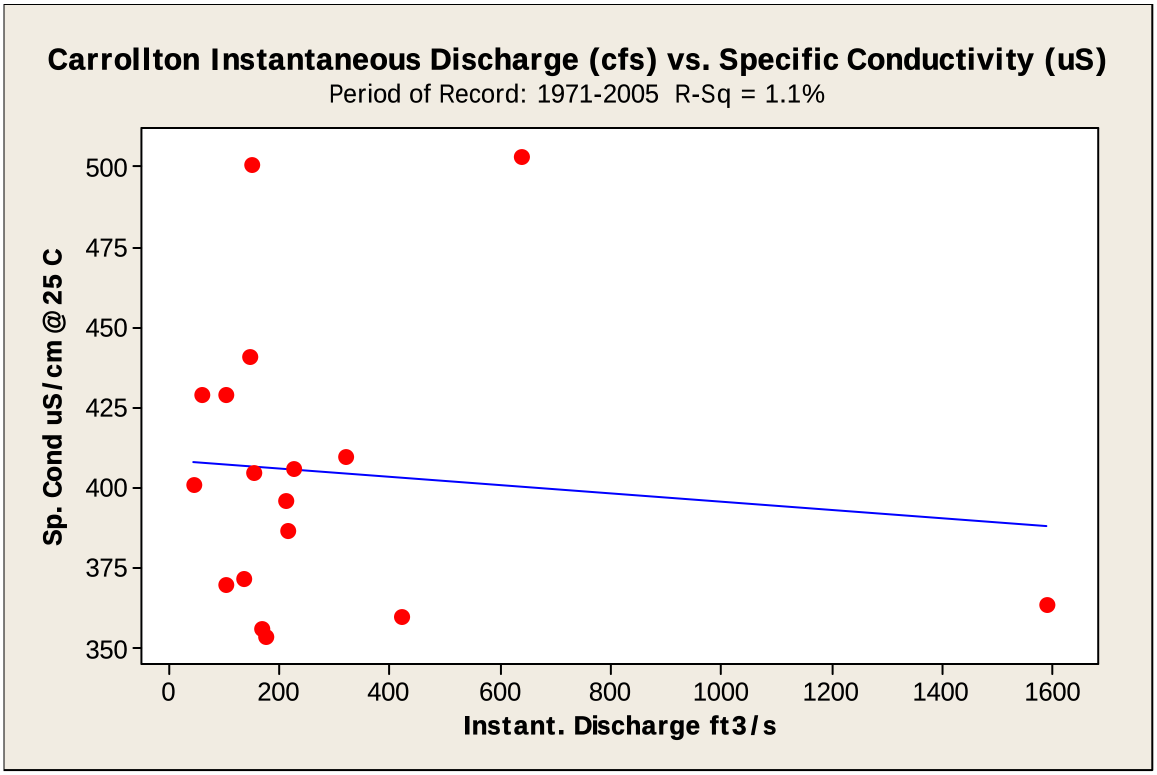


Figure 42. Flow versus specific conductance at the Elm Fork Trinity River gage near Carrollton (08055500) during 1971 through 2005.

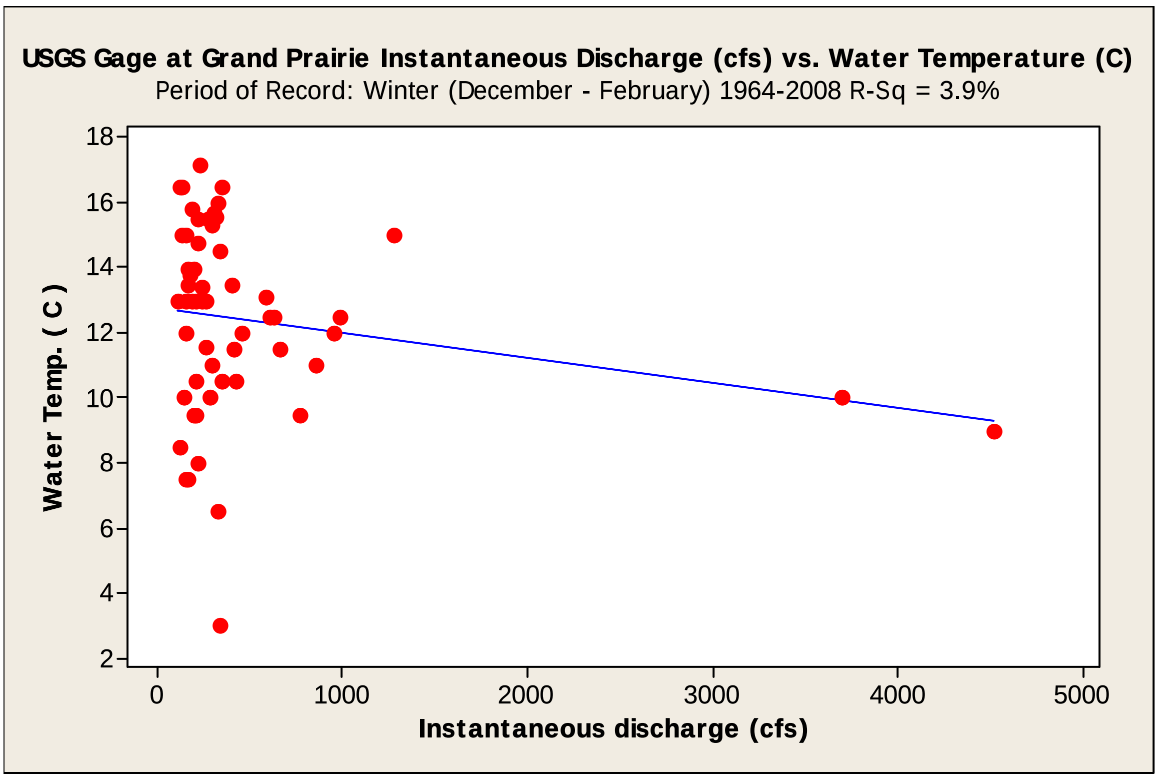


Figure 43. Flow versus winter water temperature at the West Fork Trinity River at Grand Prairie 08049500 gage during 1964 through 2008.

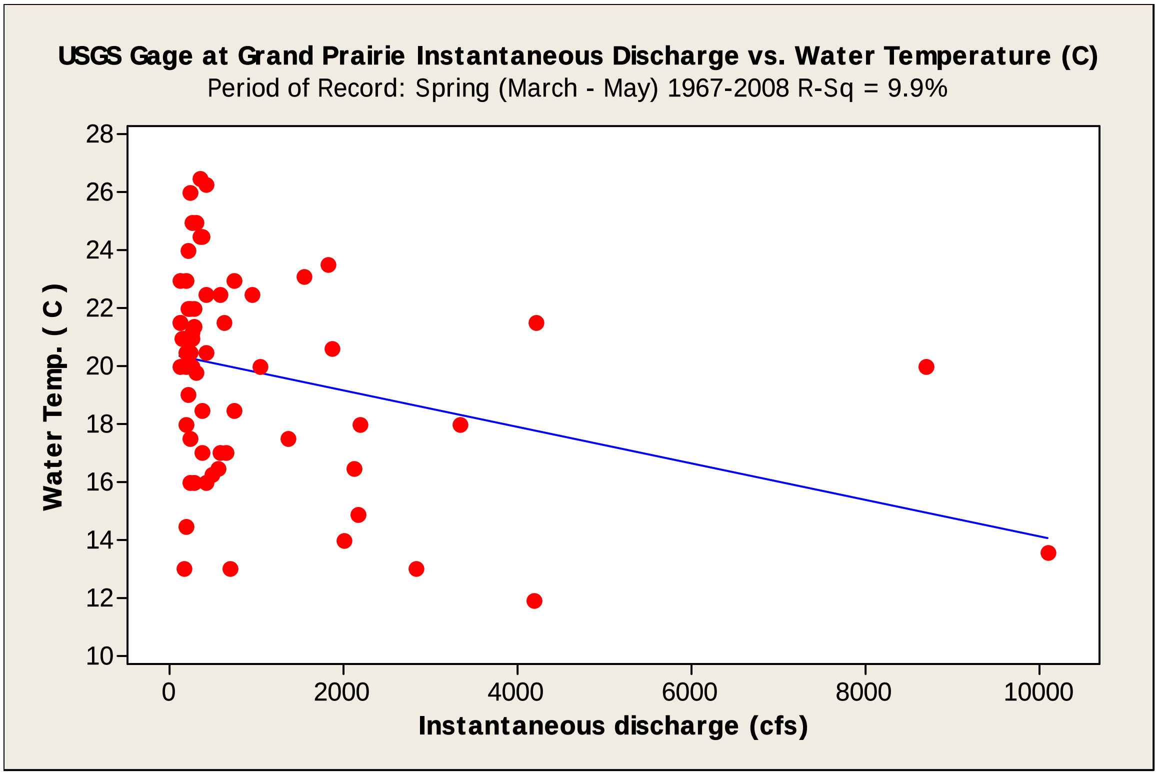


Figure 44. Flow versus spring water temperature at the West Fork Trinity River at Grand Prairie 08049500 gage during 1967 through 2008.

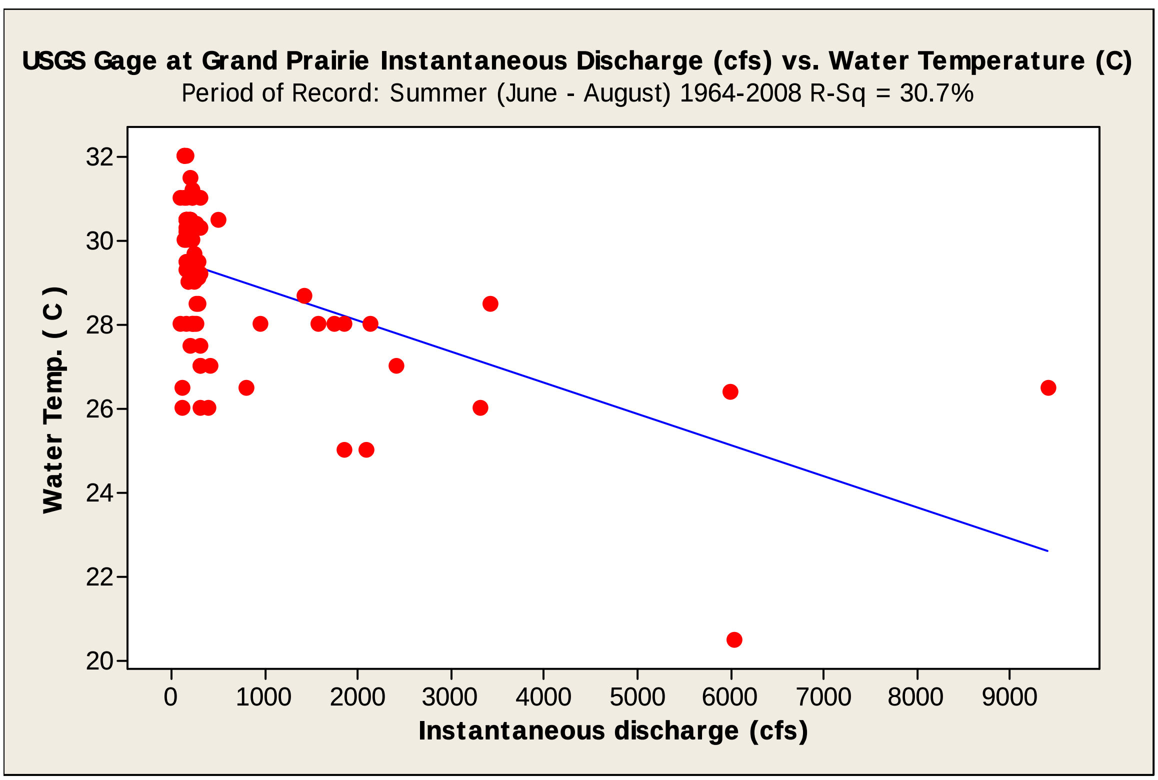


Figure 45. Flow versus summer water temperature at the West Fork Trinity River at Grand Prairie 08049500 gage during 1964 through 2008.

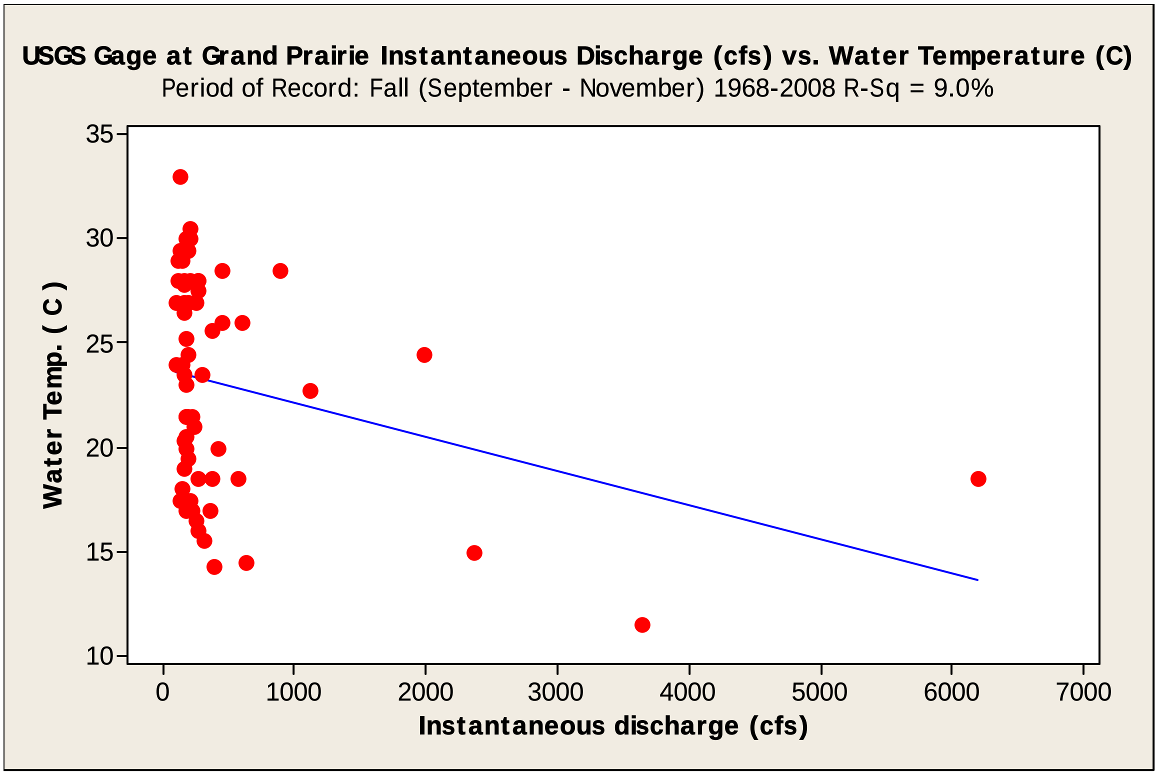


Figure 46. Flow versus fall water temperature at the West Fork Trinity River at Grand Prairie 08049500 gage during 1968 through 2008.

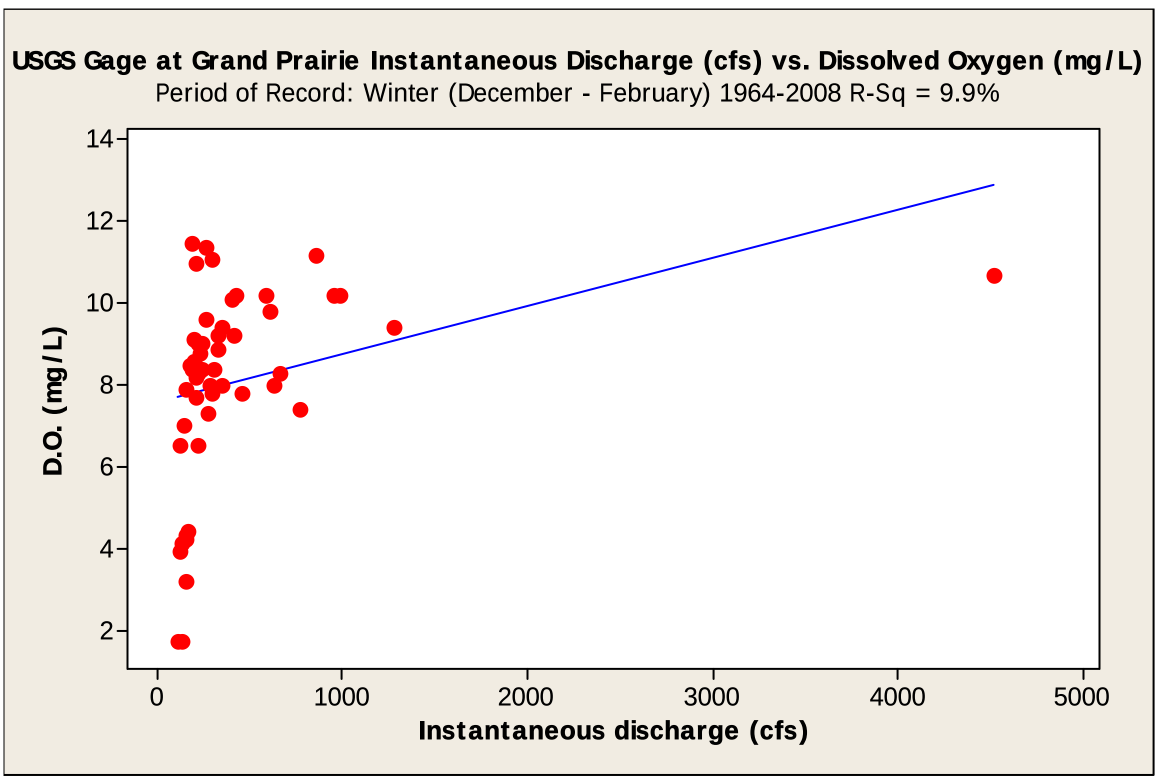


Figure 47. Flow versus winter dissolved oxygen at the West Fork Trinity River at Grand Prairie 08049500 gage during 1964 through 2008.

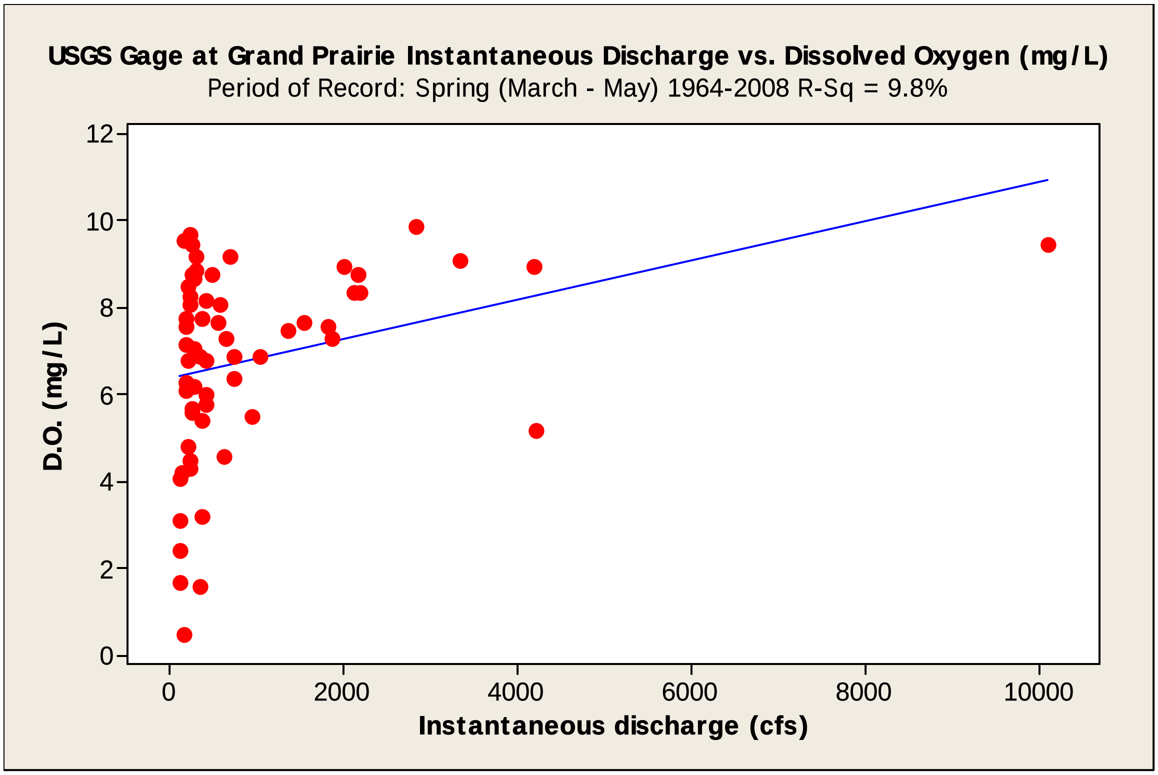


Figure 48. Flow versus spring dissolved oxygen at the West Fork Trinity River at Grand Prairie 08049500 gage during 1964 through 2008.

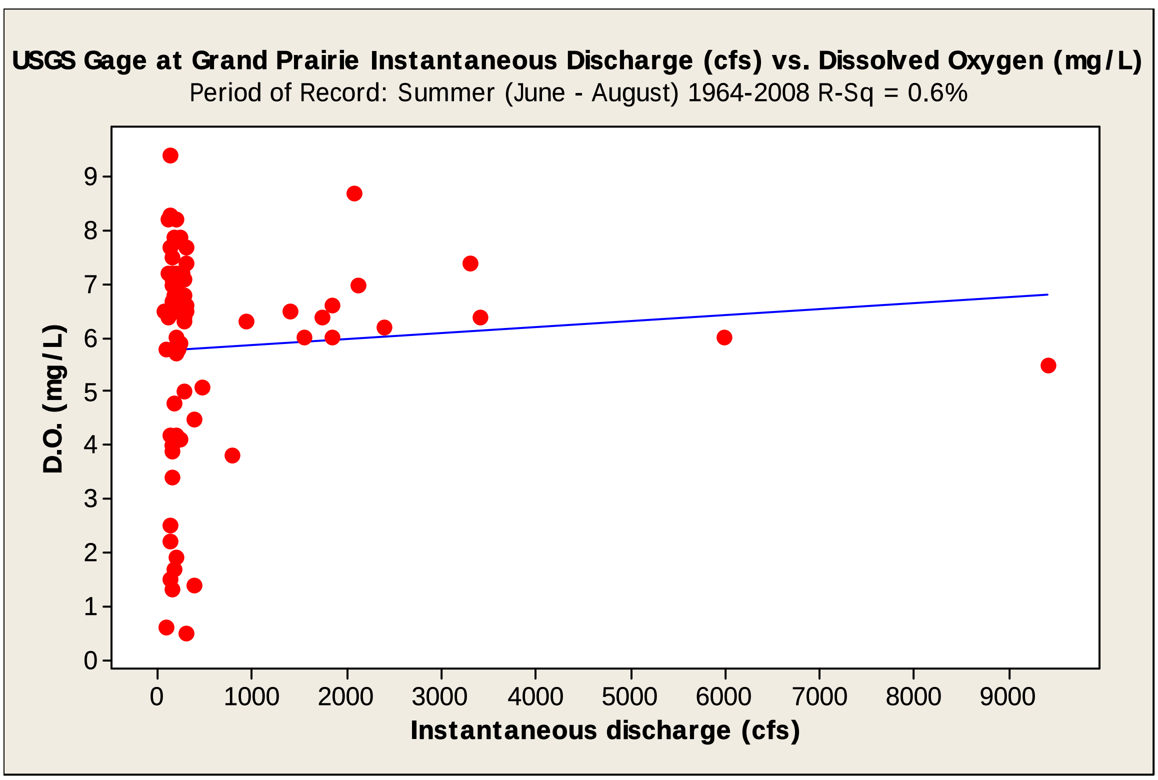


Figure 49. Flow versus summer dissolved oxygen at the West Fork Trinity River at Grand Prairie 08049500 gage during 1964 through 2008.

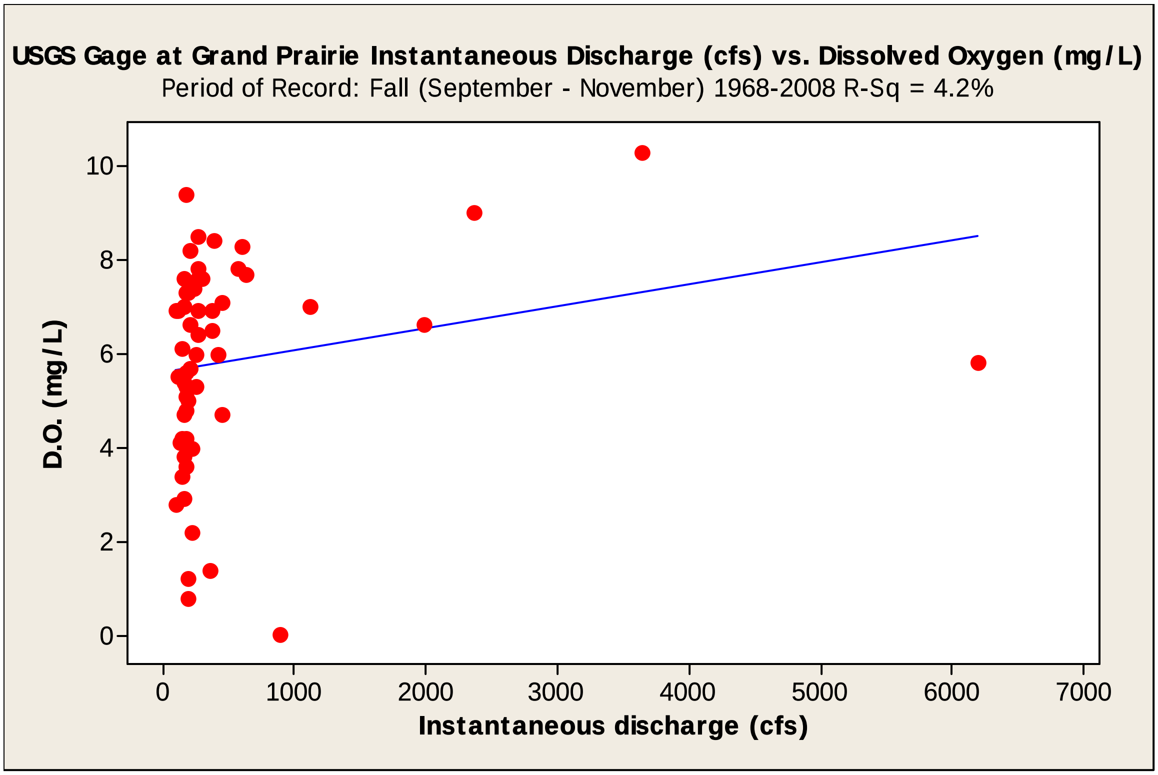


Figure 50. Flow versus fall dissolved oxygen at the West Fork Trinity River at Grand Prairie 08049500 gage during 1964 through 2008.

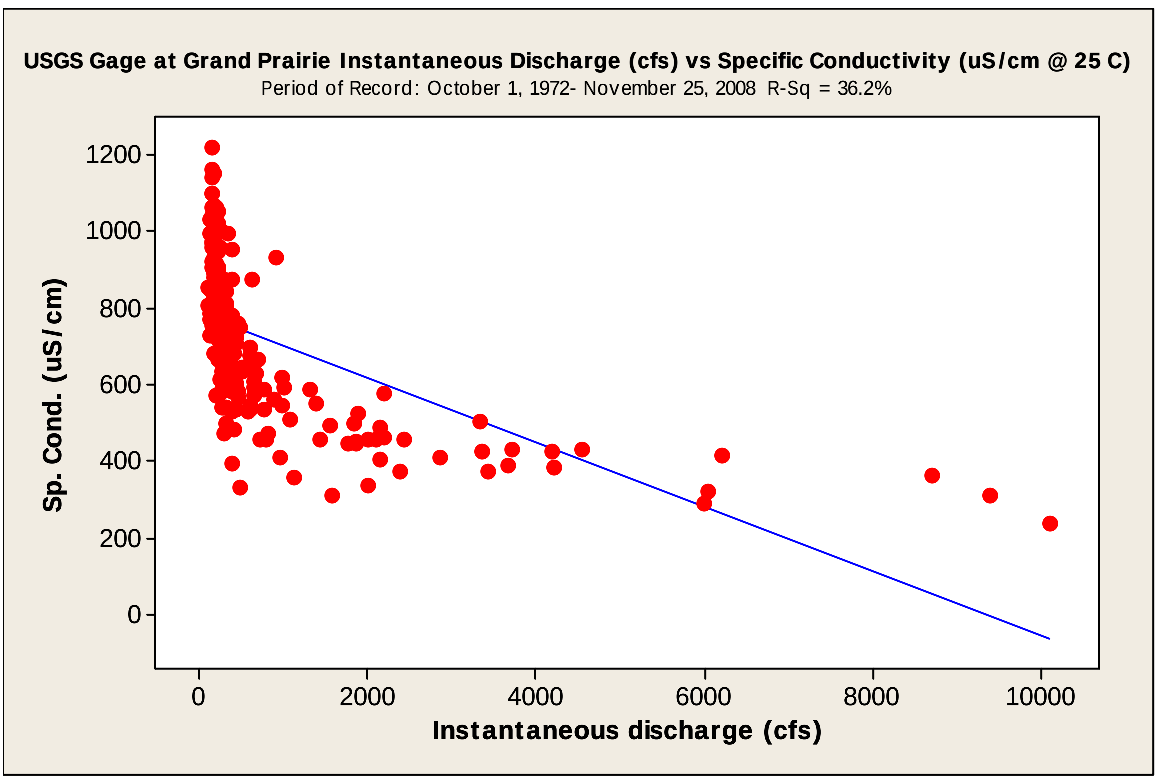


Figure 51. Flow versus specific conductance at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008.

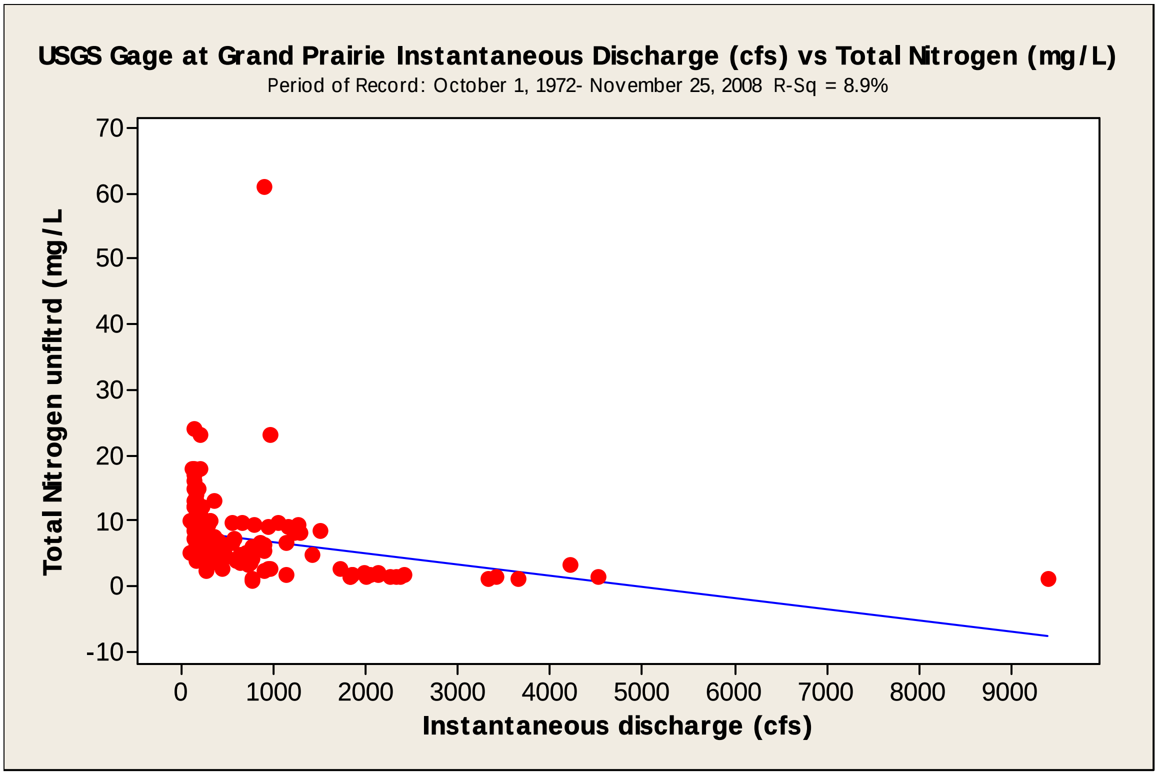


Figure 52. Flow versus total nitrogen at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008.

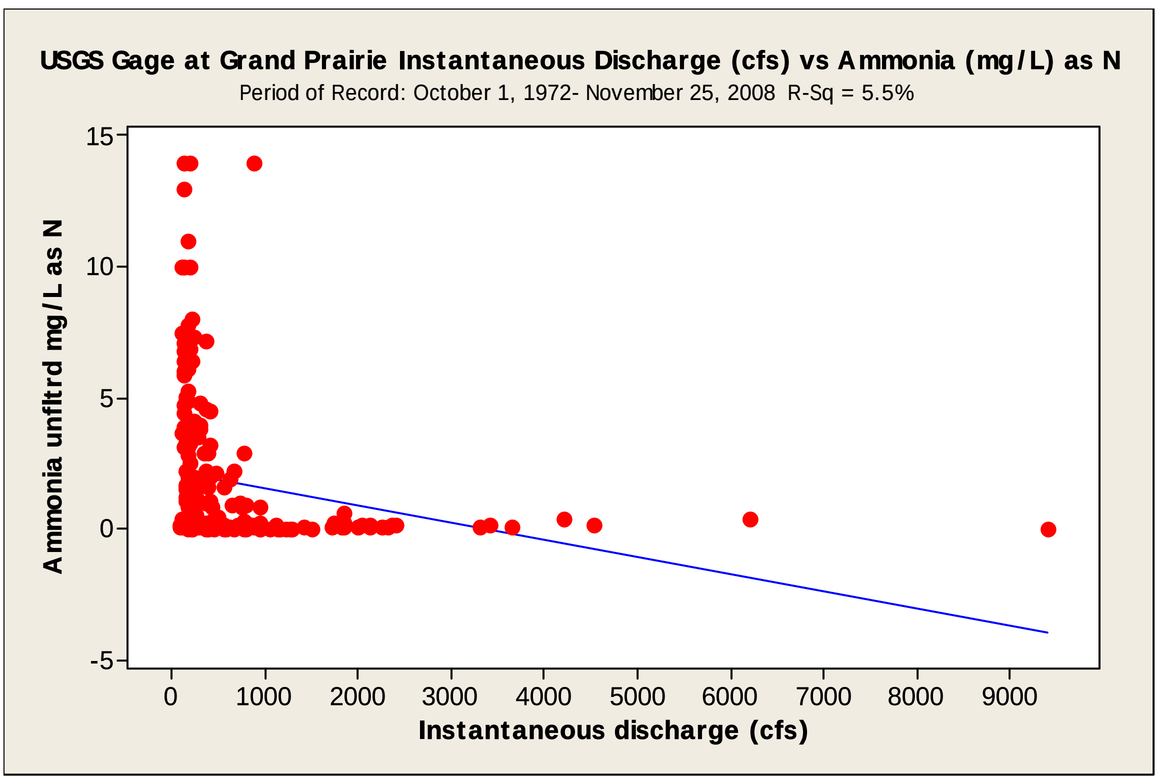


Figure 53. Flow versus ammonia nitrogen at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008.

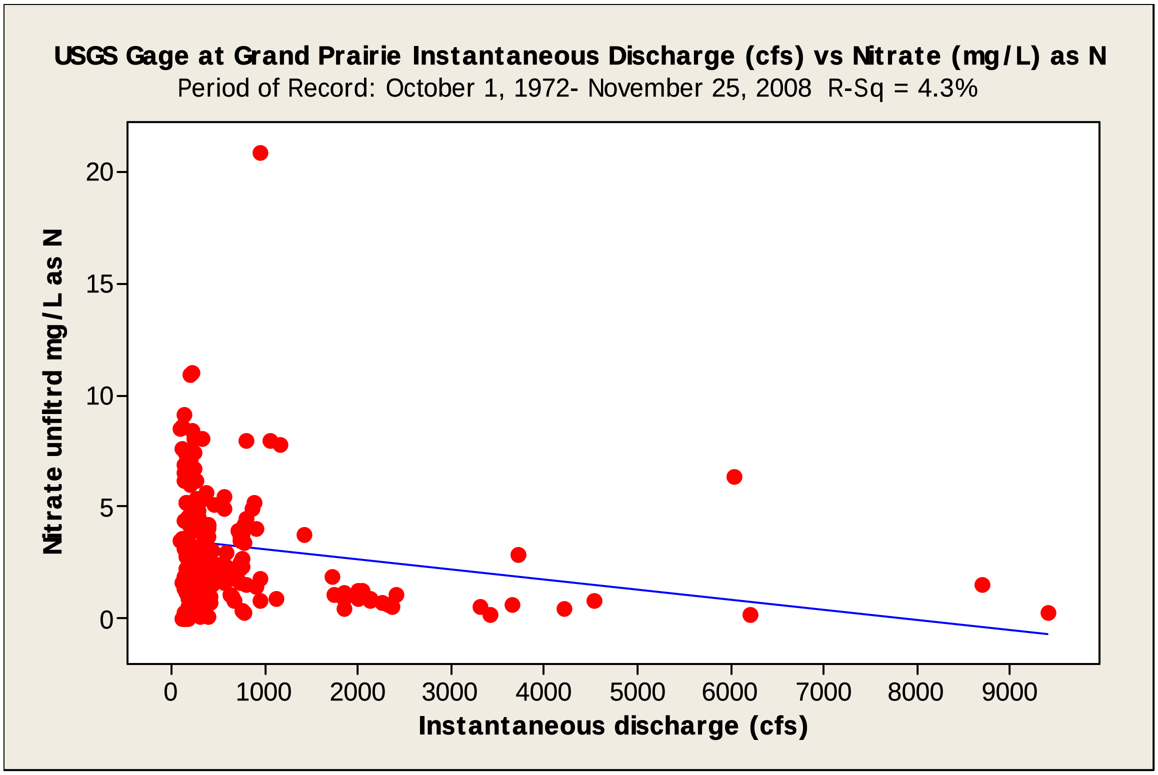


Figure 54. Flow versus nitrate at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008

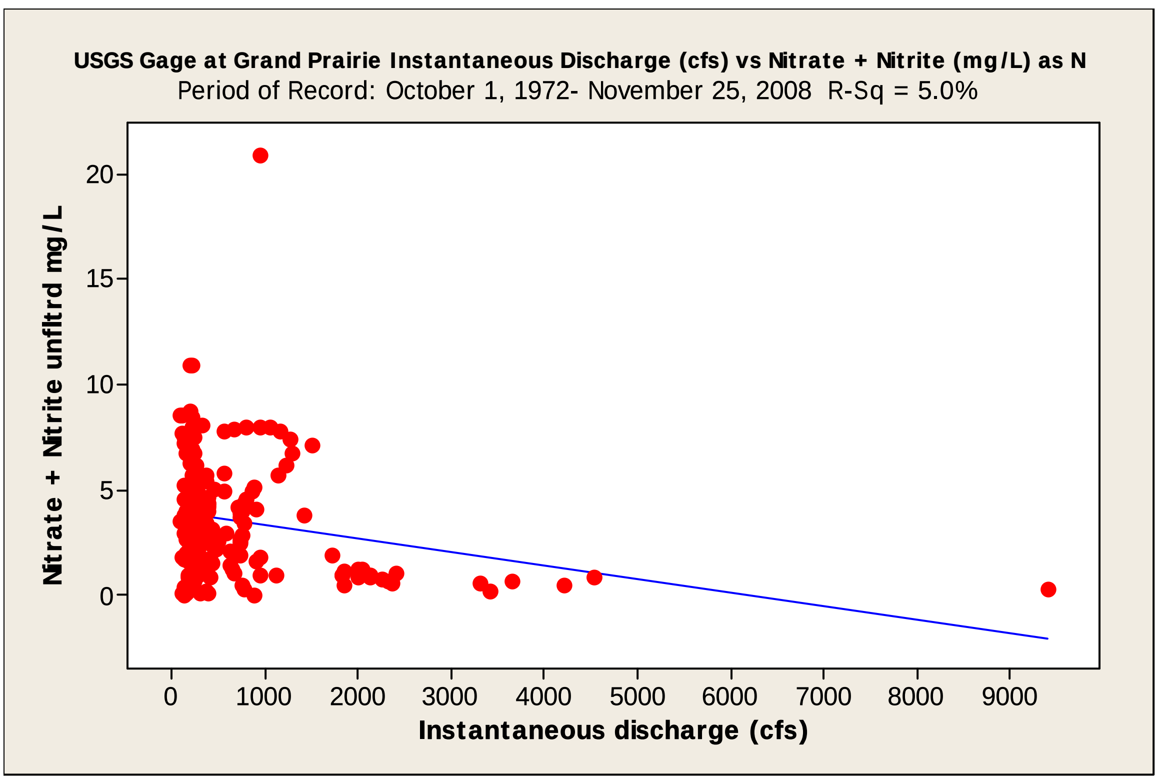


Figure 55. Flow versus nitrate+nitrite at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008

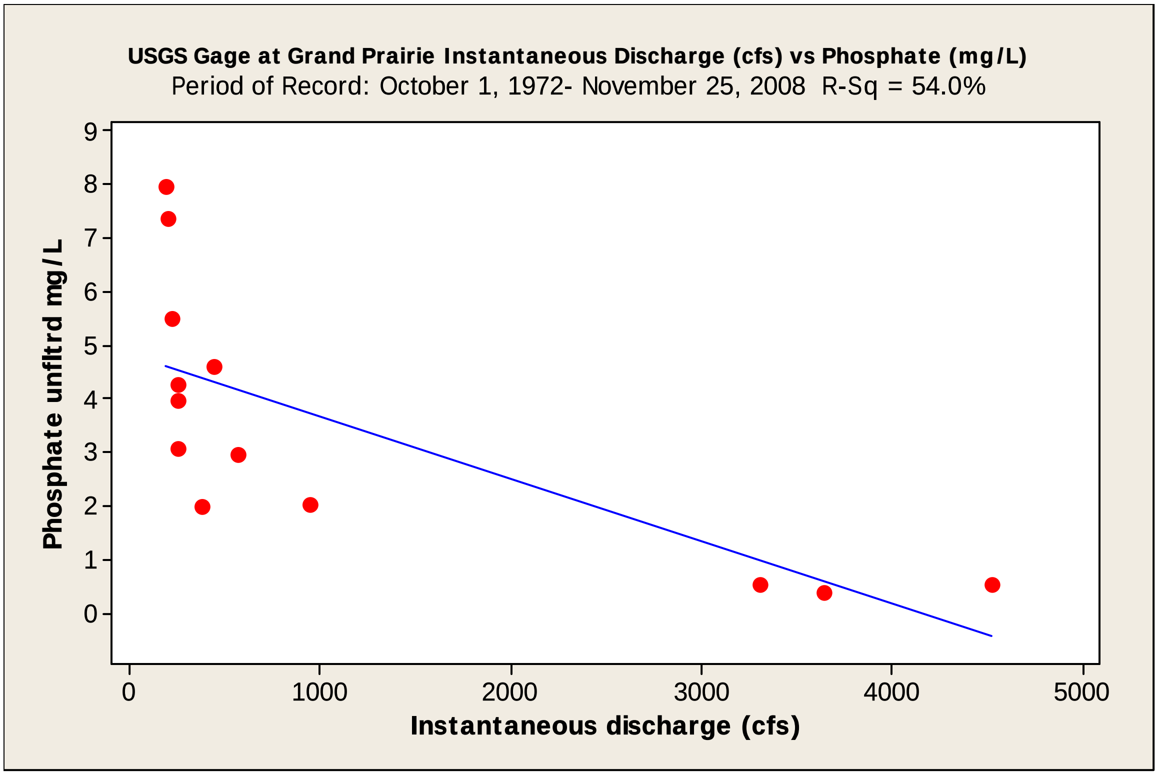


Figure 56. Flow versus phosphate at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008

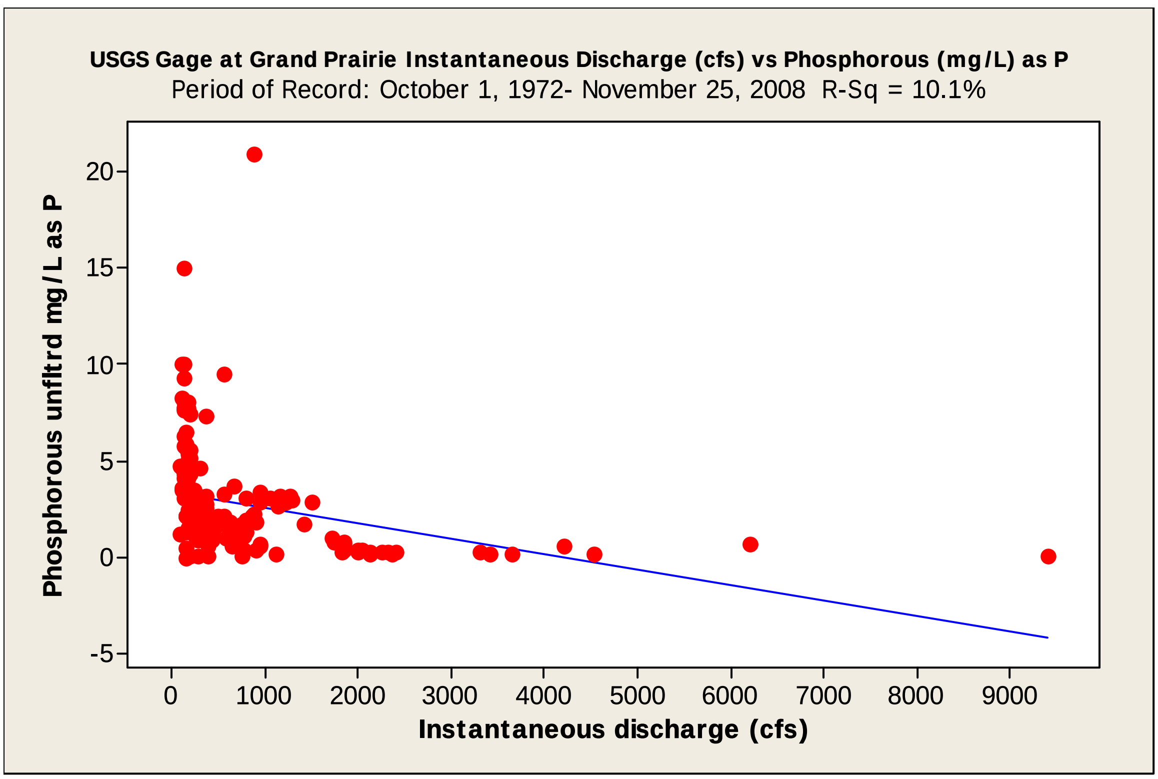


Figure 57. Flow versus phosphorus at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008.

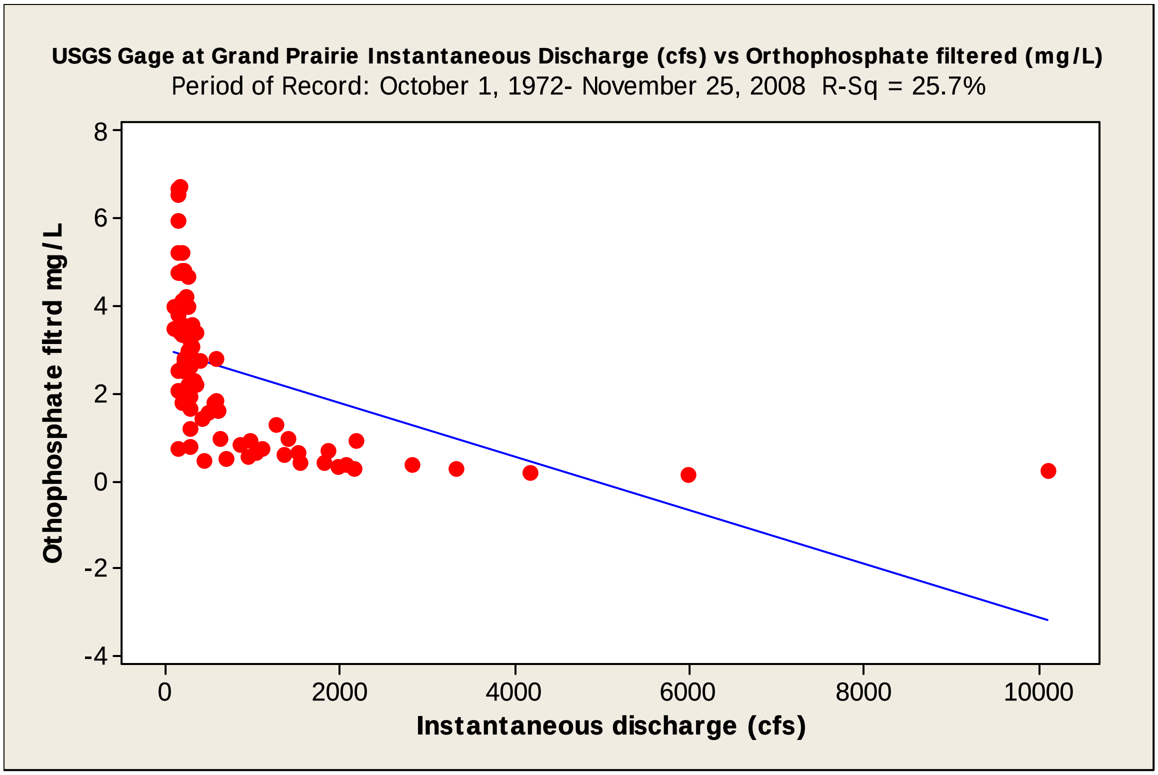


Figure 58. Flow versus orthophosphate at the West Fork Trinity River at Grand Prairie 08049500 gage during 1972 through 2008.

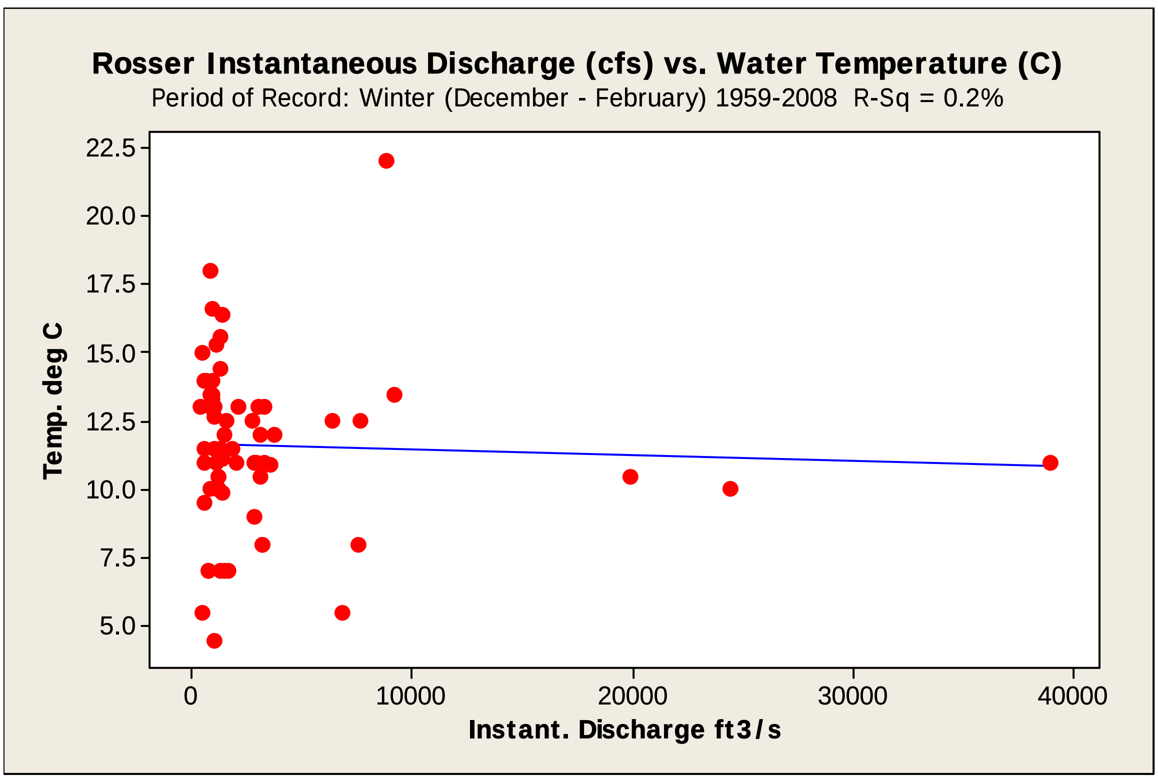


Figure 59. Flow versus winter temperature at the Trinity River at Rosser 08062500 gage during 1959 through 2008.

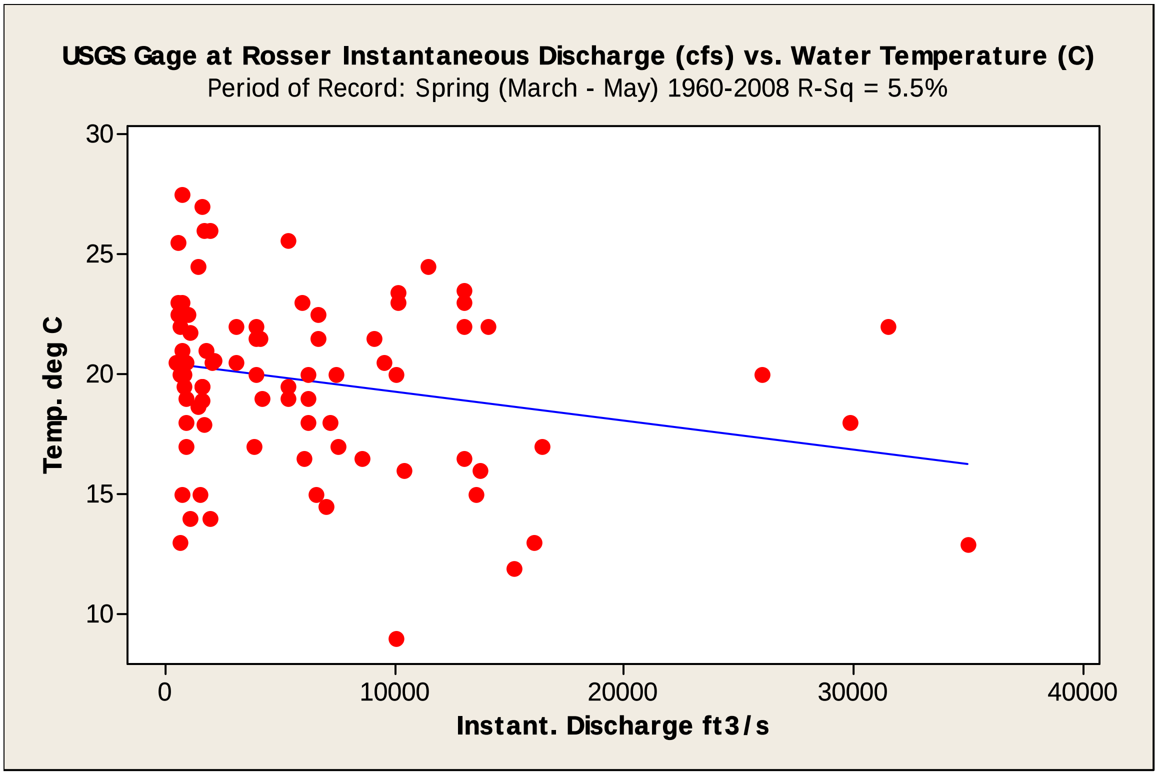


Figure 60. Flow versus spring water temperature at the Trinity River at Rosser 08062500 gage during 1959 through 2008.

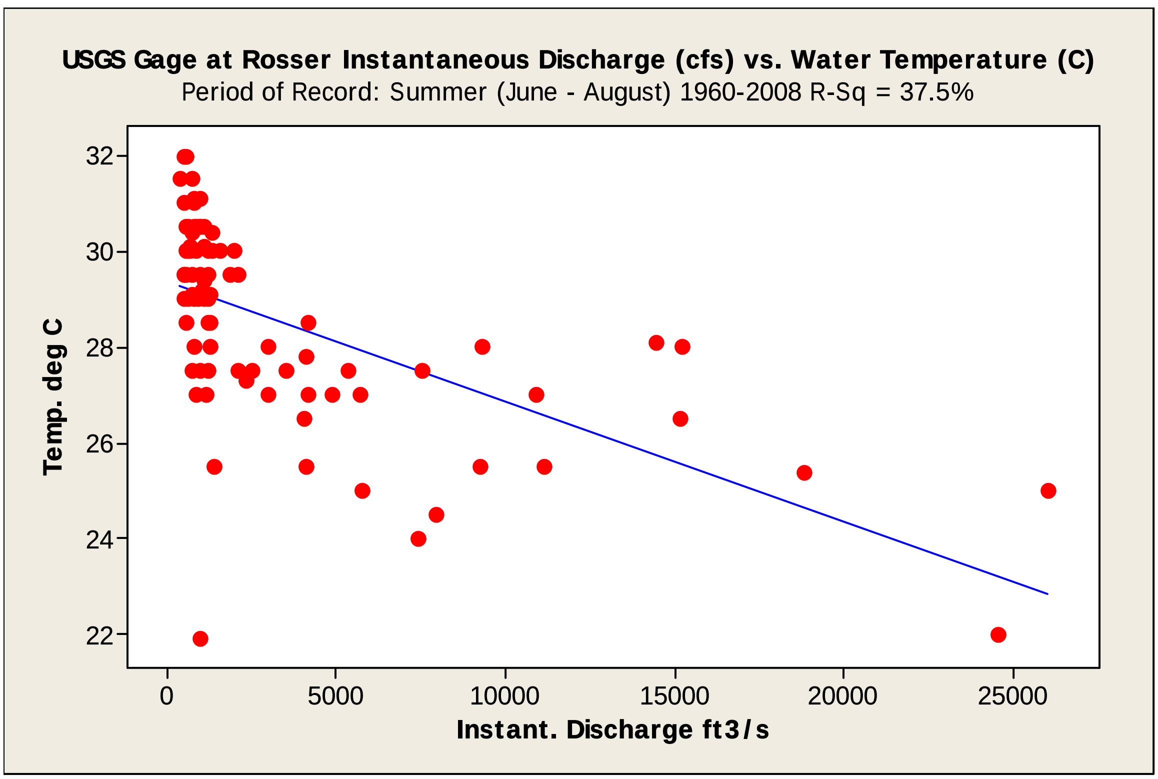


Figure 61. Flow versus summer water temperature at the Trinity River at Rosser 08062500 gage during 1959 through 2008.

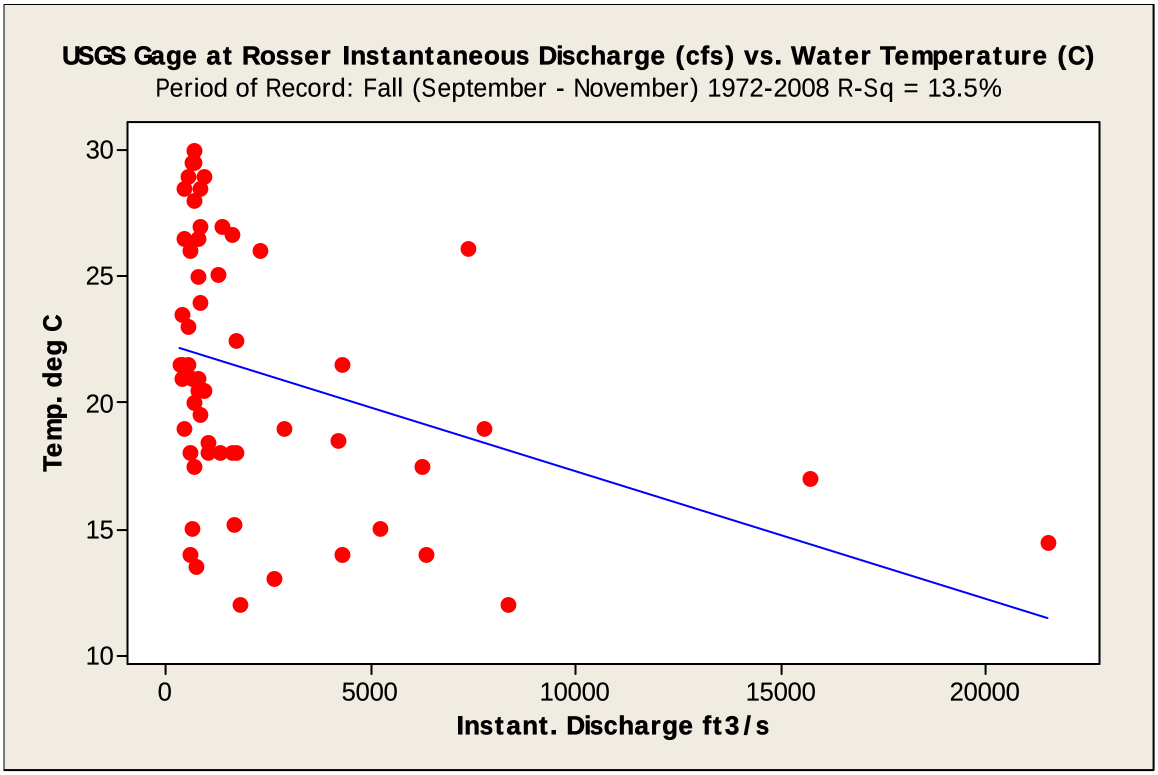


Figure 62. Flow versus fall water temperature at the Trinity River at Rosser 08062500 gage during 1959 through 2008.

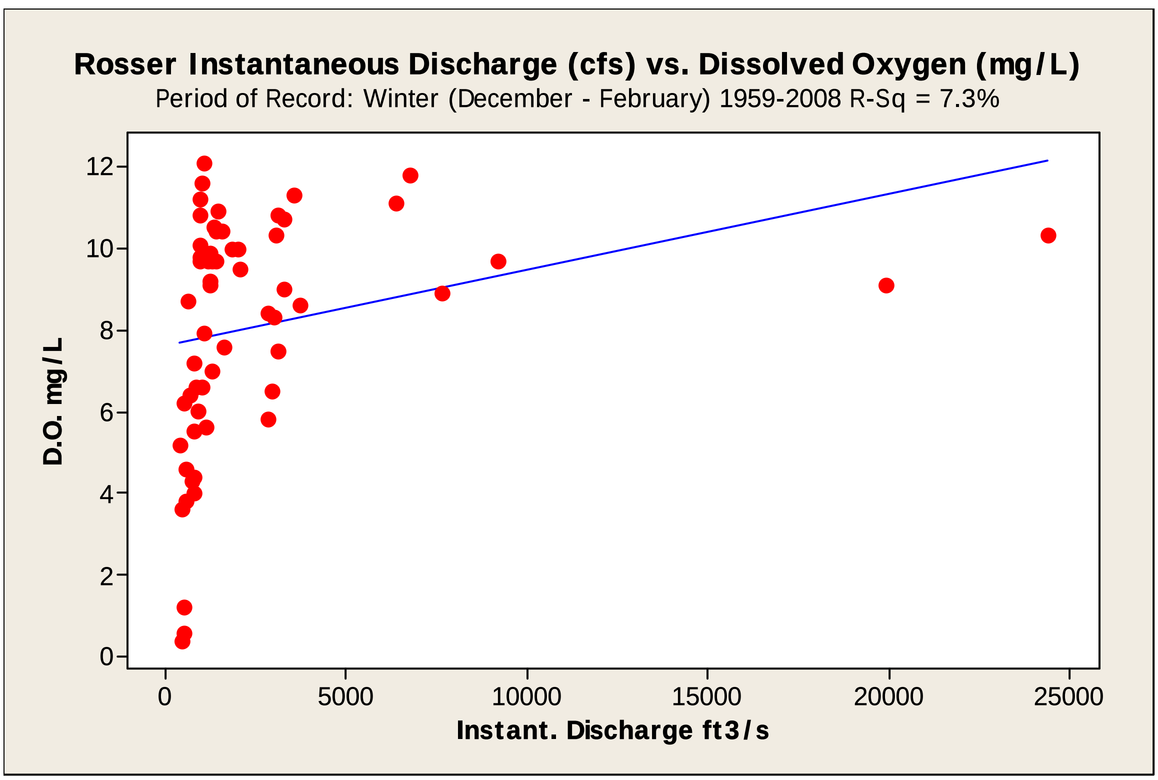


Figure 63. Flow versus winter dissolved oxygen at the Trinity River at Rosser 08062500 gage during 1959 through 2008.

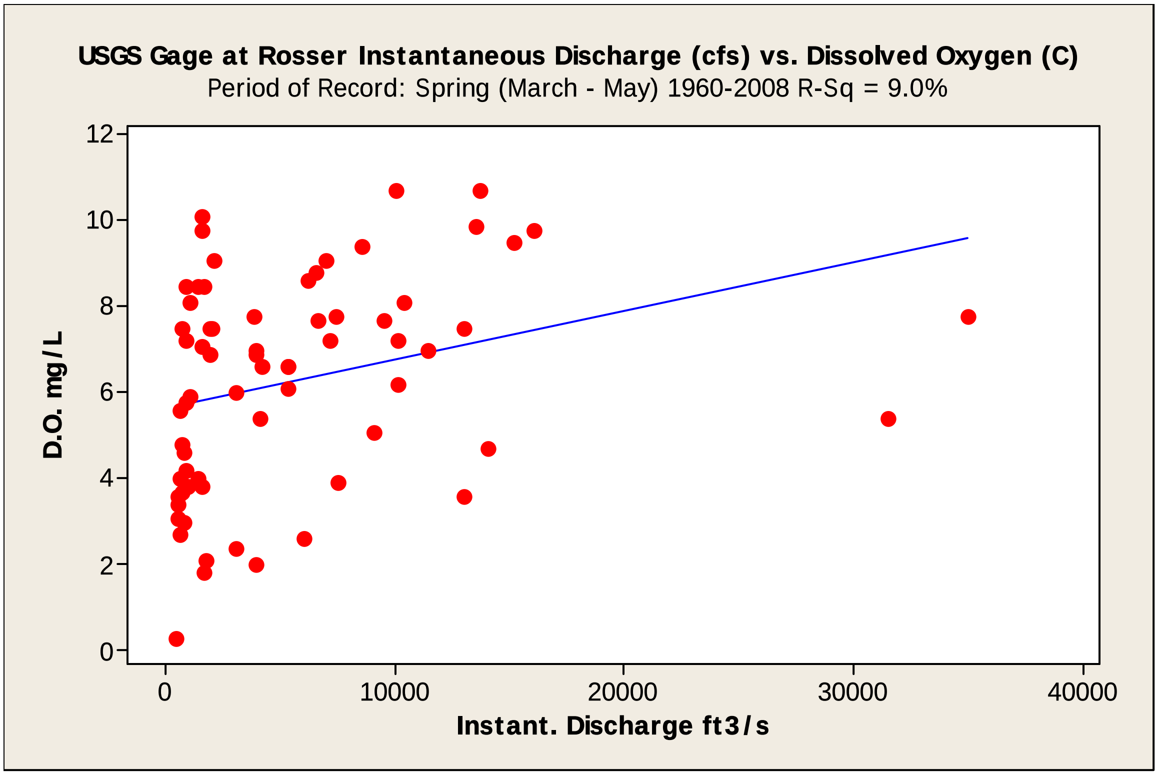


Figure 64. Flow versus spring dissolved oxygen at the Trinity River at Rosser 08062500 gage during 1960 through 2008.

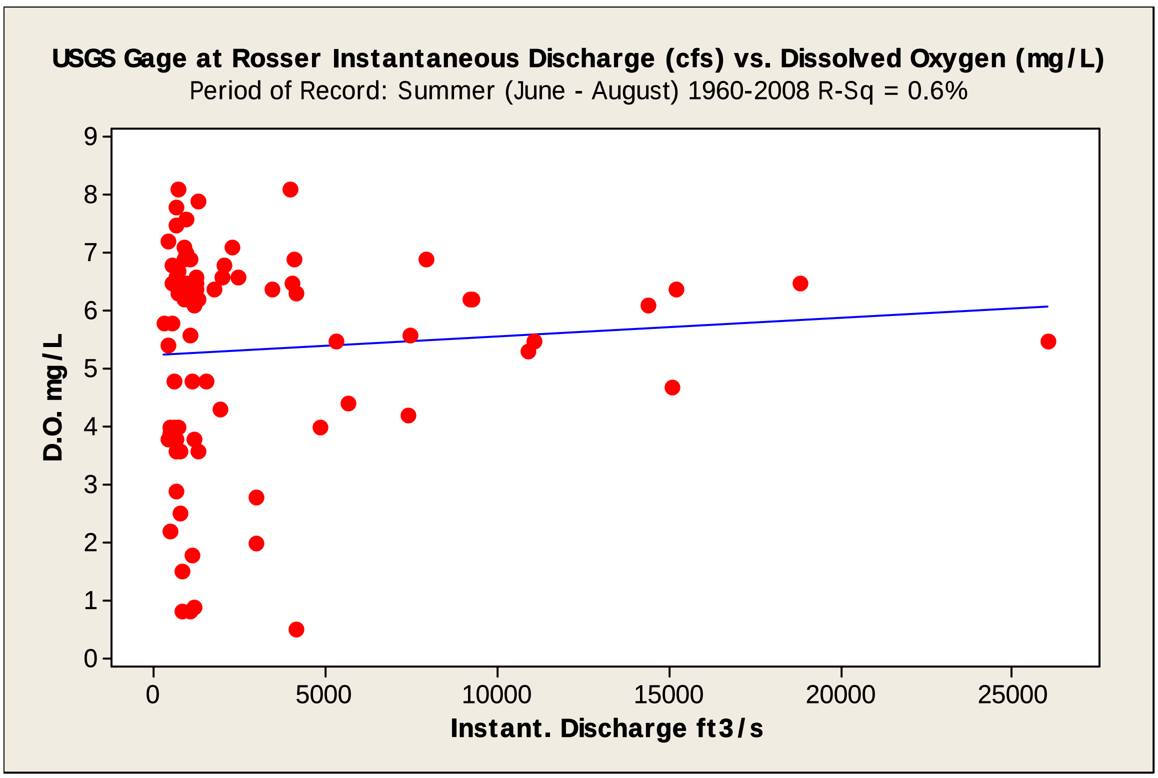


Figure 65. Flow versus summer dissolved oxygen at the Trinity River at Rosser 08062500 gage during 1960 through 2008.

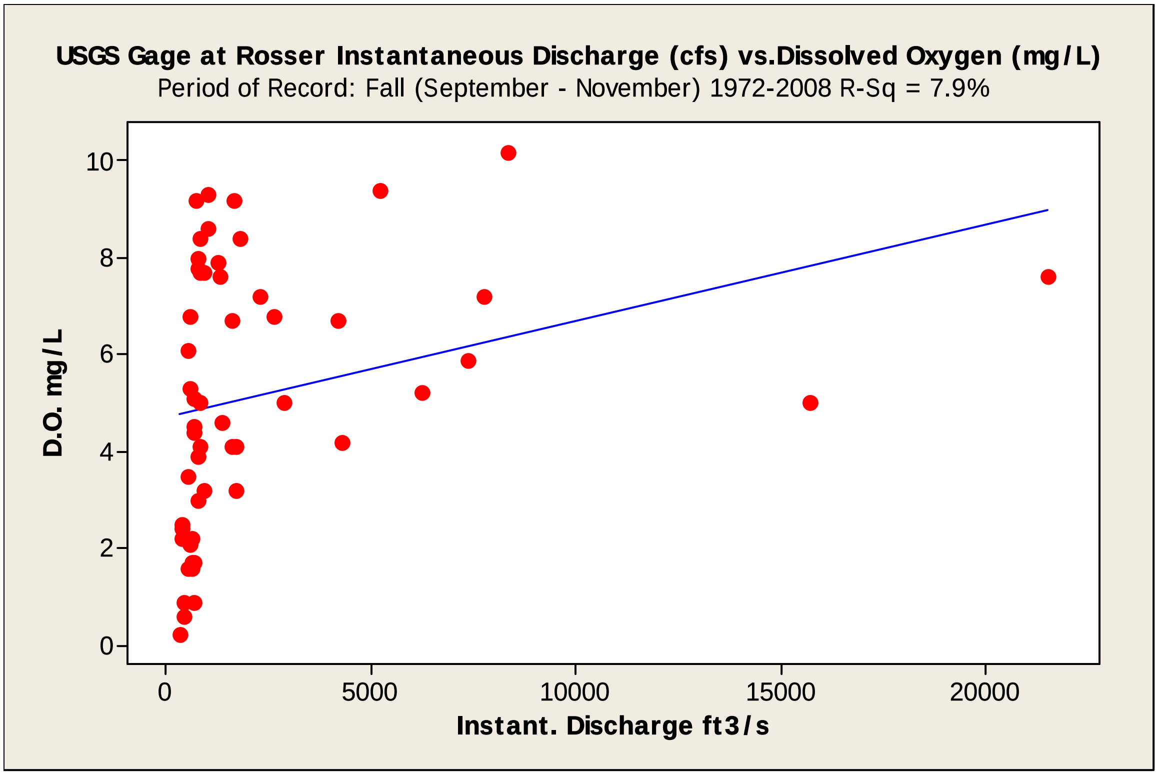


Figure 66. Flow versus fall dissolved oxygen at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

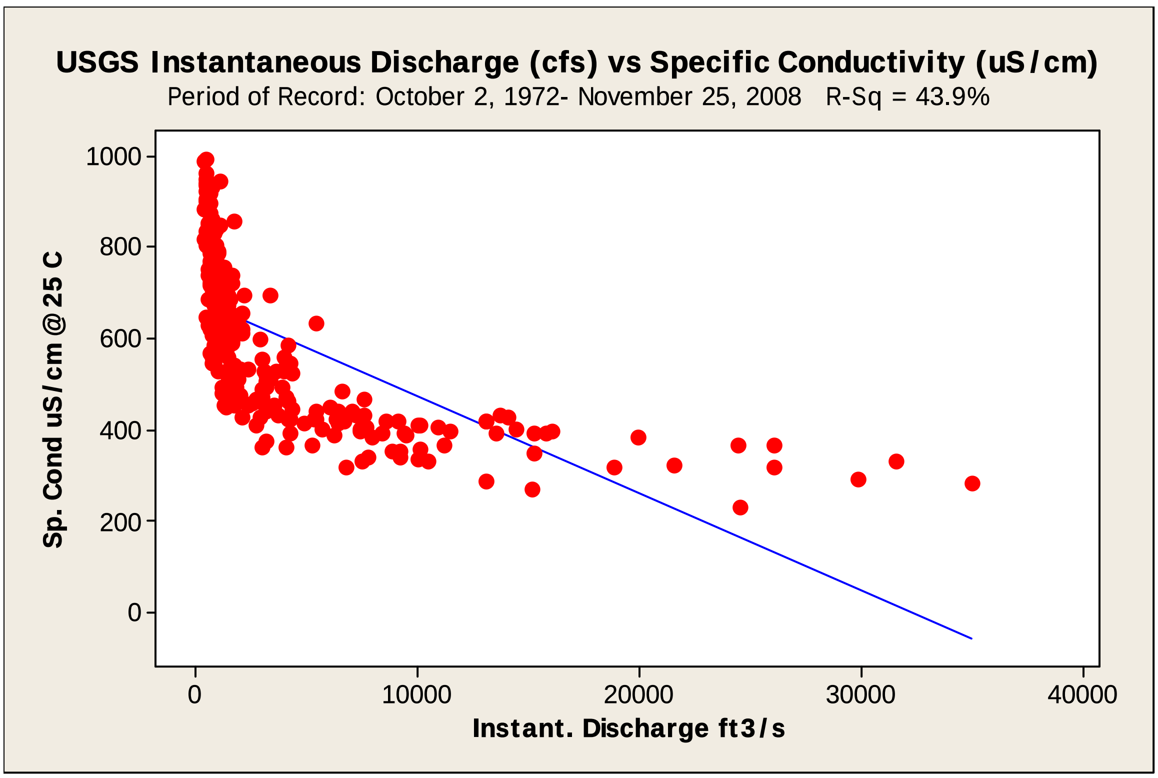


Figure 67. Flow versus specific conductance at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

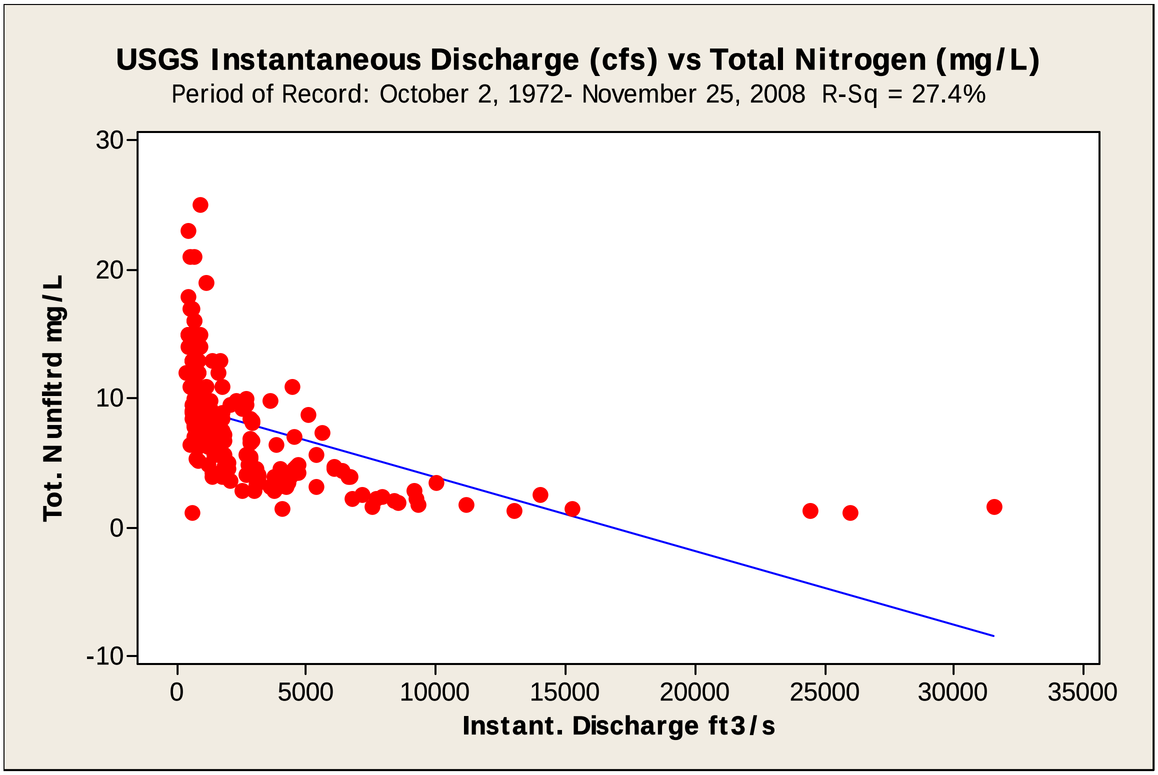


Figure 68. Flow versus total nitrogen (unfiltered) at the Trinity River at Rosser 08062500 gages during 1972 through 2008.

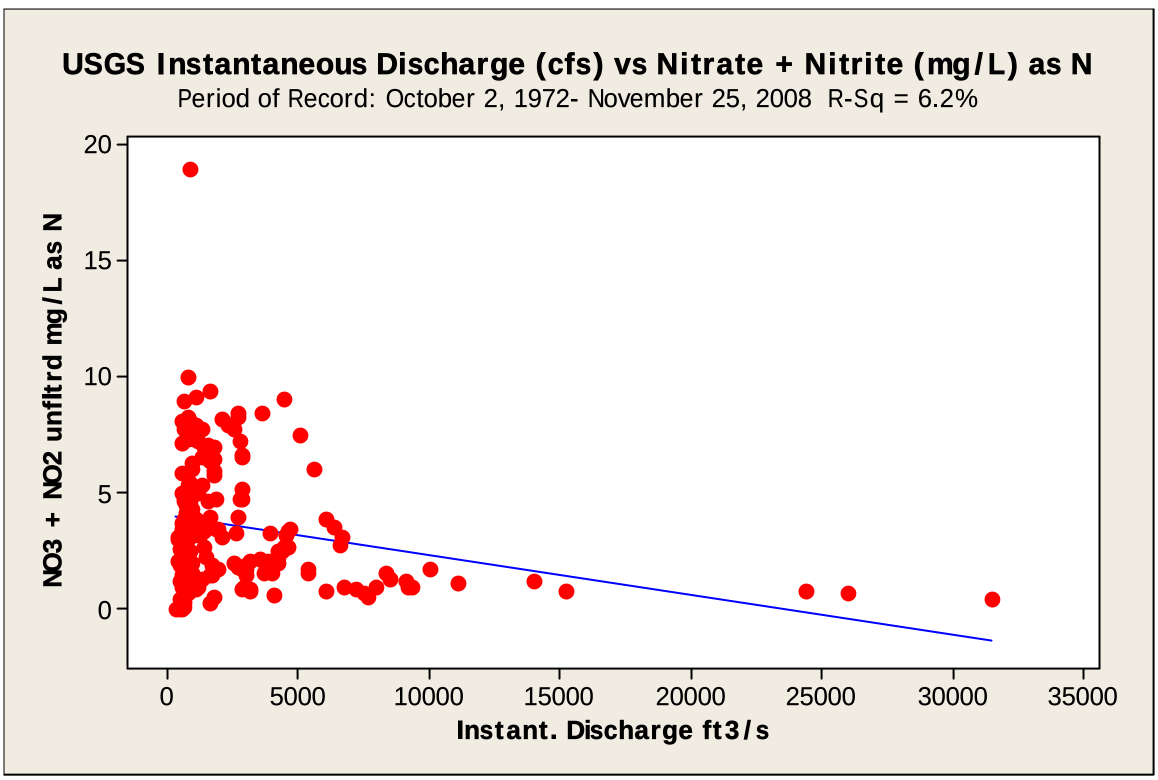


Figure 69. Flow versus nitrate + nitrite as N at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

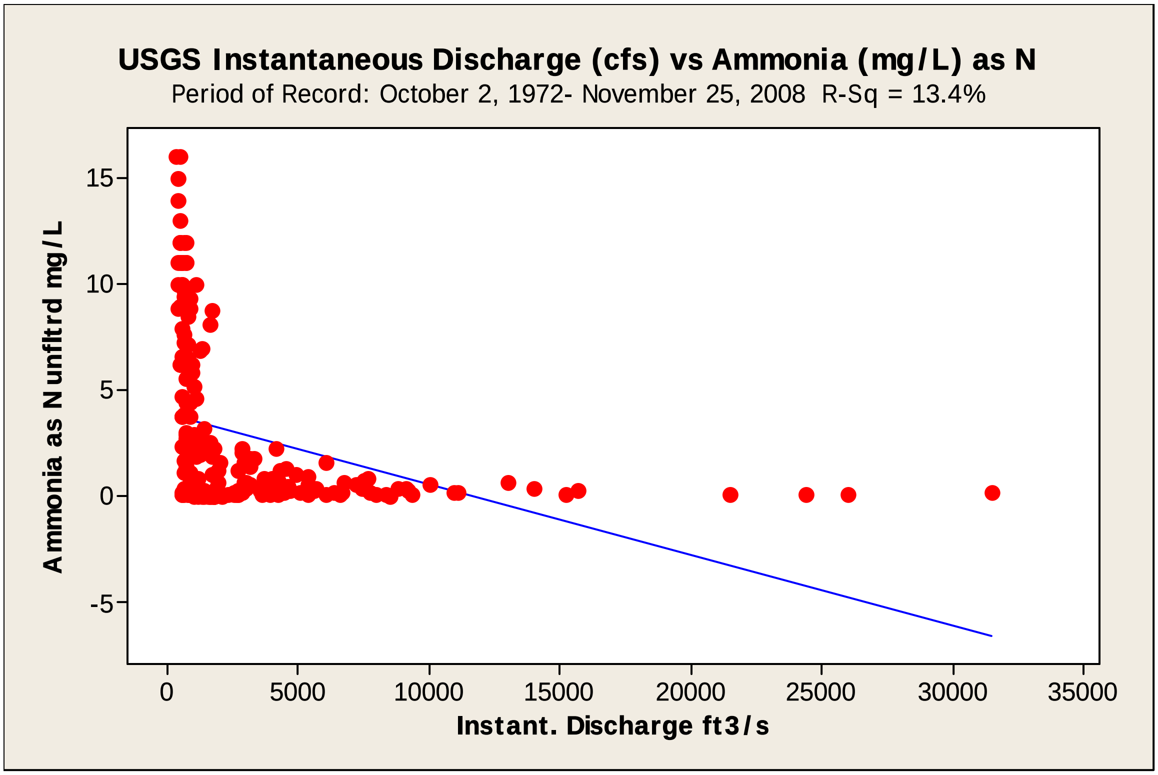


Figure 70. Flow versus ammonia as N unfiltered at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

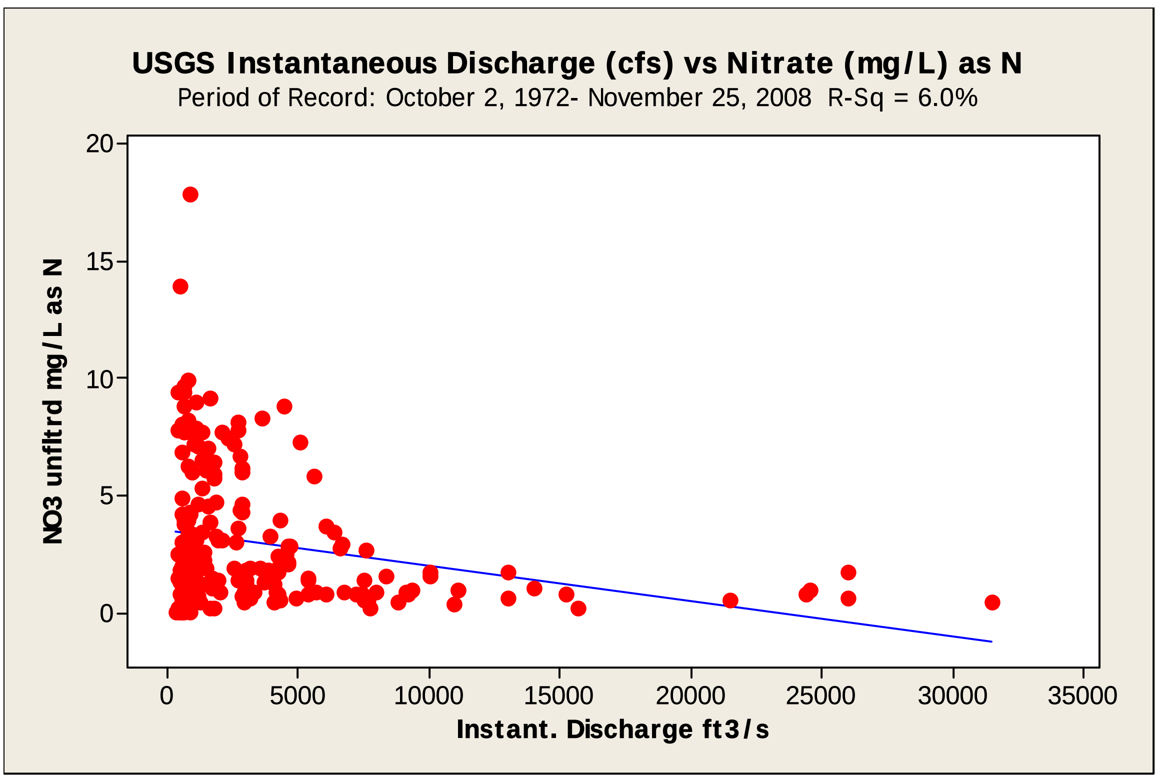


Figure 71. Flow versus nitrate as N unfiltered at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

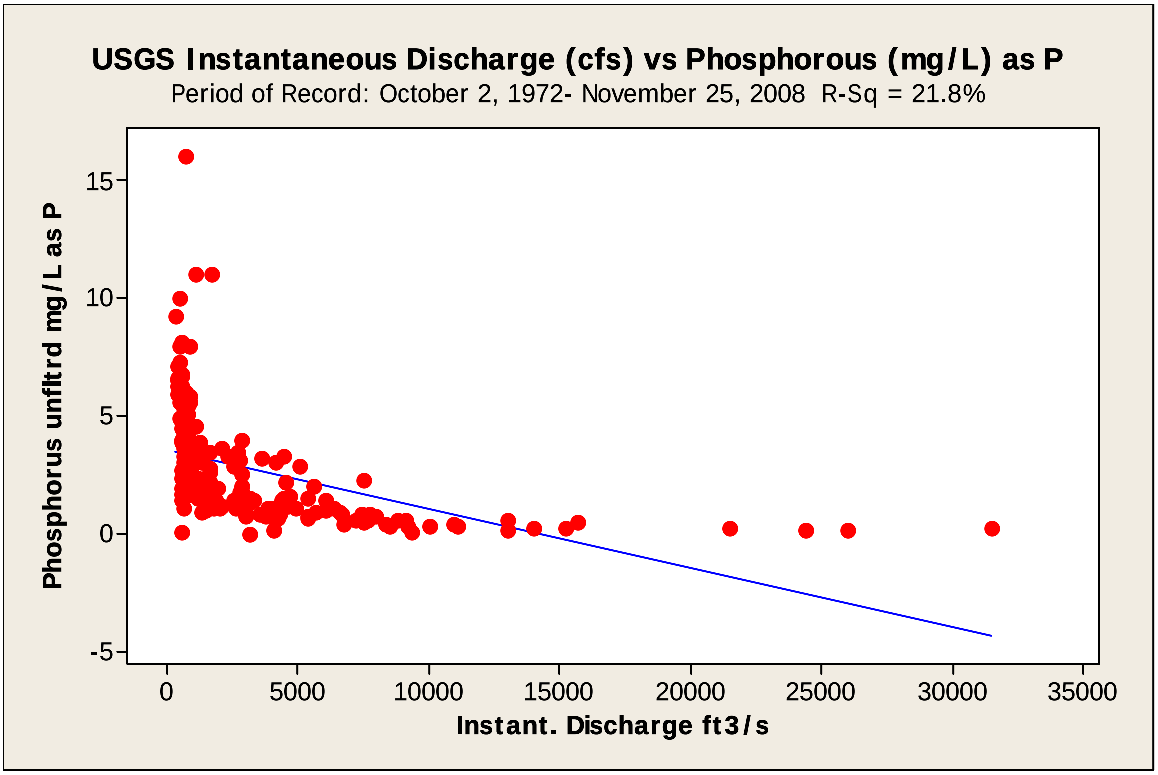


Figure 72. Flow versus phosphate as P unfiltered at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

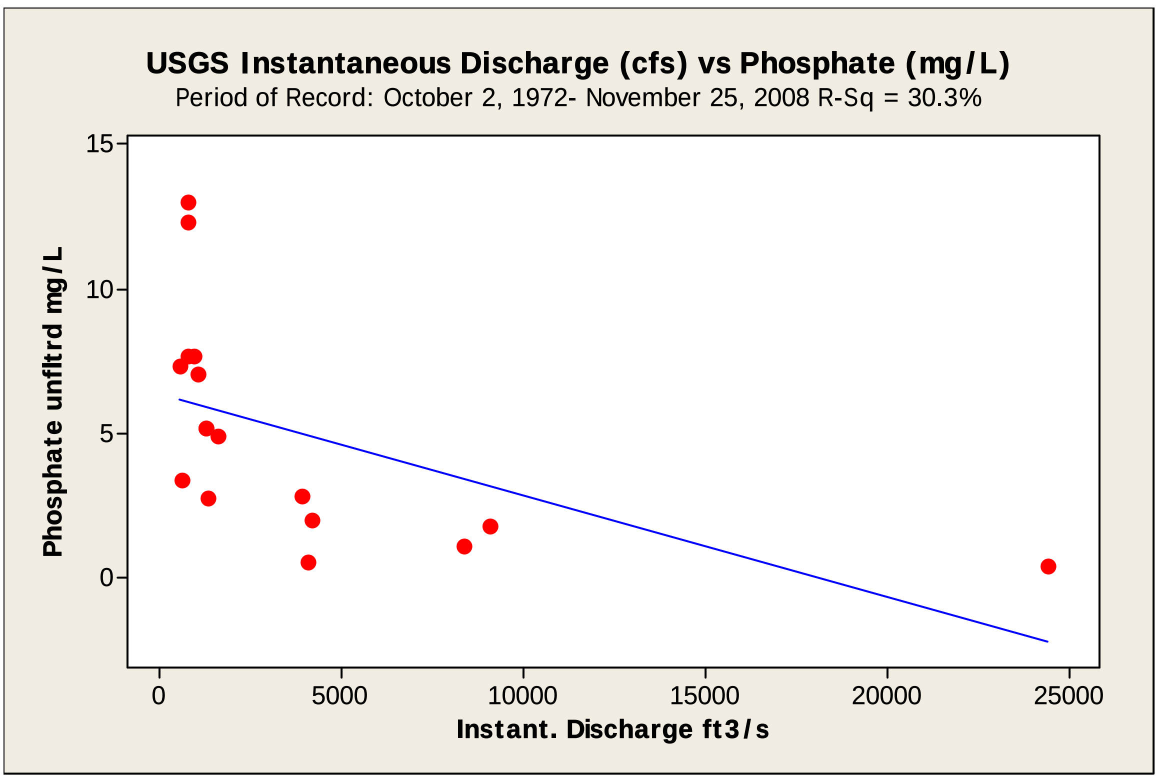


Figure 73. Flow versus phosphate unfiltered at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

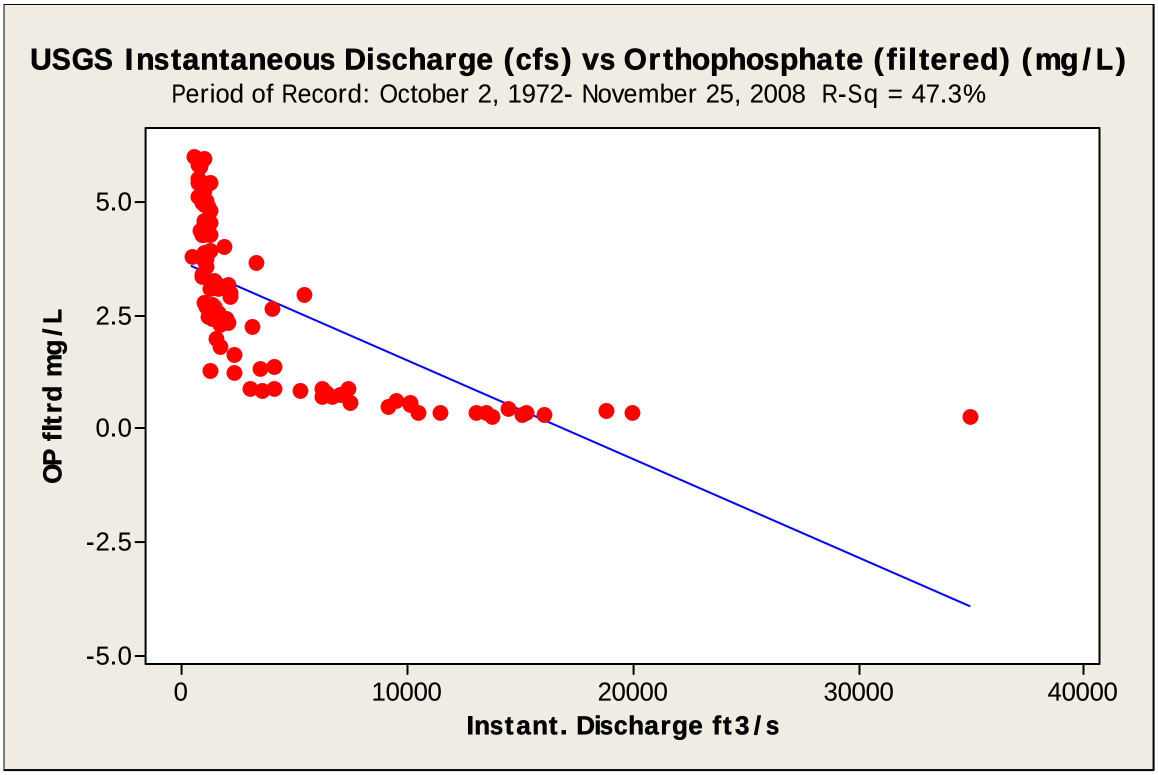


Figure 74. Flow versus filtered orthophosphate at the Trinity River at Rosser 08062500 gage during 1972 through 2008.

During the period of record, summer and to a lesser extent fall water temperatures appear to respond negatively to increases discharges (Figures 75-78). In addition, dissolved oxygen appeared to be positively correlated with increased stream flows (Figures 79-82). This was most evident during the spring and summer months (Figure 81). At flows above 5000 cfs dissolved oxygen was seldom below 4.0 mg/l. The frequency of hypoxia increased when stream flows were below 2000 cfs. At low flows in the spring and summer we also observed very high (>10 mg/l) dissolved oxygen levels. This suggests the potential presence of algal blooms that can cause large diurnal fluctuations in dissolved oxygen. Specific conductance levels generally declined with higher flows reflecting dilutions of dissolved ions (Figure 80). Higher variability was observed at low to moderate flows (1000 to 5000 cfs) reflecting possible effects of increased stormwater runoff and loading of dissolved ions. Similar responses in nutrients were observed at this gage (Figures 84-90). In contrast suspended sediment concentrations increased between 500 and 7000 cfs and peaked at about 8000 cfs declining thereafter at higher flows (Figure 90). This suggests the maximum sediment transport is occurring at intermediate flows. We calculated sediment loading using the same data set and estimated using a quadratic equation that maximum sediment transport occurs at approximately 8000-12000 cfs (Figure 93). During these flows it is likely that erosion and downstream sediment transport would be maximized.

During the winter, spring and fall, water temperature did not fluctuate appreciably with changing flow levels within the river near the Trinity River near Crockett gage (08065350) (Figures 93-96). During the summer when flows were above 10000 cfs water temperature was generally lower (< 28 C). Water temperature during the summer was generally elevated above 28C when streamflow was below 2500 cfs (Figure 95).

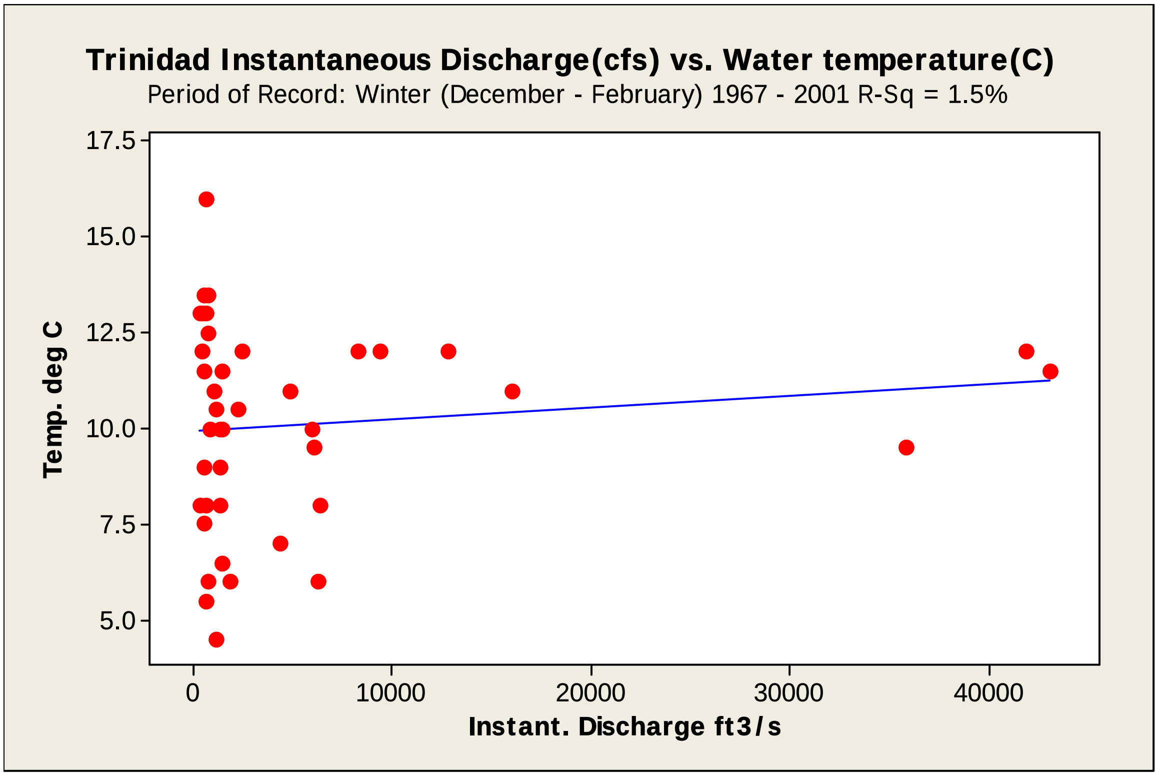


Figure 75. Flow versus winter water temperature at the Trinity River at Trinidad 08062700 gage during 1967 through 2001.

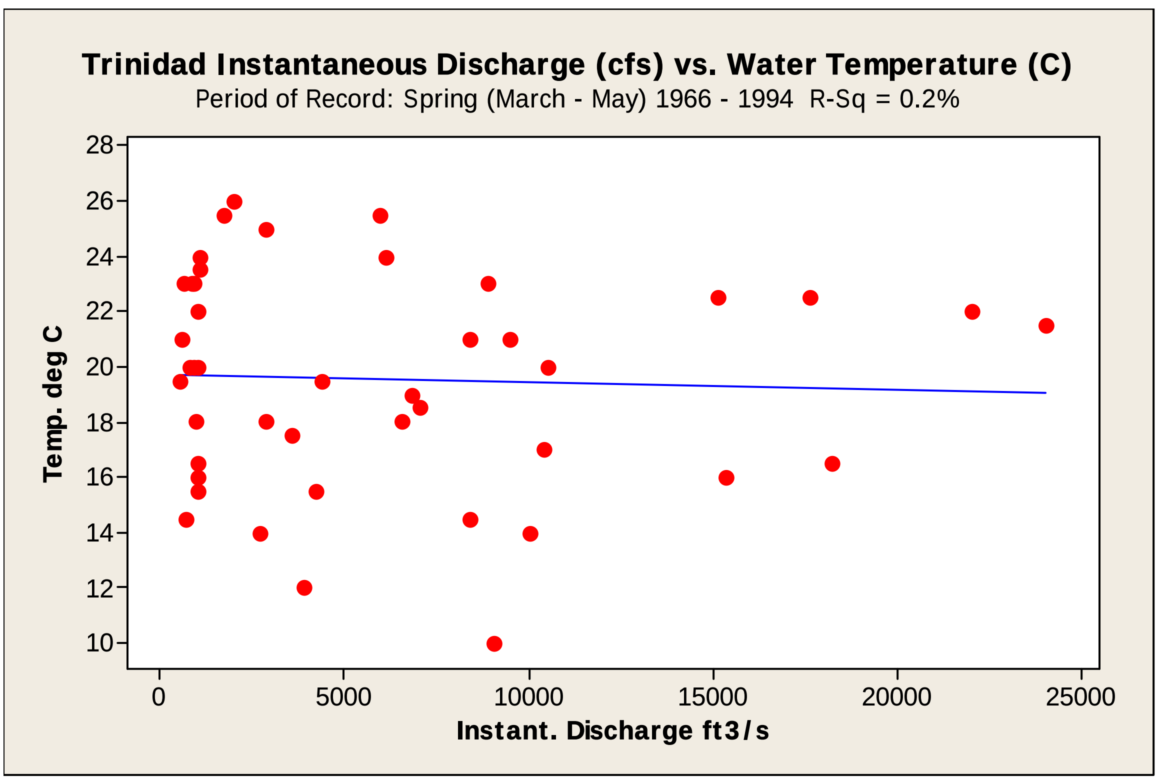


Figure 76. Flow versus spring water temperature at the Trinity River at Trinidad 08062700 gage during 1966 through 1994.

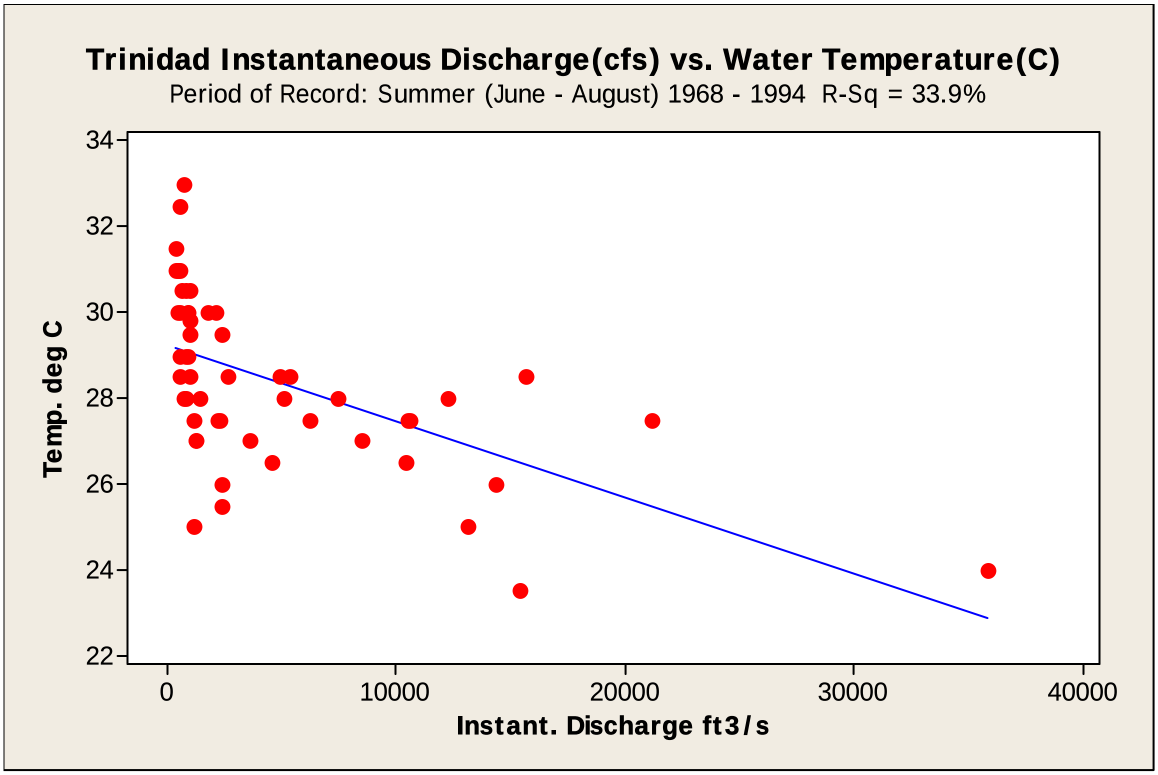


Figure 77. Flow versus summer water temperature at the Trinity River at Trinidad 08062700 gage during 1966 through 1994.

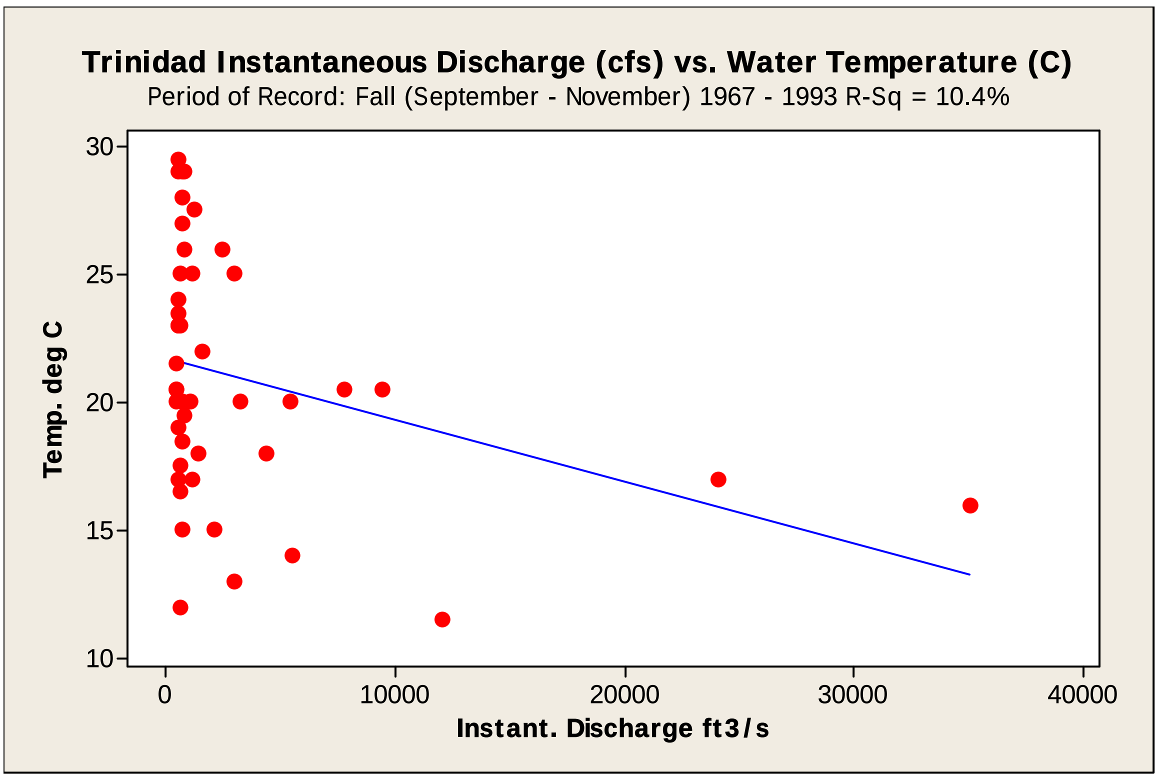


Figure 78. Flow versus fall water temperature at the Trinity River at Trinidad 08062700 gage during 1967 through 1993.

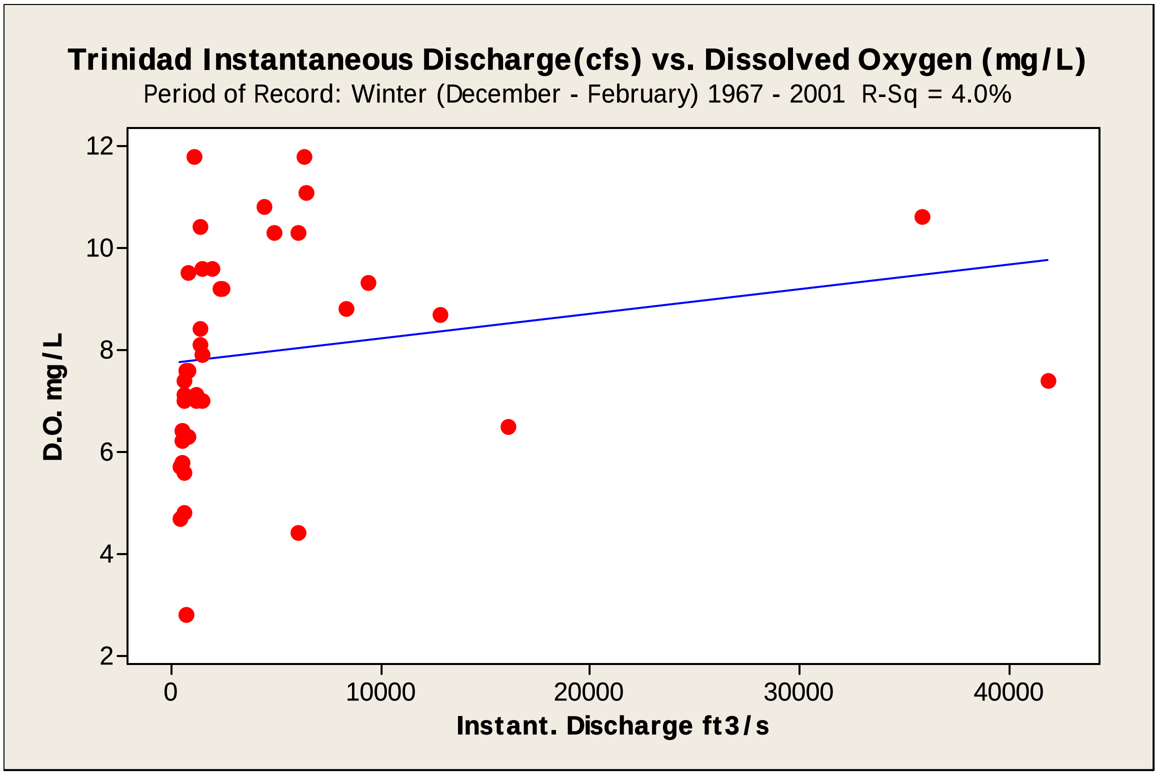


Figure 79. Flow versus winter dissolved oxygen at the Trinity River at Trinidad 08062700 gage during 1967 through 2001.

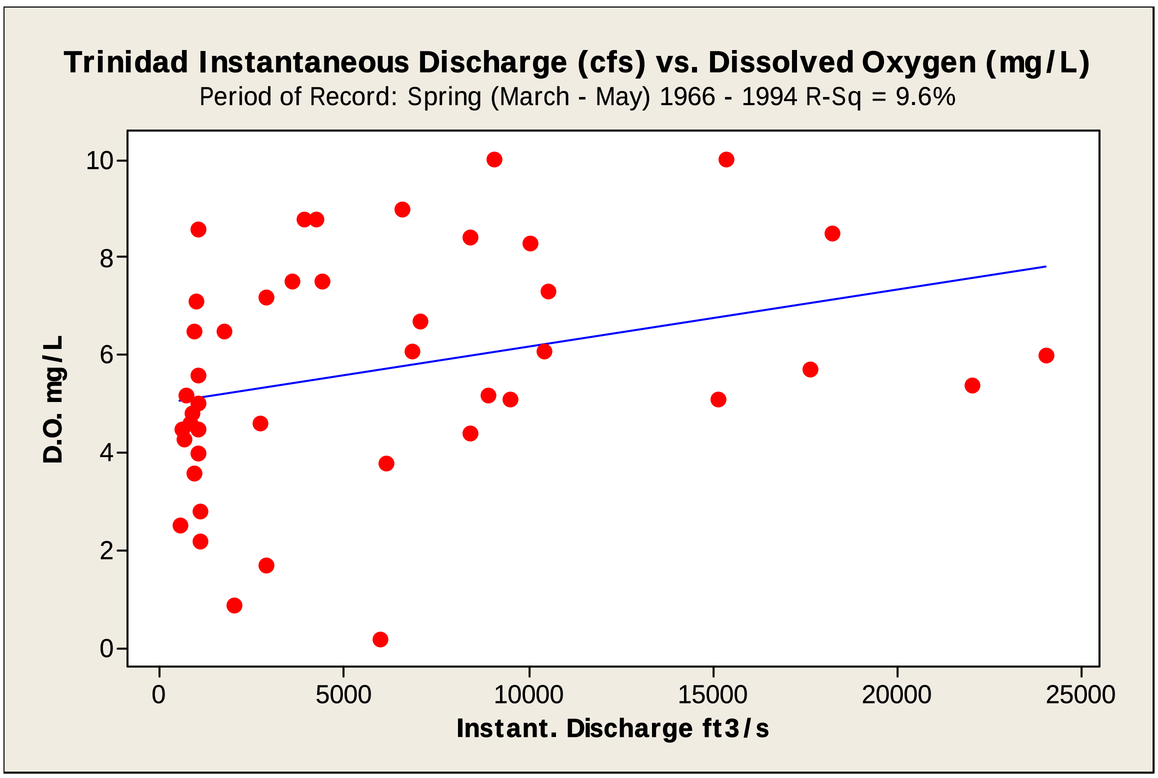


Figure 80. Flow versus spring dissolved oxygen at the Trinity River at Trinidad 08062700 gage during 1967 through 2001.

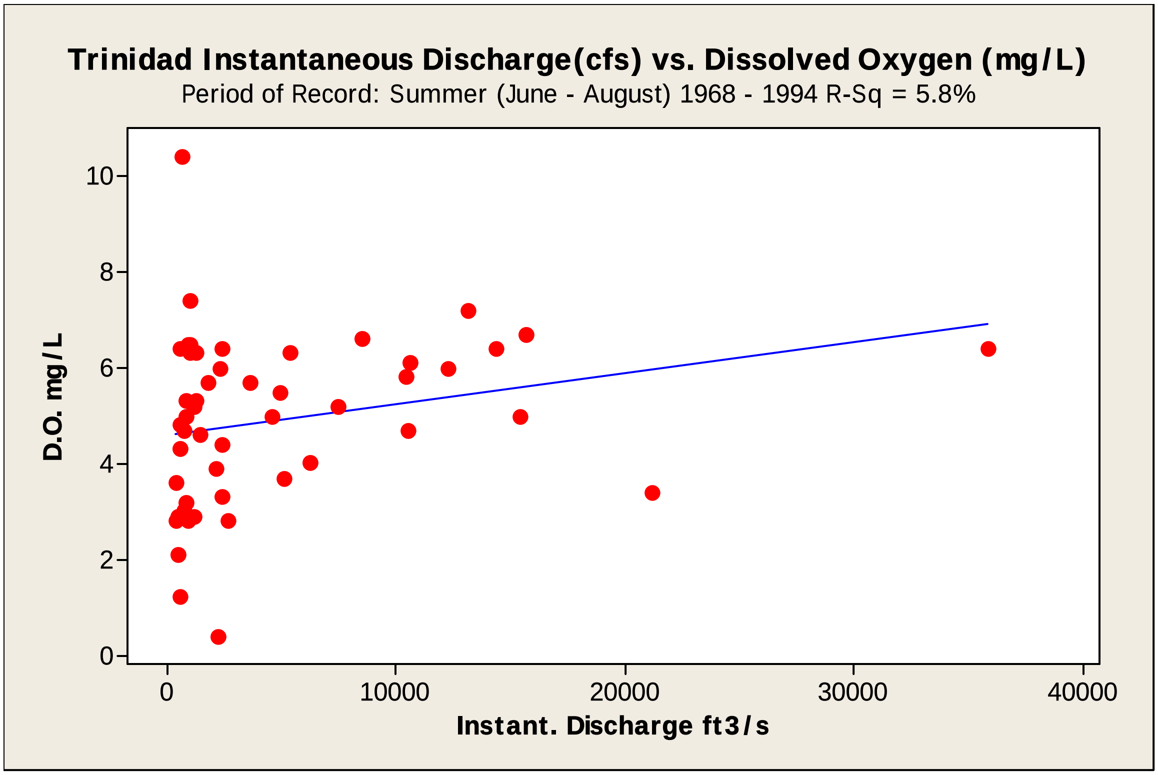


Figure 81. Flow versus summer dissolved oxygen at the Trinity River at Trinidad 08062700 gage during 1968 through 1994.

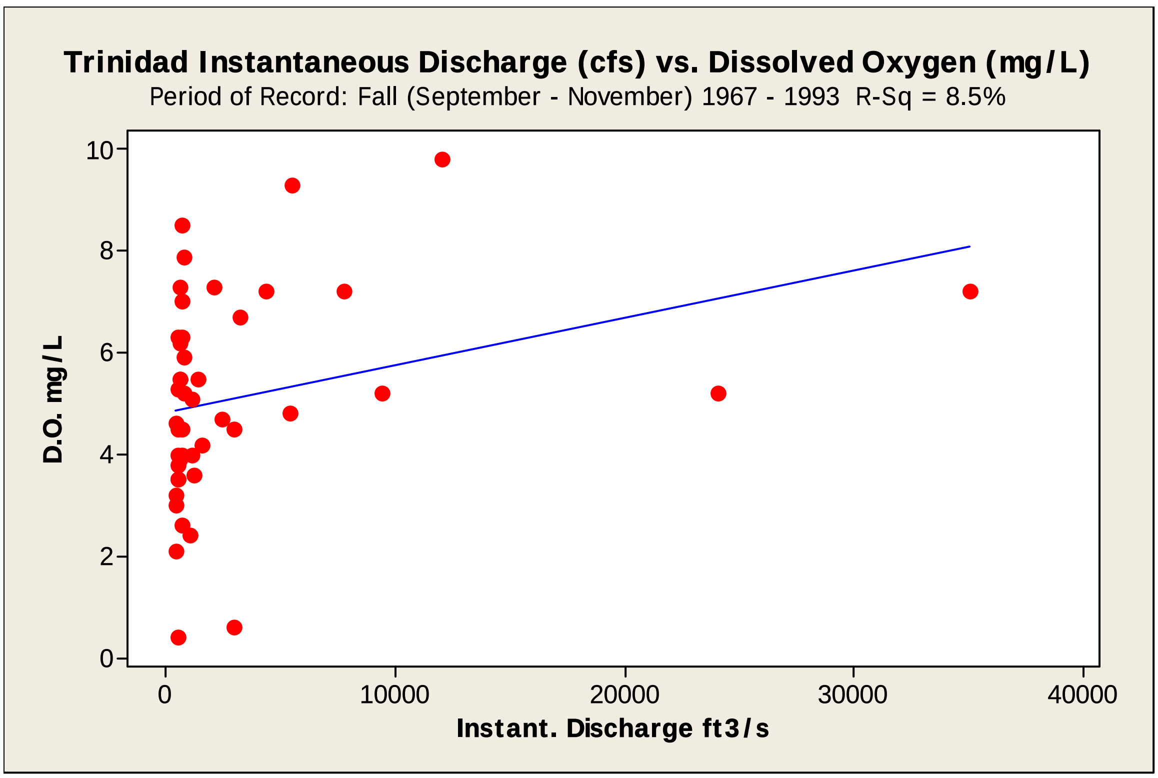


Figure 82. Flow versus fall dissolved oxygen at the Trinity River at Trinidad 08062700 gage during 1968 through 1994.

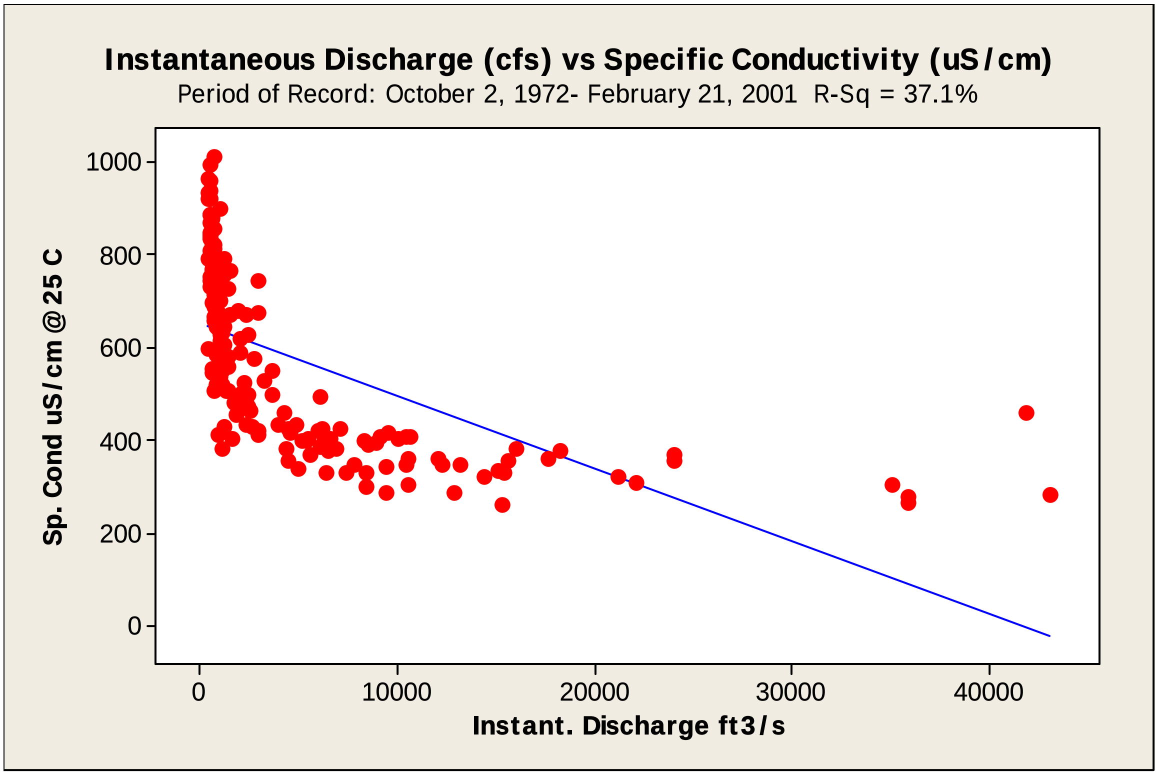


Figure 83. Flow versus specific conductance at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

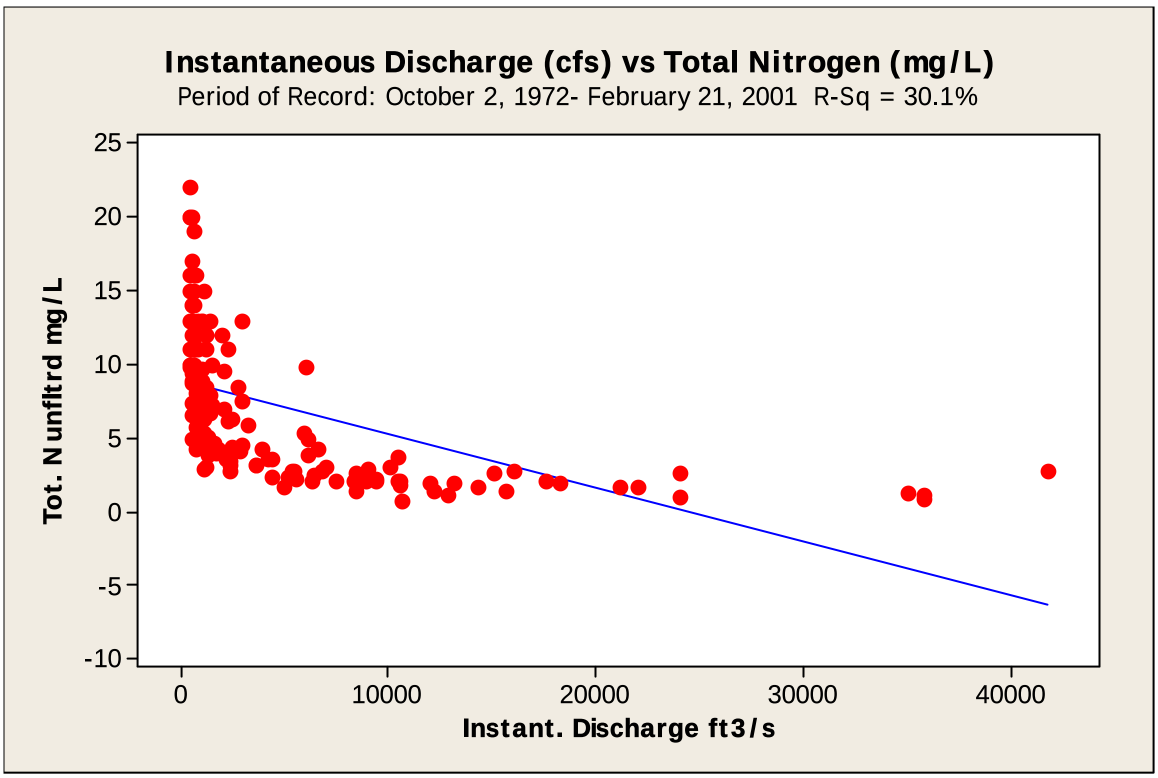


Figure 84. Flow versus total nitrogen unfiltered at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

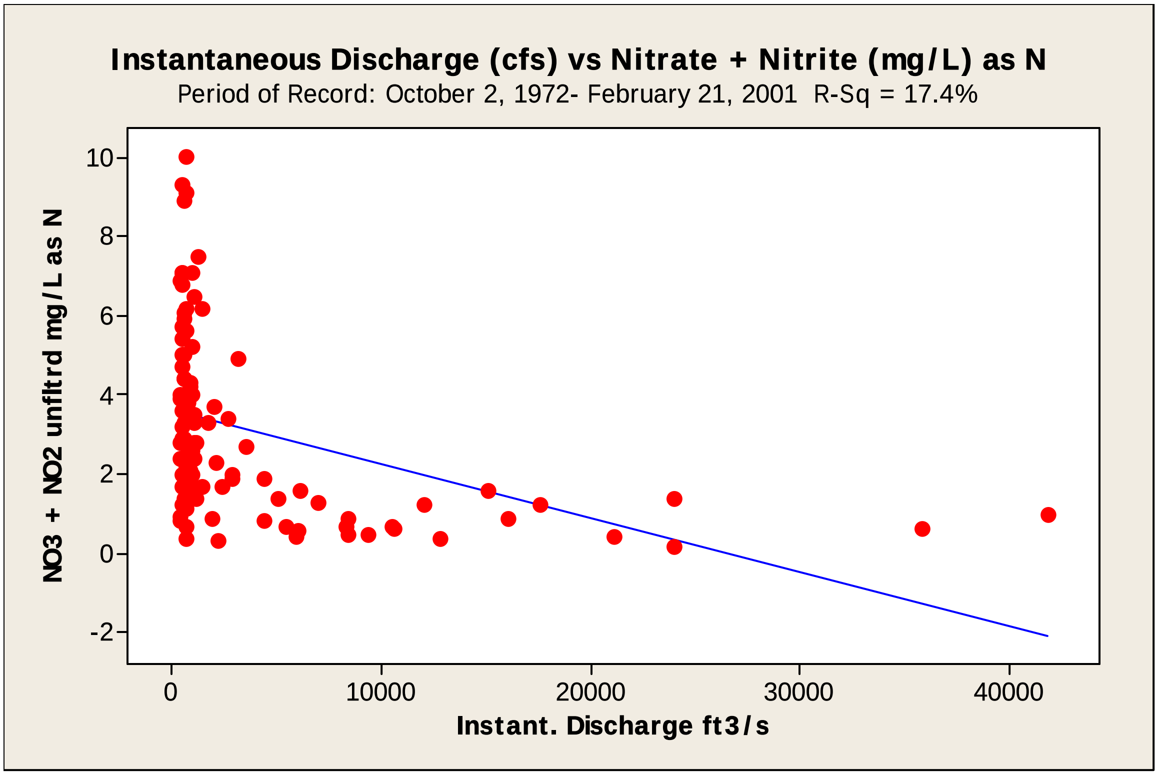


Figure 85. Flow versus nitrate + nitrite as N unfiltered at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

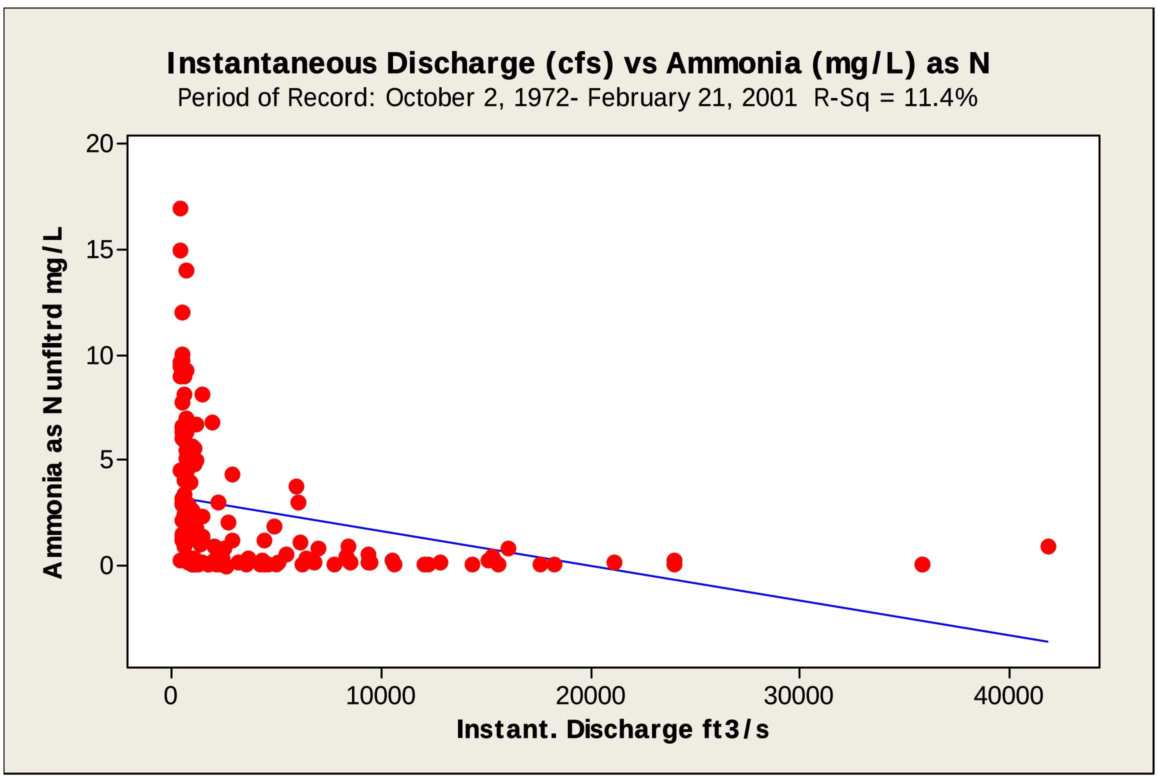


Figure 86. Flow versus ammonia as N unfiltered at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

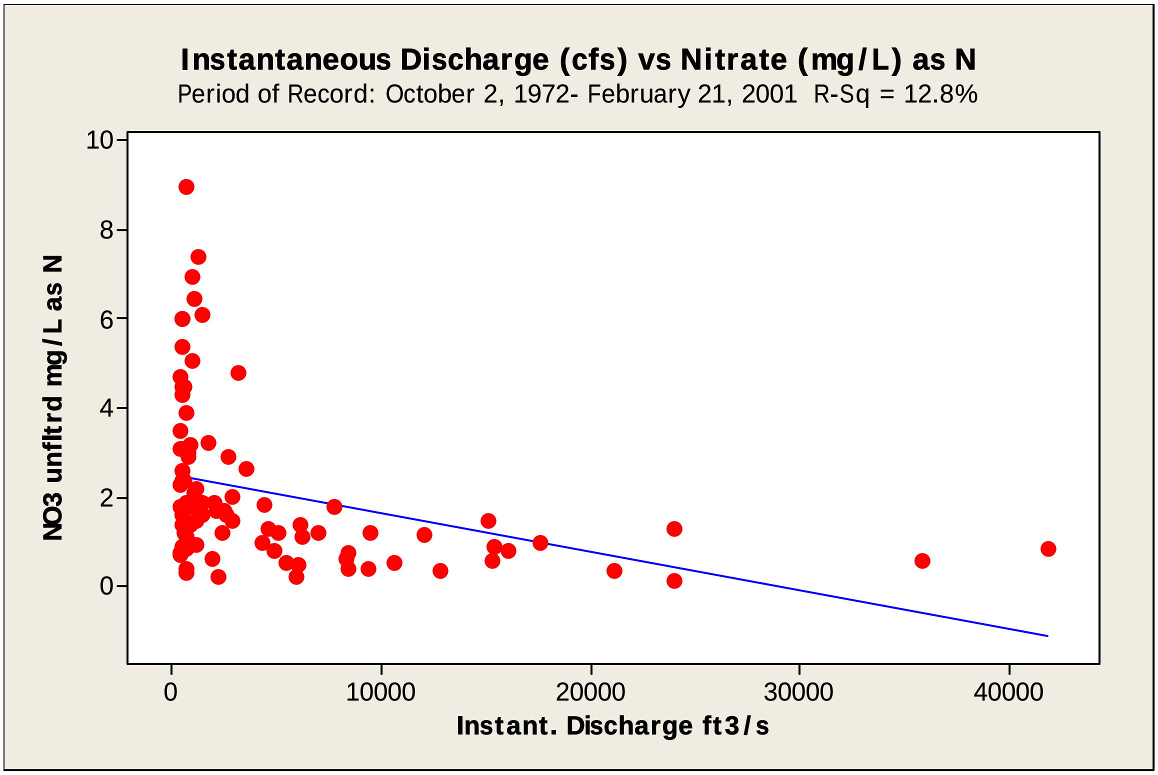


Figure 87. Flow versus nitrate as N unfiltered at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

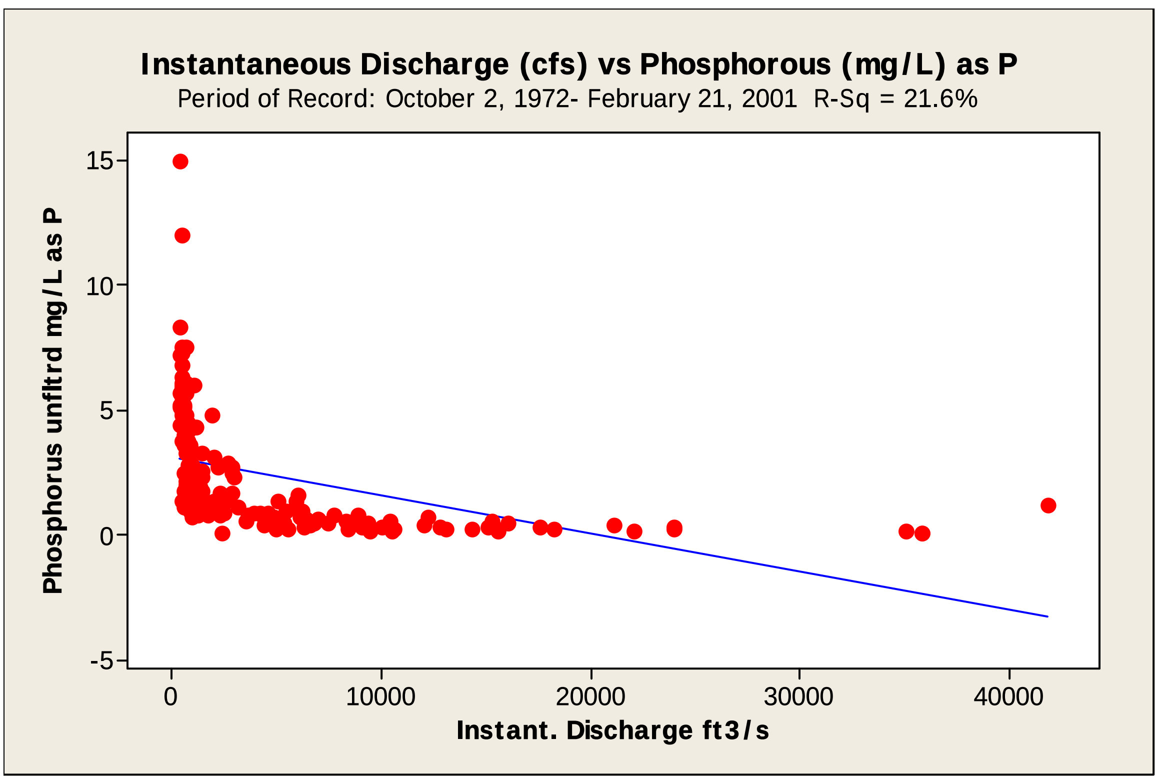


Figure 88. Flow versus phosphorus unfiltered at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

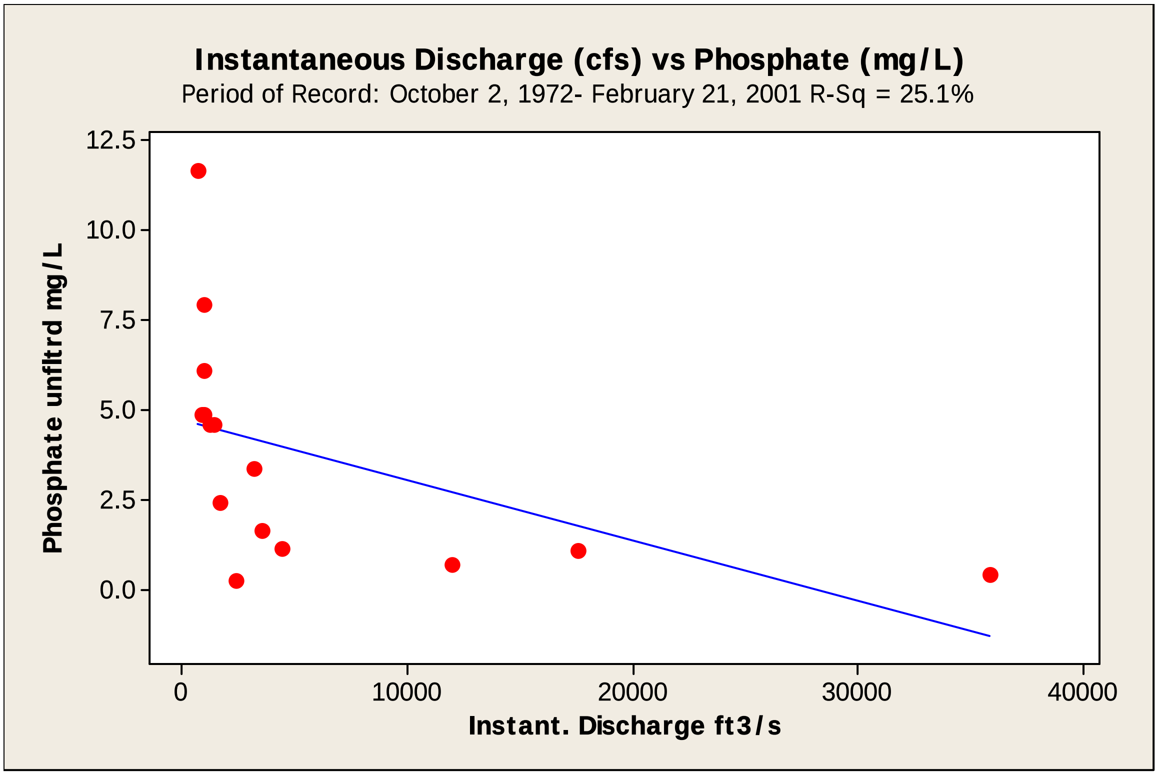


Figure 89. Flow versus phosphate unfiltered at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

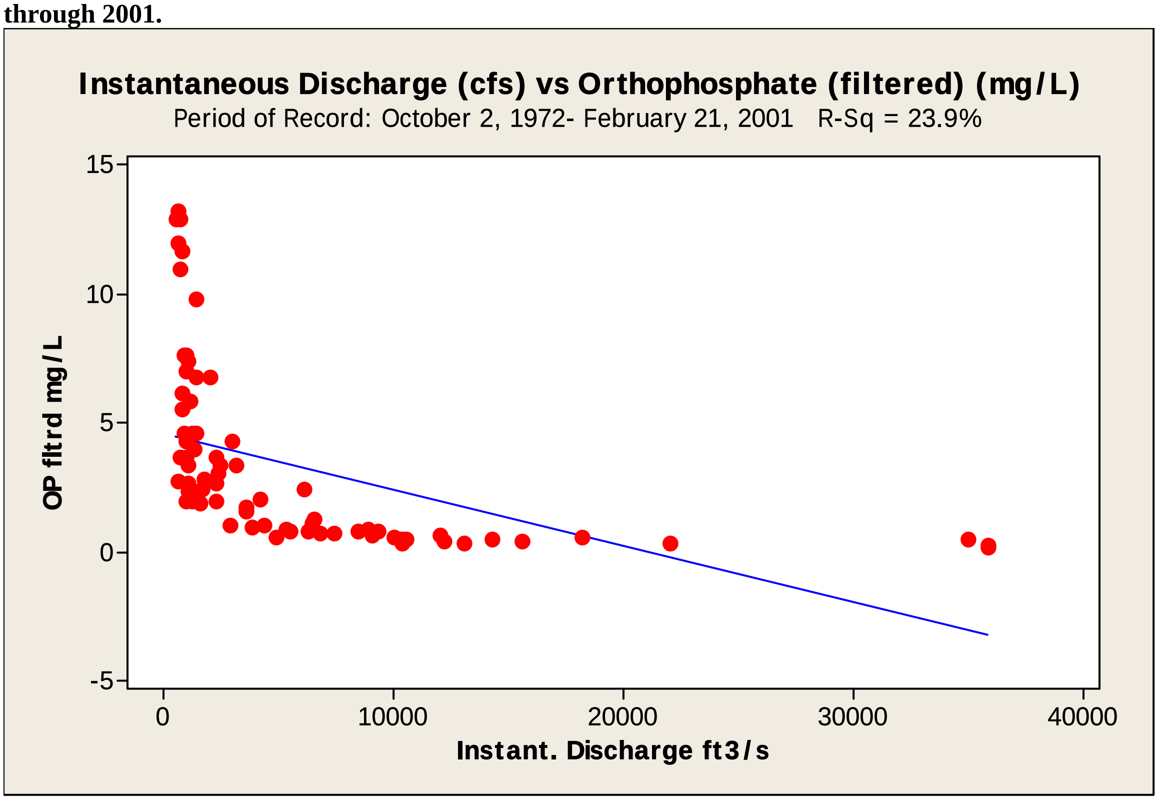


Figure 90. Flow versus orthophosphate filtered at the Trinity River at Trinidad 08062700 gage during 1972 through 2001.

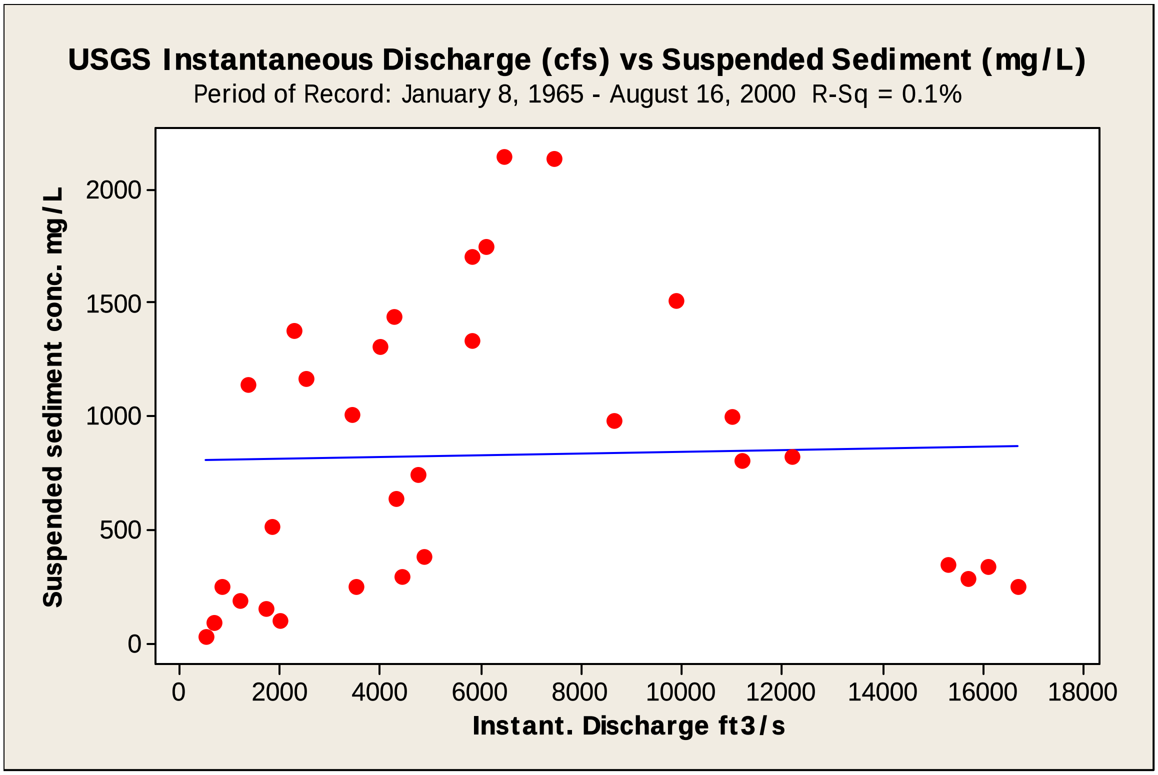


Figure 91. Flow versus suspended sediment concentrations at the Trinity River near Oakwood 08065000 gage during 1965 through 2000.

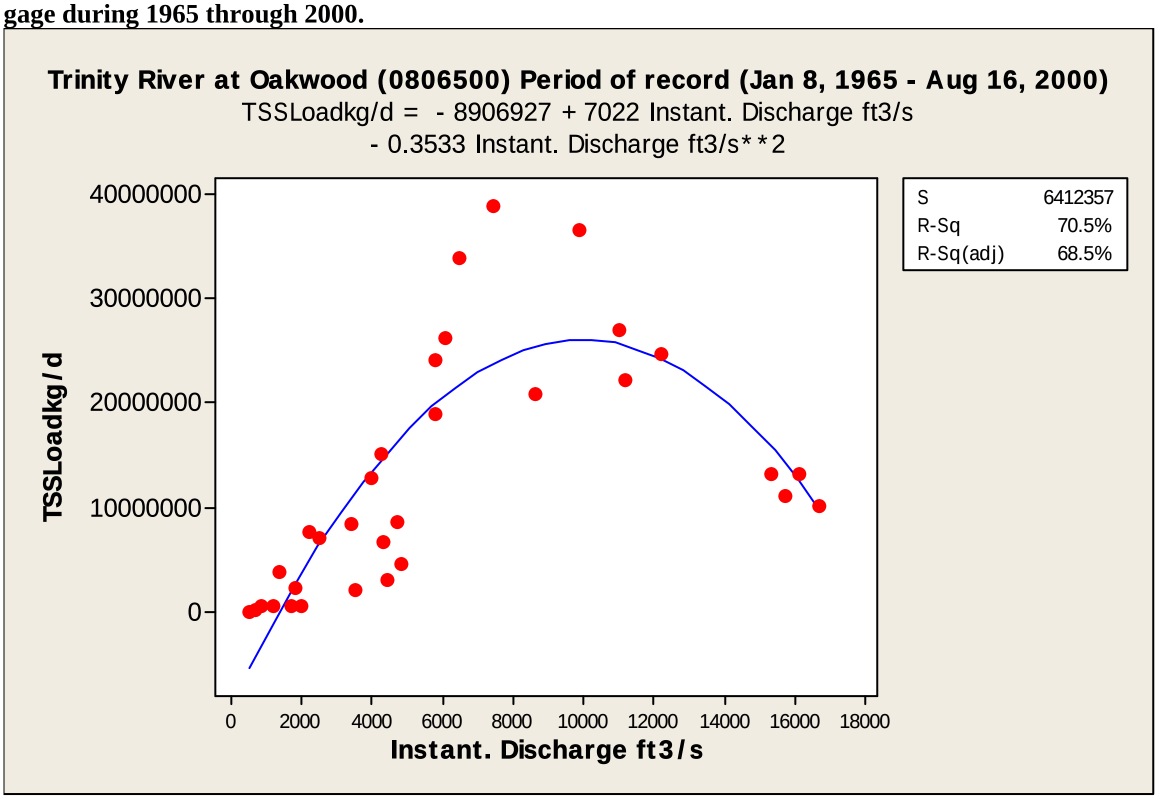


Figure 92. Flow versus suspended sediment load at the Trinity River near Oakwood 08065000 gage during 1965 through 2000.

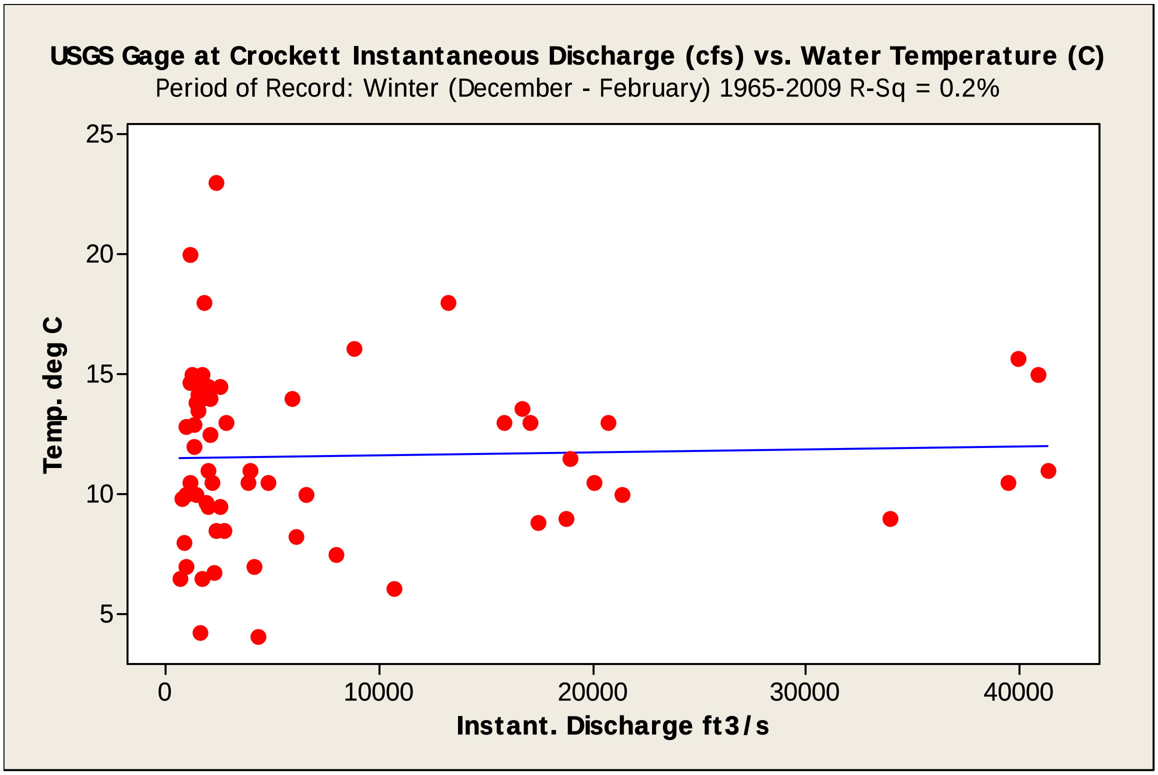


Figure 93. Flow versus winter water temperature at the Trinity River near Crockett 08065350 gage during 1965 through 2009.

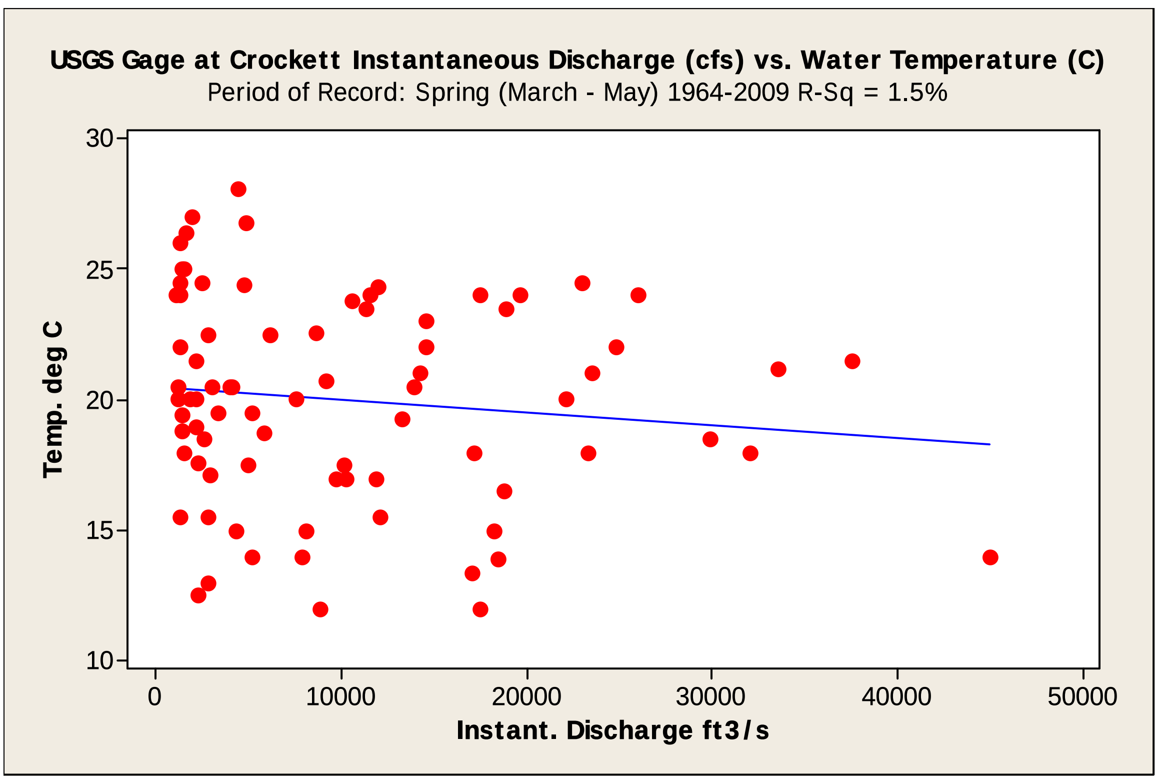


Figure 94. Flow versus spring water temperature at the Trinity River near Crockett 08065350 gage during 1964 through 2009.

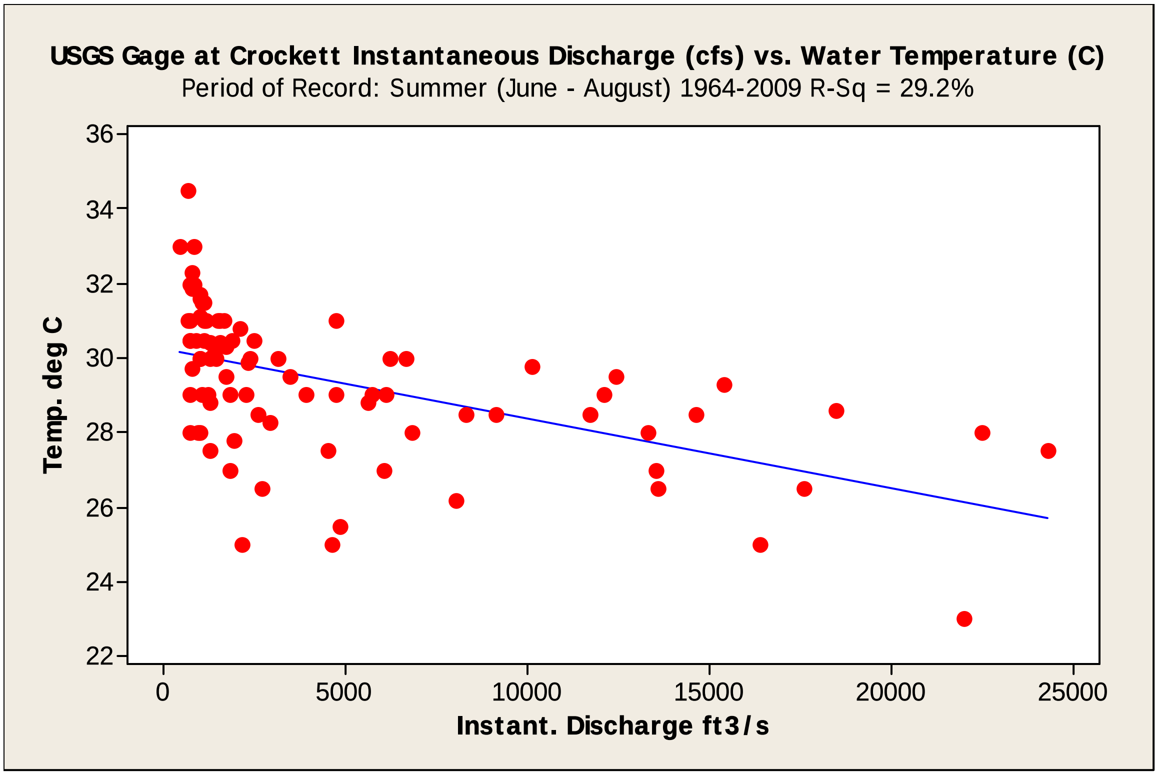


Figure 95. Flow versus summer water temperature at the Trinity River near Crockett 08065350 gage during 1964 through 2009.

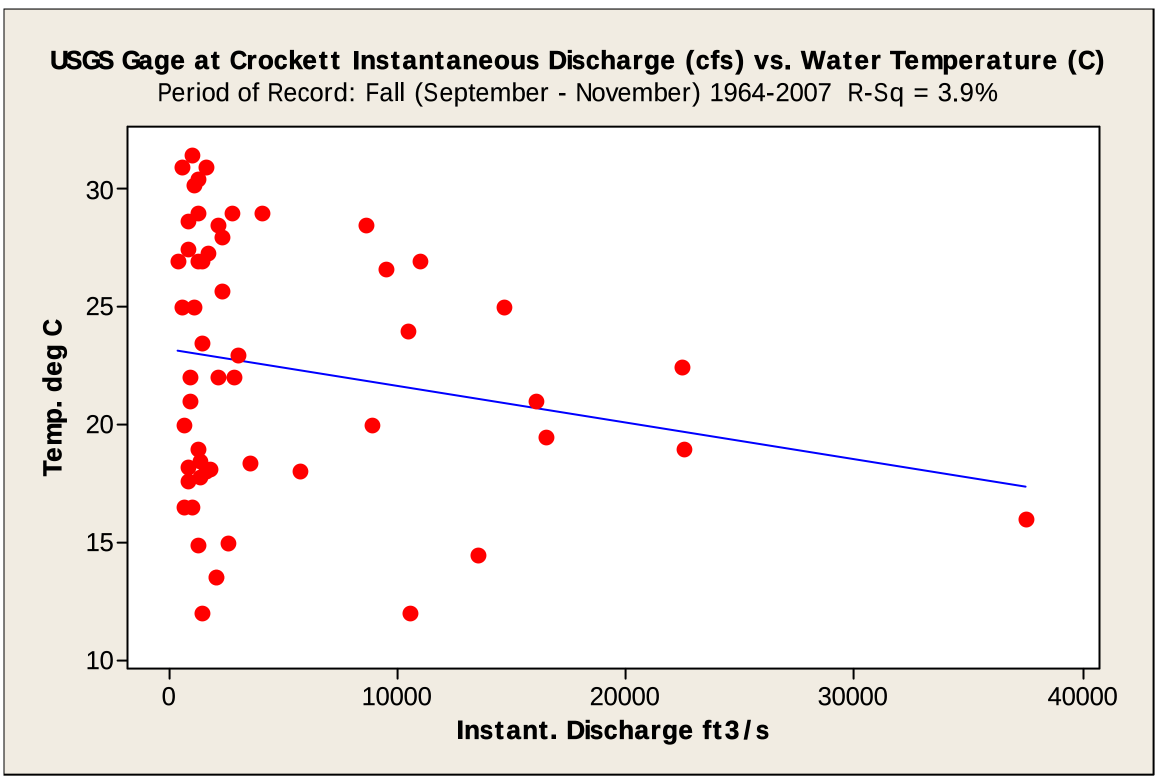


Figure 96. Flow versus fall water temperature at the Trinity River near Crockett 08065350 gage during 1964 through 2007.

The Crockett gage is an important gage that measures streamflow immediately upstream of Lake Livingston (Figure 1). A comparison of data between this site and the next gage located below Lake Livingston at Romayor provides useful information on the possible influence of Lake Livingston on downstream transport of sediment and nutrients. Unfortunately historical paired data sets containing instantaneous discharge and sediment data were largely lacking. Strong seasonal patterns in dissolved oxygen were observed at the Crockett gage (Figure 97-100). Unlike the previous upstream gages, dissolved oxygen levels actually decreased with increasing flows during the summer. This may be due to the fact that the period of record includes data from the 1960s through 2009 which includes the period (late 1980s) when fish kills had become more common due to periodic anoxic episodes associated with the release of improperly treated wastewater and runoff during storms. Many of the lowest dissolved oxygen values were associated with high flow events that occurred between 1982 and 1989. Specific conductance and nutrient concentrations generally declined rapidly when flows increased above 2000 cfs at the Crockett gage (Figures 101-105, 107, 109-110). As with many of the upstream gages, maximum variability of these variables occurred more frequently at lower stream flows. Since the Crockett gage is the last long term monitoring site for hydrology above Lake Livingston, the lowest reservoir in the watershed, we also calculated total nitrogen and phosphorus loading at this gage to later compare with values at the river downstream of the reservoir (Figures 106 and 108). The log-log model generated the best fit for total nitrogen loading at this site while the cubic model fit the phosphorus data best. At flows of approximately 1000 cfs, the corresponding loading was 12,340 kg/d total nitrogen. At flows of 14,600 the total nitrogen loading was 57,152 kg/d (Figure 106). The maximum phosphorus levels, 18,000 kg/d occurred when discharges were approximately 15,000 cfs (Figure 108).

The final priority gage on the non-tidal portion of the Trinity River provides useful information on the chemical characteristics of water entering the Galveston Bay system (Trinity Bay) (Figure 1). The construction of Lake Livingston dam in 1969 is often considered to be one of the major alterations in hydrology in the lower Trinity River. However, annual average flows did not decline after construction of the reservoir (Figure 111). Using a non-parametric Mann-Whitney t-test we also found that the two time periods were not statistically different at the $p = 0.104$ level. The overall median of mean flows was however 8905.5 cfs after dam construction versus 7303.0 cfs before. Based on a very limited analysis of the historical record using the IHA software we found that minimum flows actually increased after construction of the dam whereas there appeared to be little effect on maximum flows (Figure 112). This agrees with previous geomorphological studies which documented no changes in high flow conditions following impoundment, while low flows became elevated (Wellmeyer et al. 2005). They indicated that increased precipitation rates during the period after dam construction may explain some of this variation. Based on this information we felt that it was unnecessary to segregate loading estimates into Galveston Bay into two time periods based on changes in hydrology.

Only summer water temperatures appear to be strongly influenced by increasing flows (Figures 113 – 116). At levels above 50,000 cfs water temperatures consistently declined (Figure 115). However under most conditions there is not a strong relationship between flow and water temperature. Similar patterns were exhibited between flow and dissolved oxygen levels (Figures 117-118). The influence of flow on specific conductance also indicates that there is considerable variation in the amount of dissolved ions unrelated to flow (Figure 121). However, these values are relatively low (<500 uS). Most nutrients increased in concentration as flows increased (Figures 122-128).

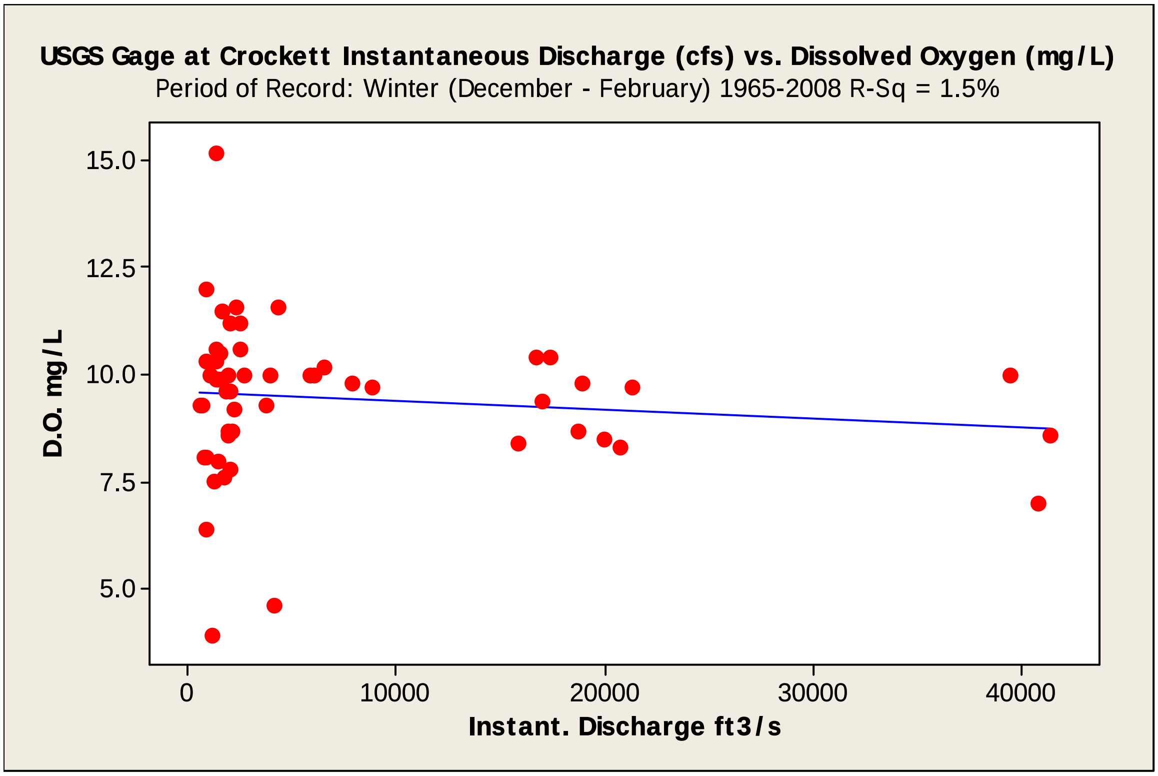


Figure 97. Flow versus winter dissolved oxygen at the Trinity River near Crockett 08065350 gage during 1965 through 2008.

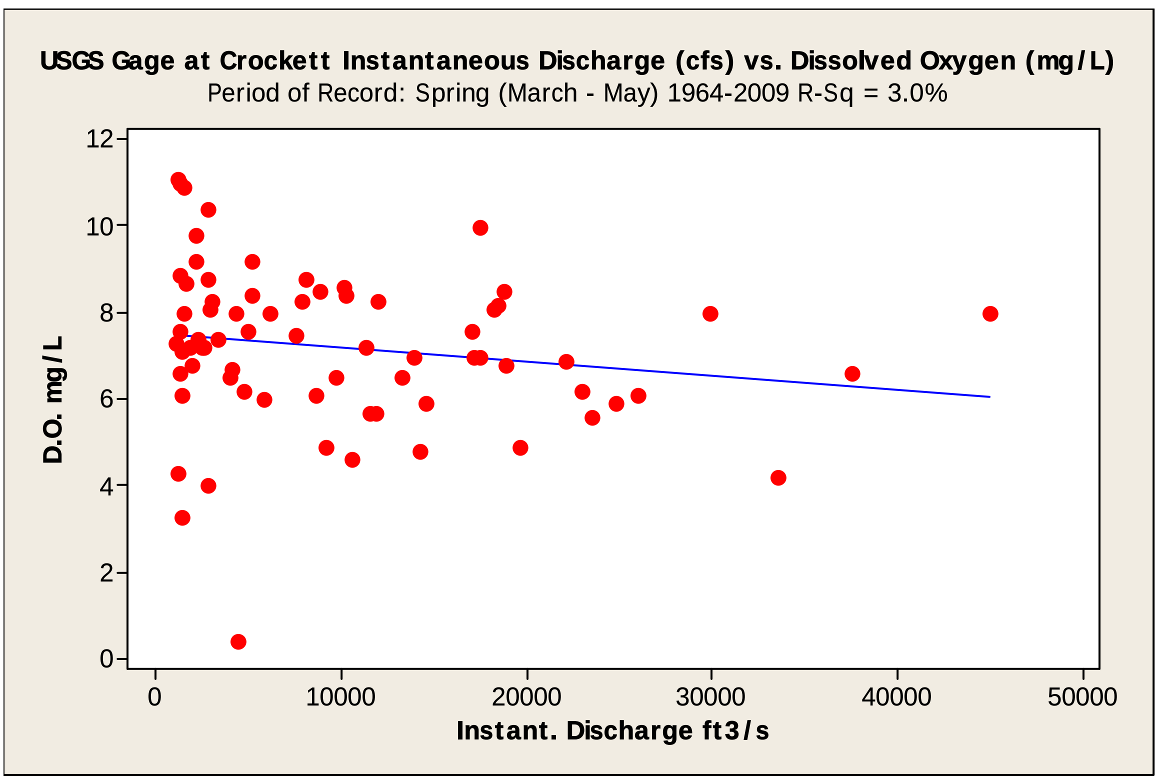


Figure 98. Flow versus spring dissolved oxygen at the Trinity River near Crockett 08065350 gage during 1964 through 2009.

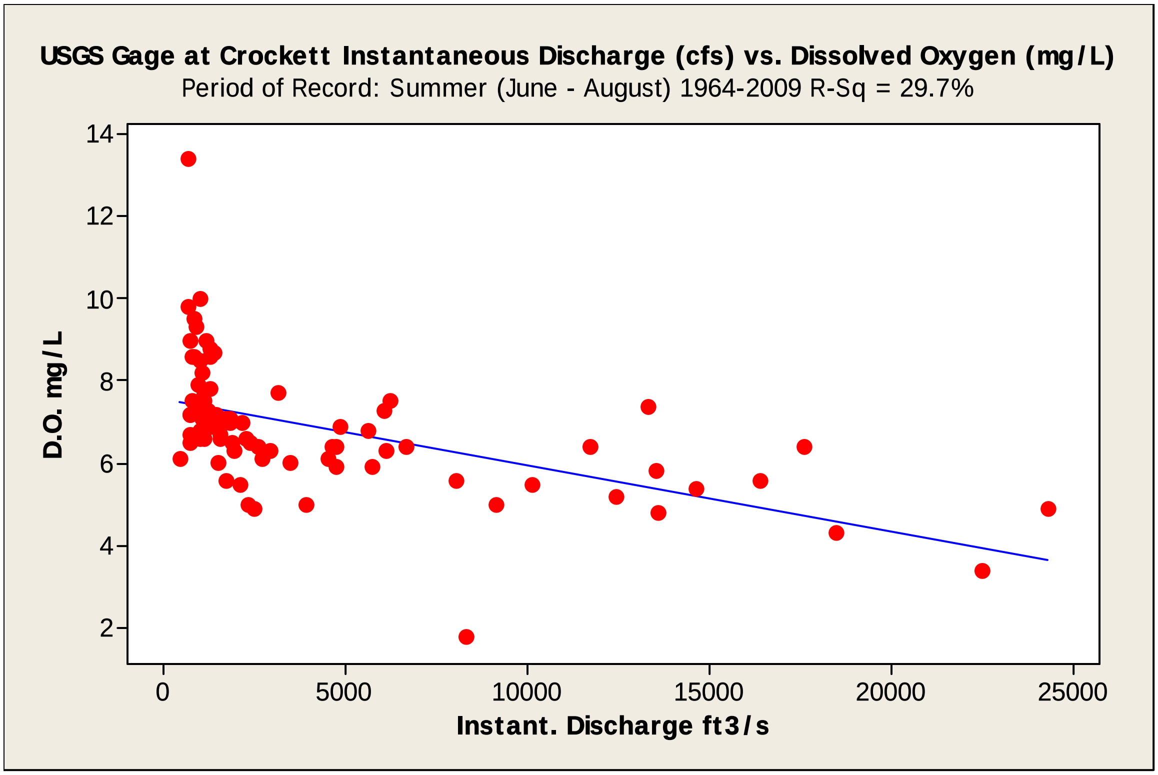


Figure 99. Flow versus summer dissolved oxygen at the Trinity River near Crockett 08065350 gage during 1965 through 2008.

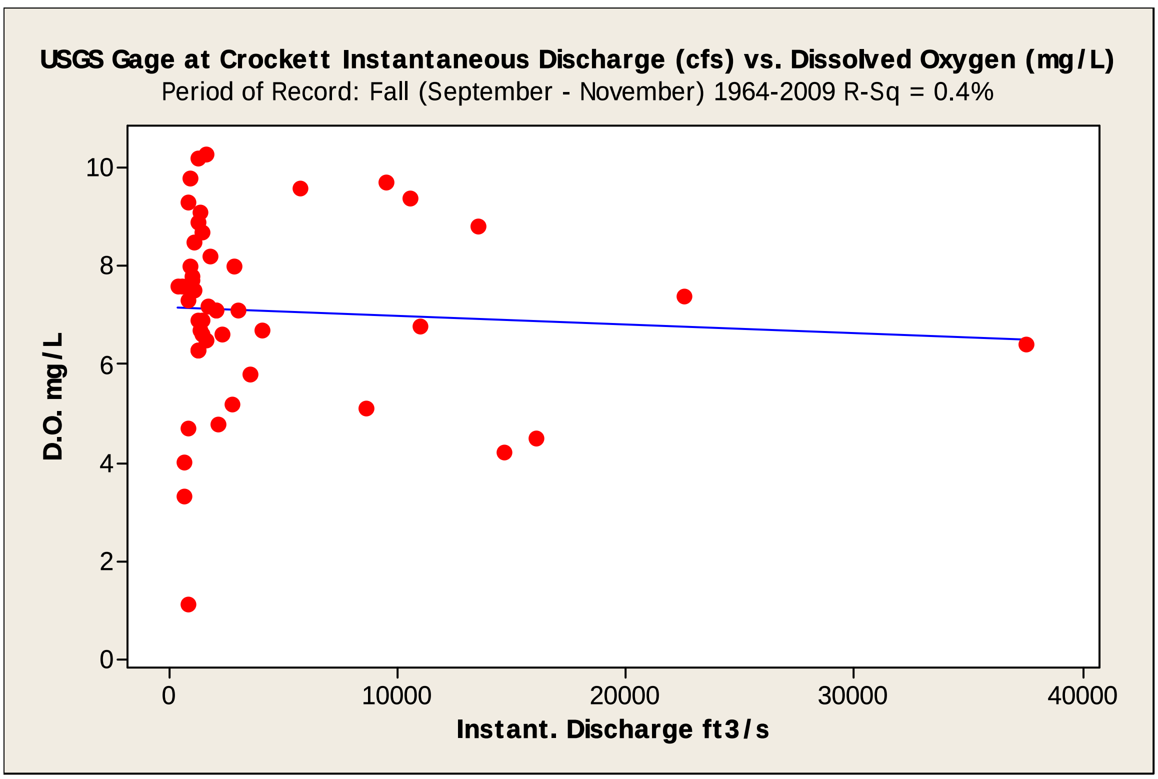


Figure 100. Flow versus fall dissolved oxygen at the Trinity River near Crockett 08065350 gage during 1964 through 2009.

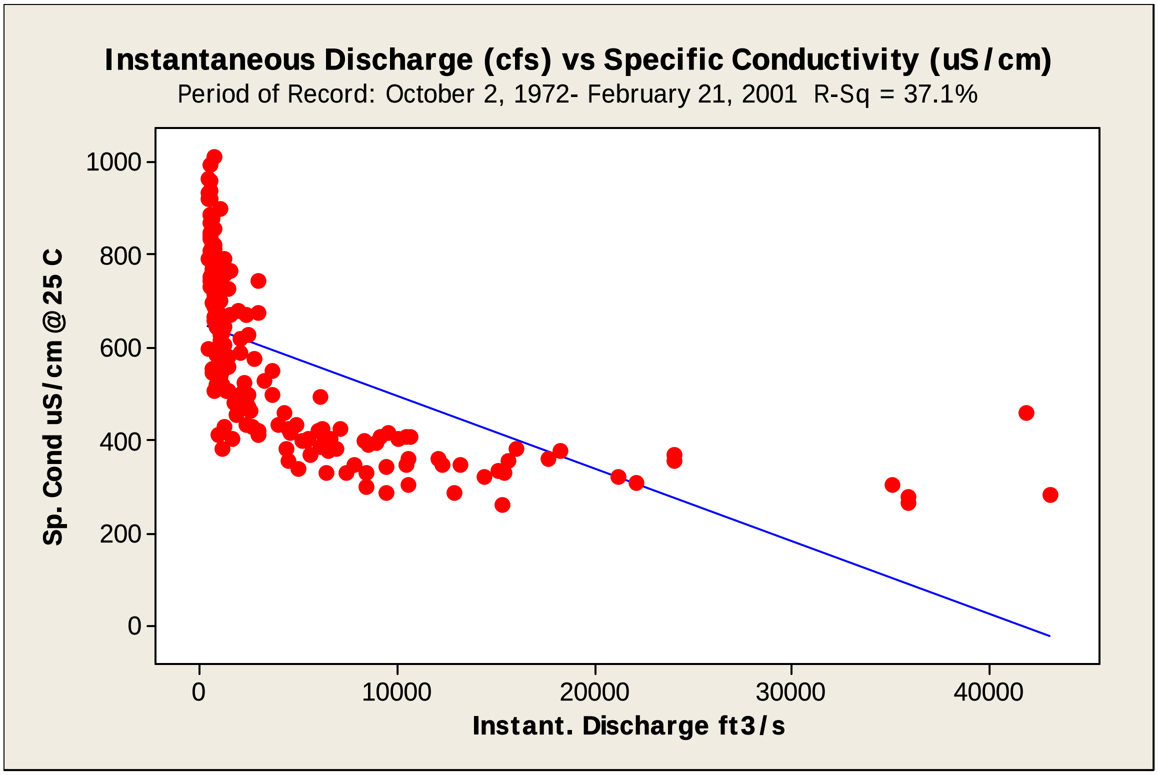


Figure 101. Flow versus specific conductance at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

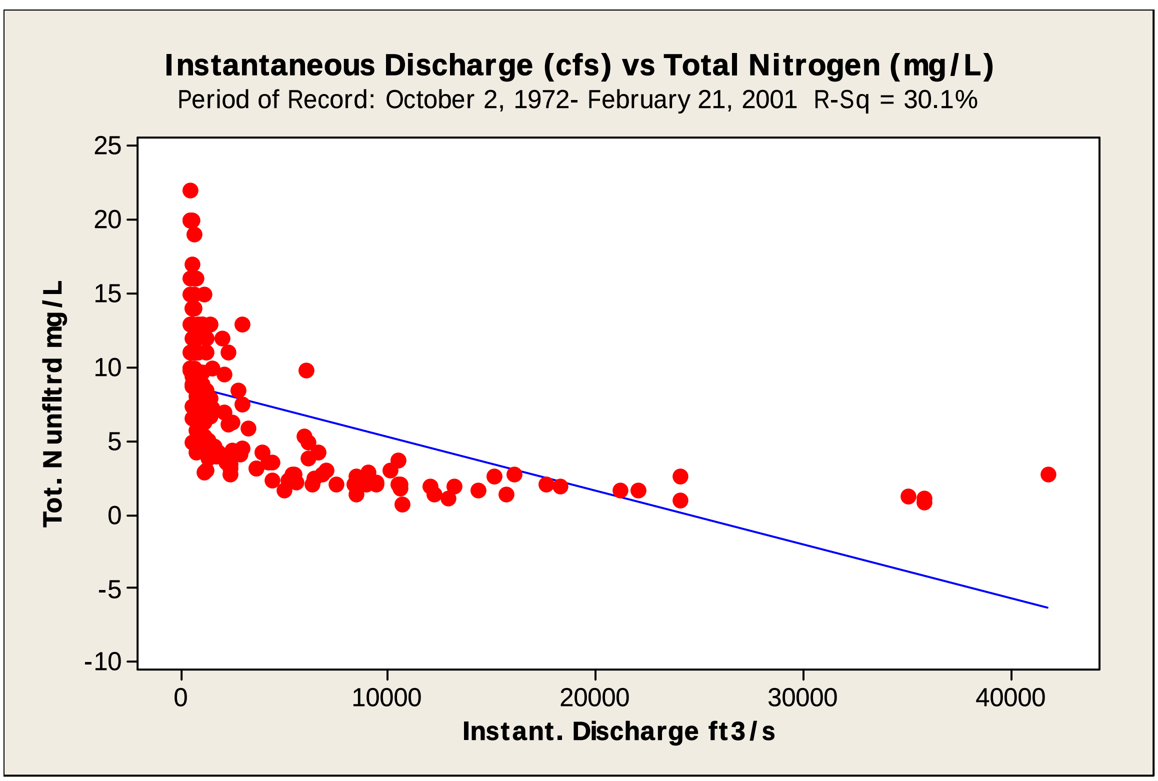


Figure 102. Flow versus total nitrogen concentration at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

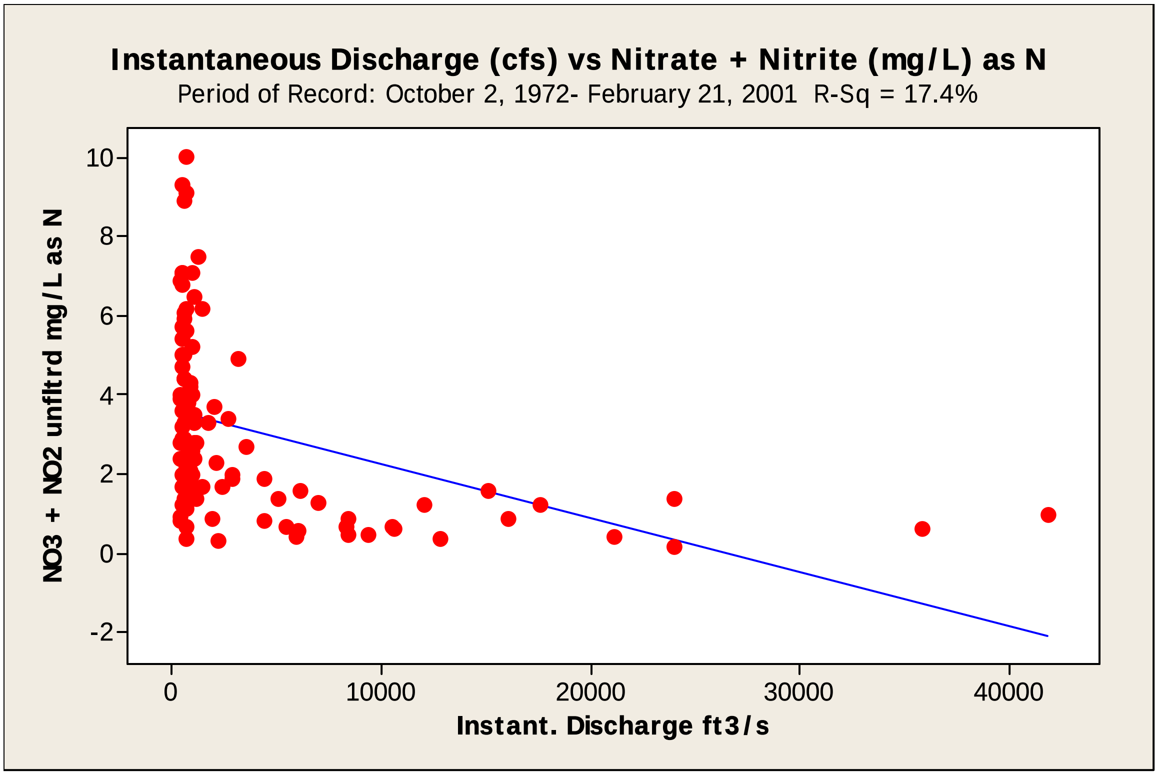


Figure 103. Flow versus nitrate and nitrite as nitrogen concentration at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

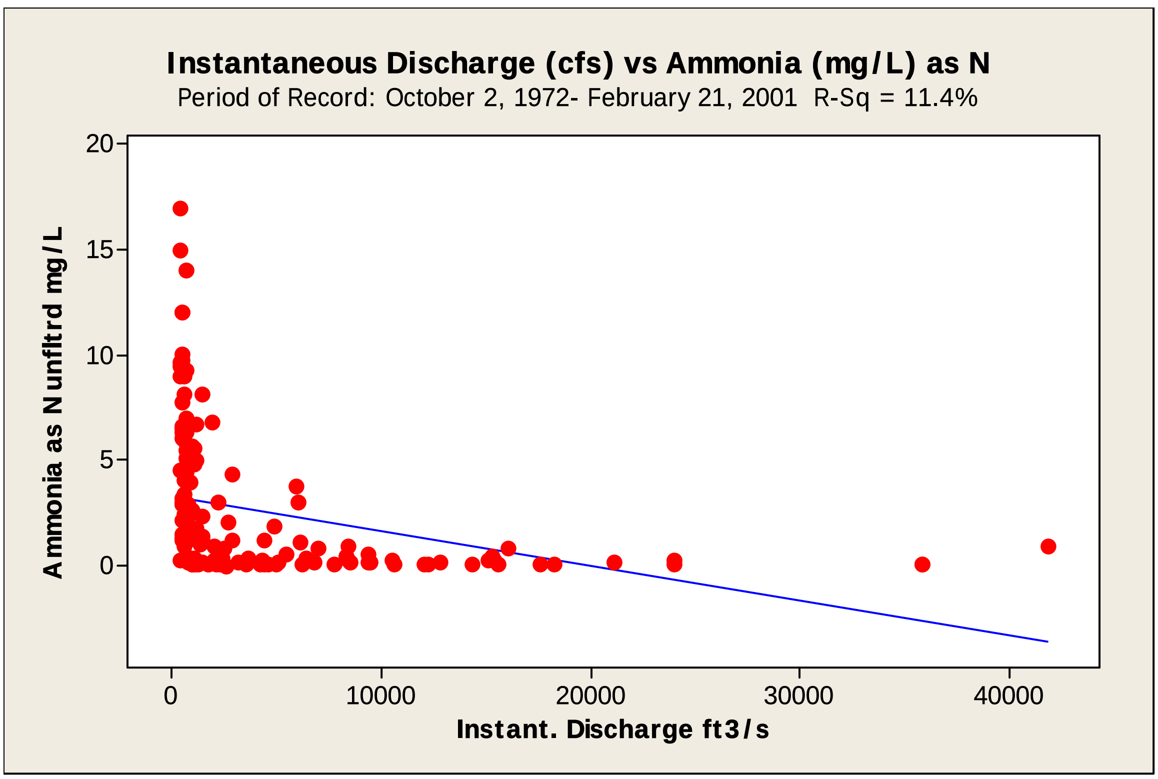


Figure 104. Flow versus ammonia as nitrogen concentration at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

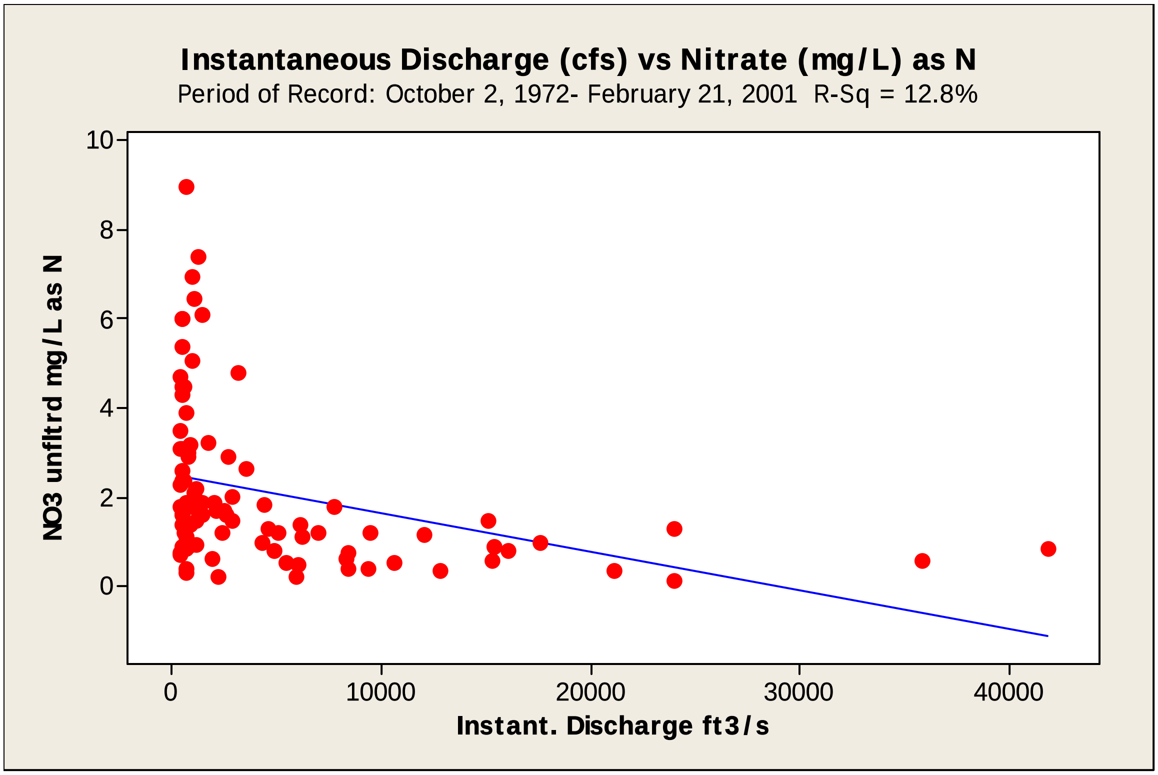


Figure 105. Flow versus nitrate as nitrogen concentration at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

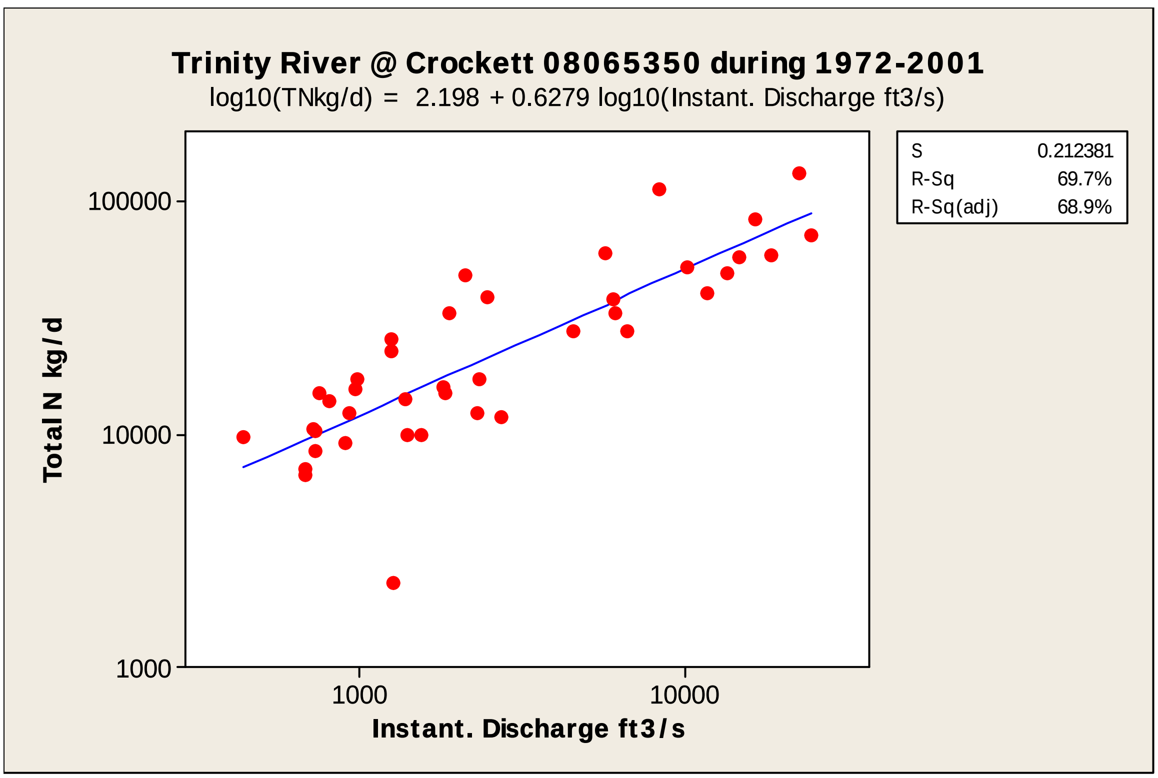


Figure 106. Flow versus total nitrogen loading at the Trinity River at Crockett 08065350 gage during 1972 through 2001.

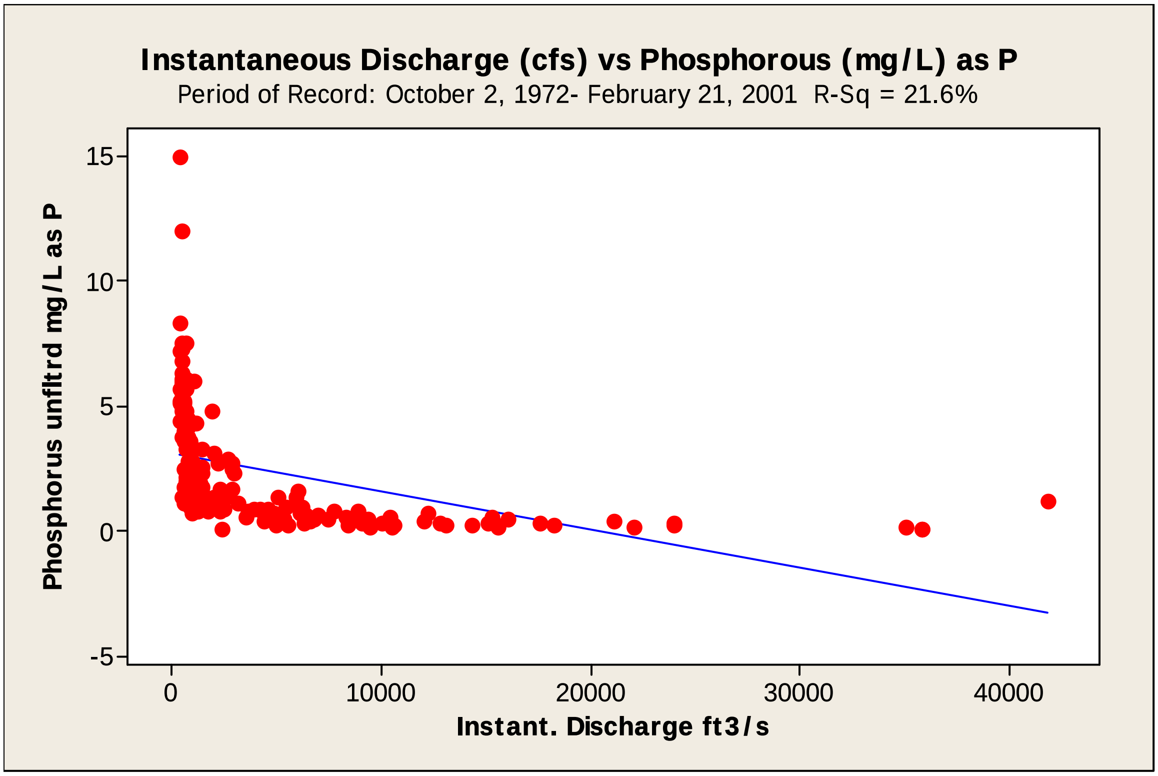


Figure 107. Flow versus phosphorus unfiltered at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

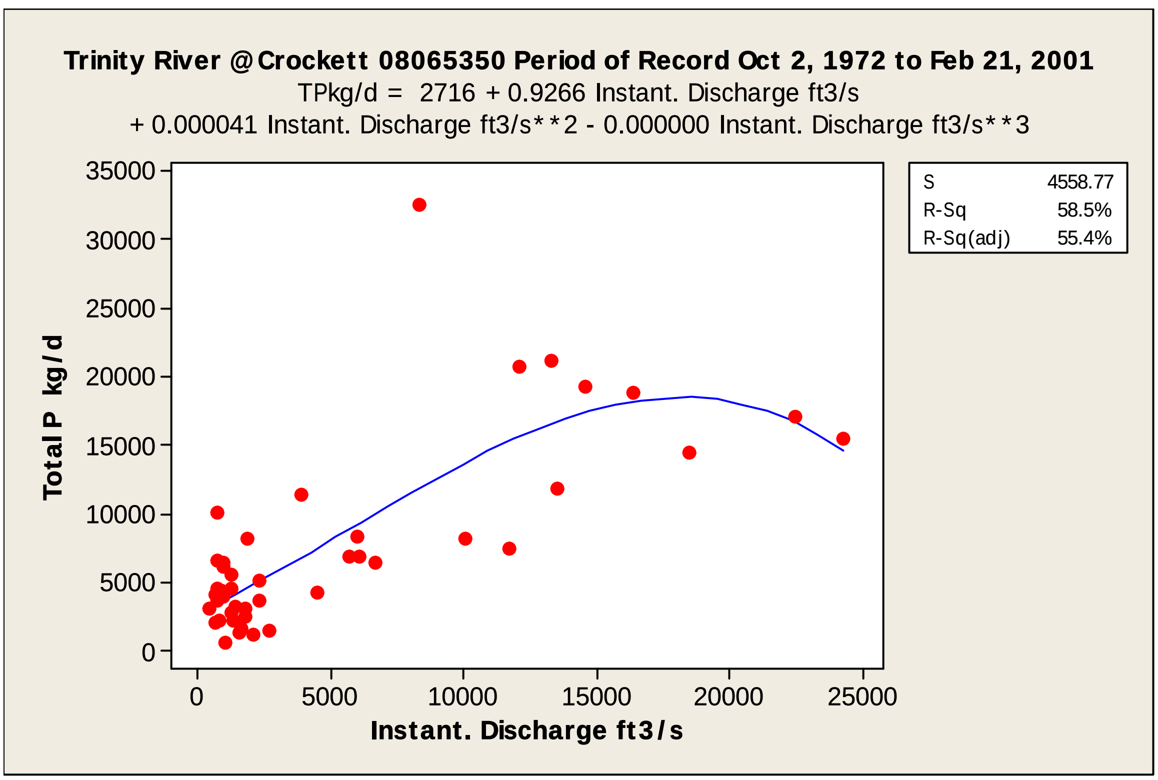


Figure 108. Flow versus total phosphorus loading (unfiltered) at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

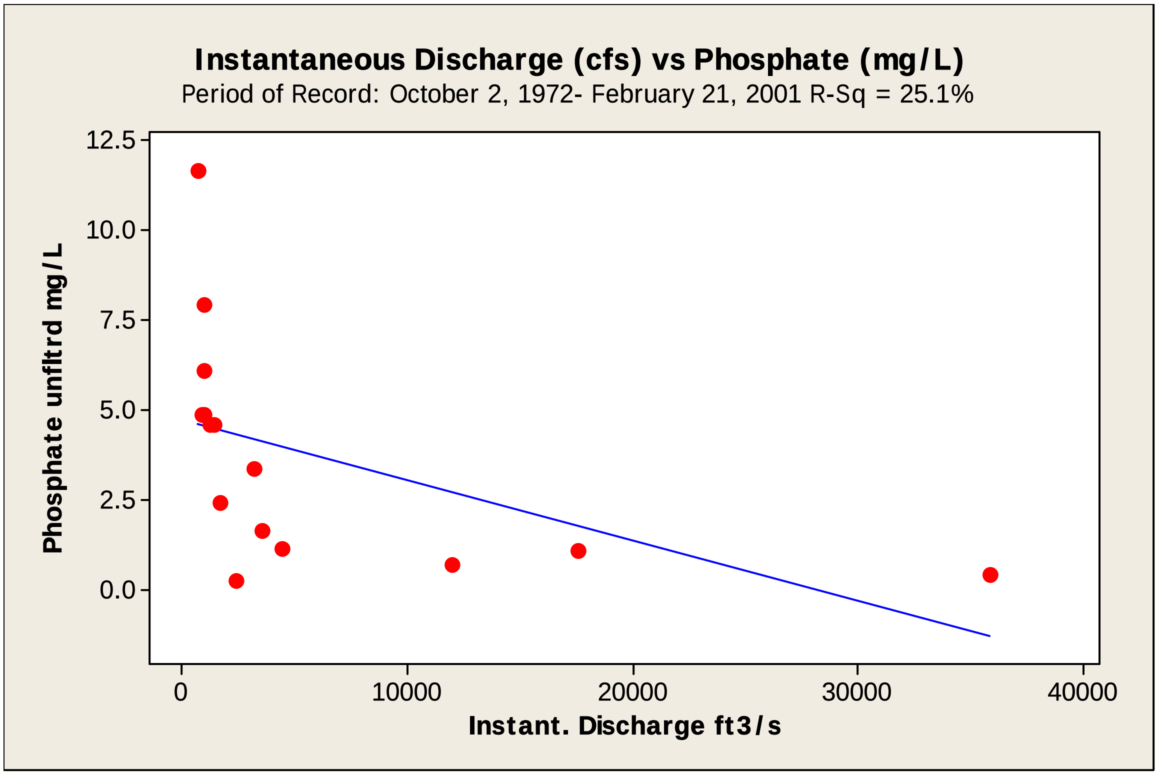


Figure 109. Flow versus phosphate concentration at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

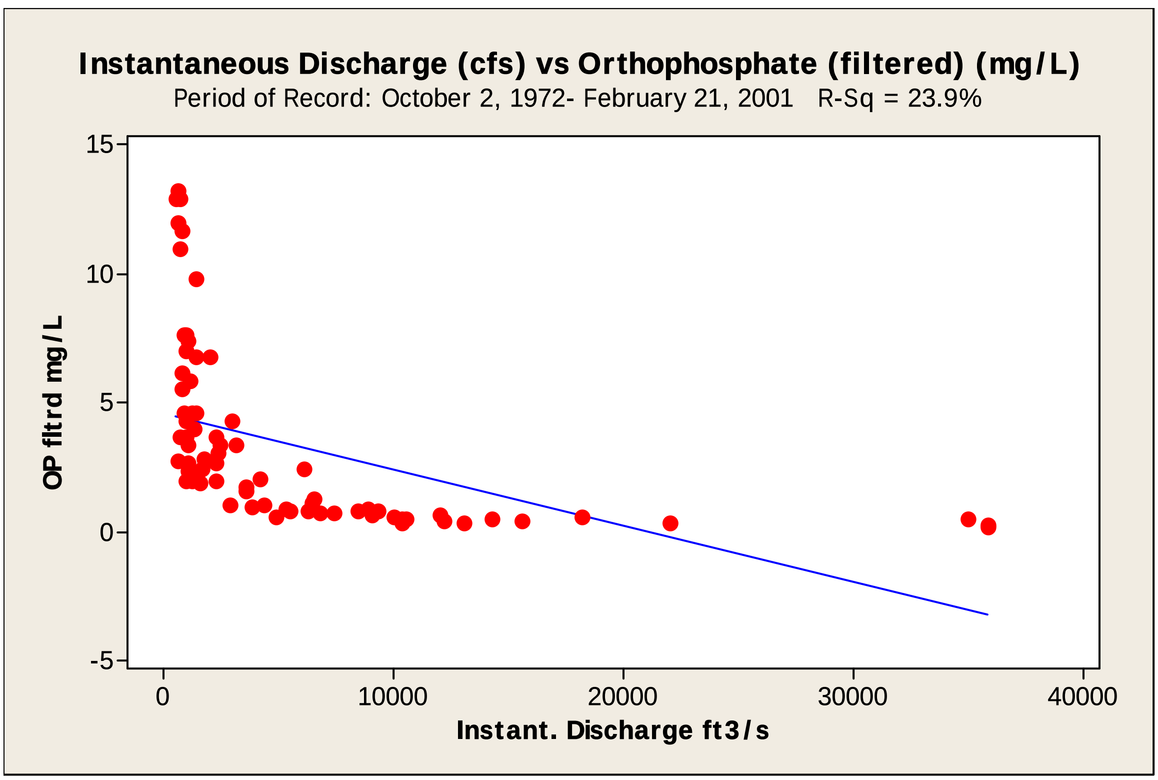


Figure 110. Flow versus orthophosphate concentration at the Trinity River near Crockett 08065350 gage during 1972 through 2001.

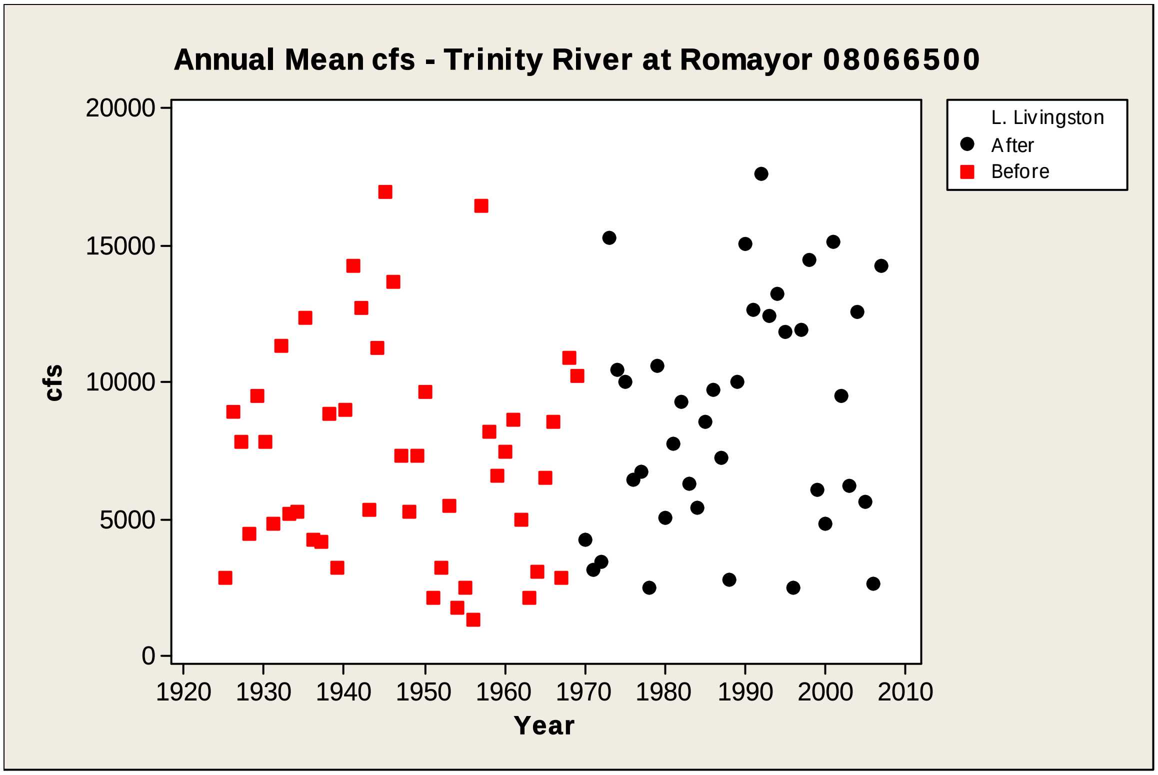
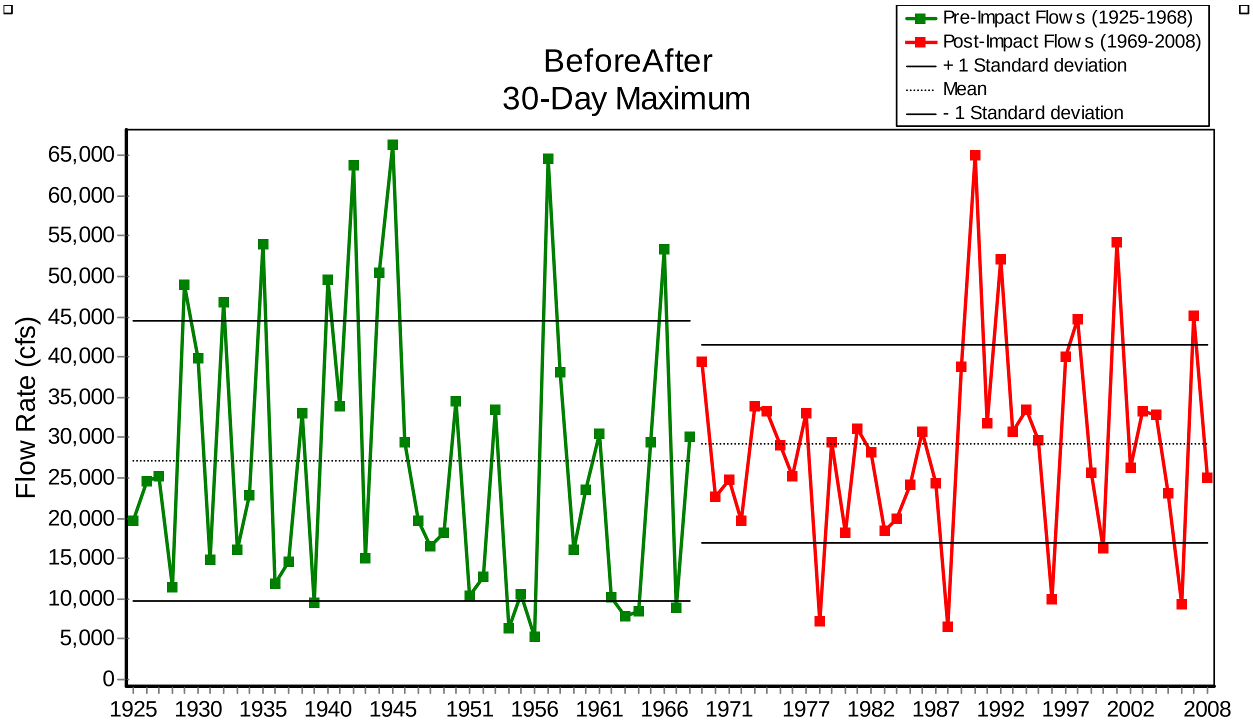


Figure 111. Comparison of annual flow (cfs) statistics for the Trinity River at Romayor (08066500) gage before and after construction of Lake Livingston. Period of record: 1925 through 2007. Source: USGS



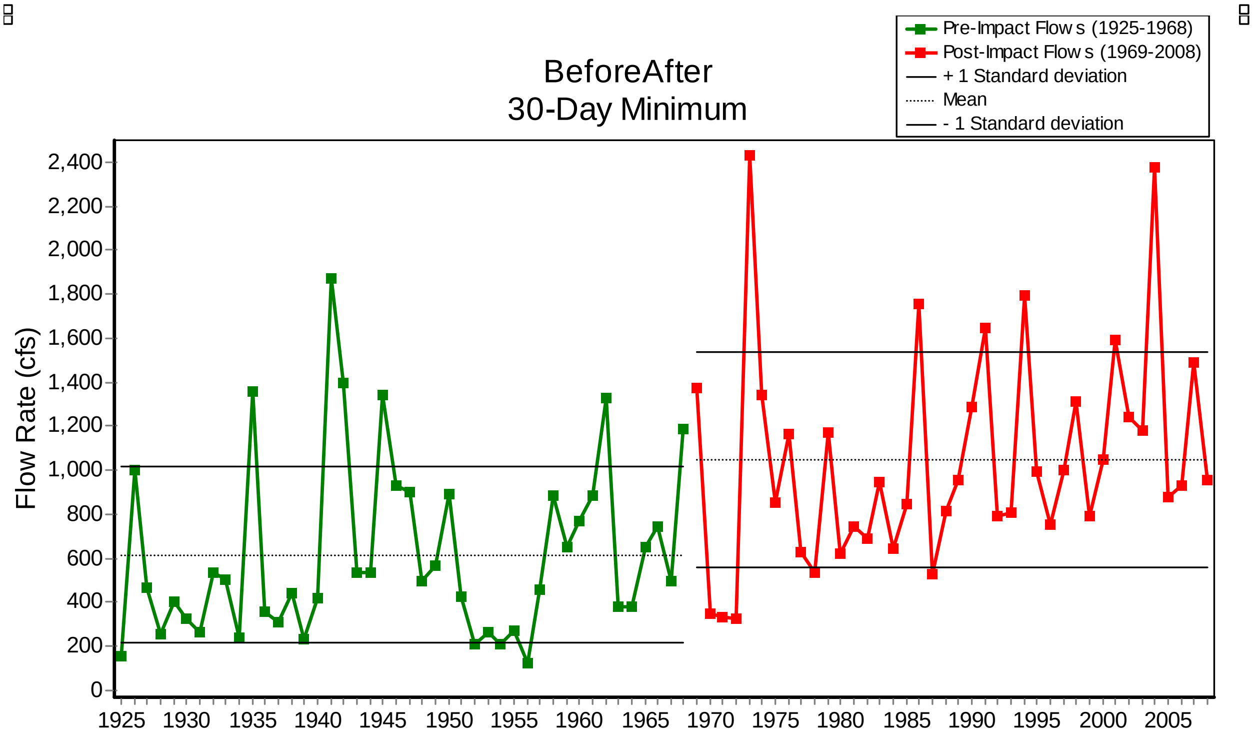


Figure 112. Effects of construction of the Lake Livingston dam on 30 day maximum and minimum flows after 1969. Similar patterns were observed for 1, 3, 7 and 90 day intervals. Data generated using IHA software. Period of record 1925-2008. Data Source: USGS

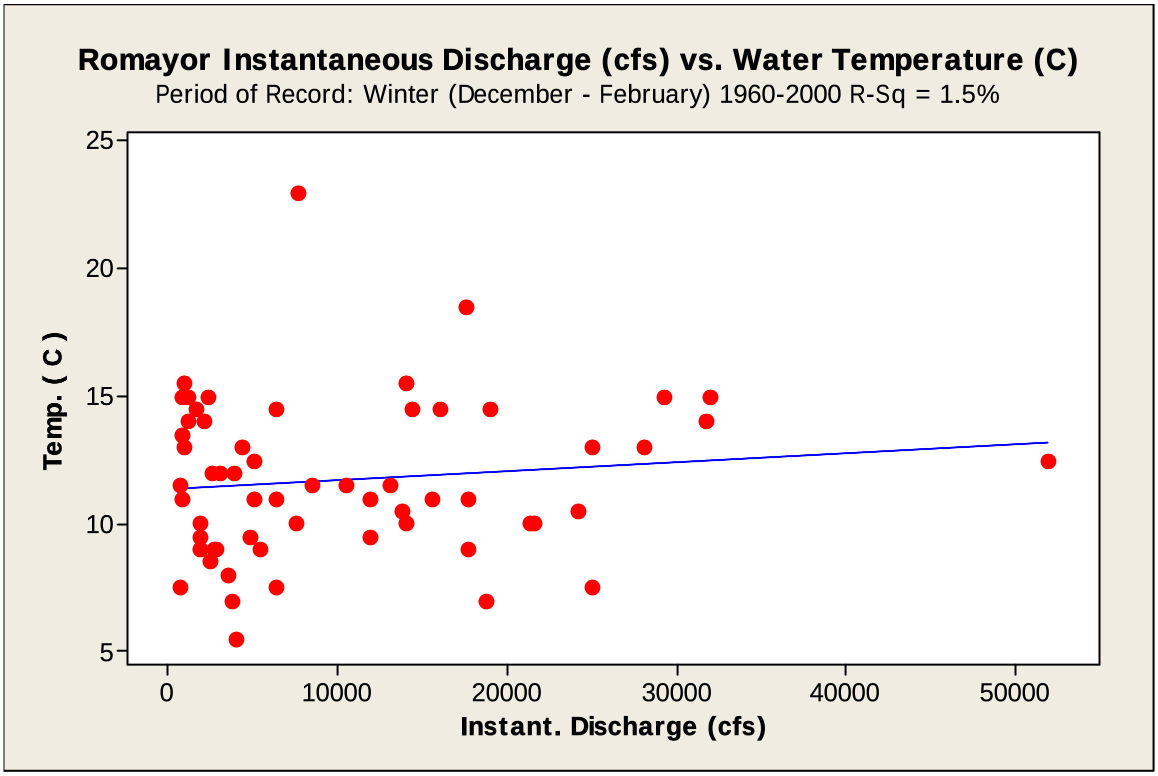


Figure 113. Flow versus winter water temperature at the Trinity River at Romayor 08066500 gage during 1960 through 1995.

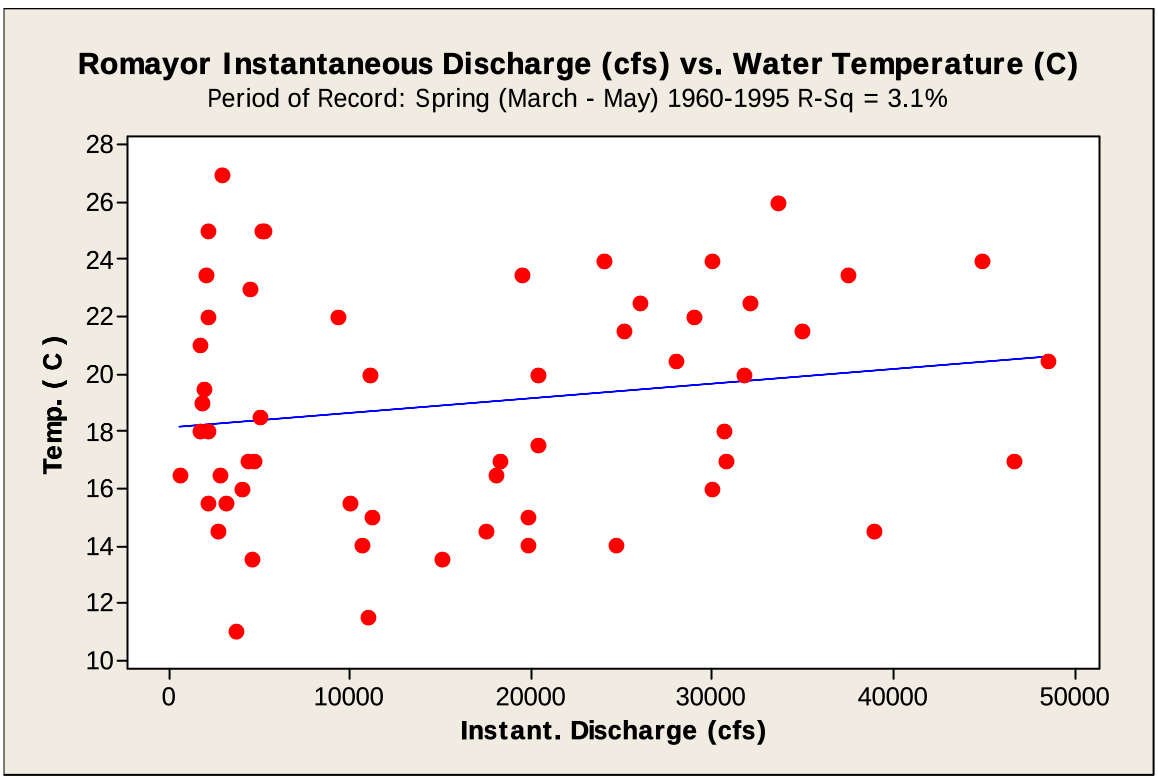


Figure 114. Flow versus spring water temperature at the Trinity River at Romayor 08066500 gage during 1960 through 1995.

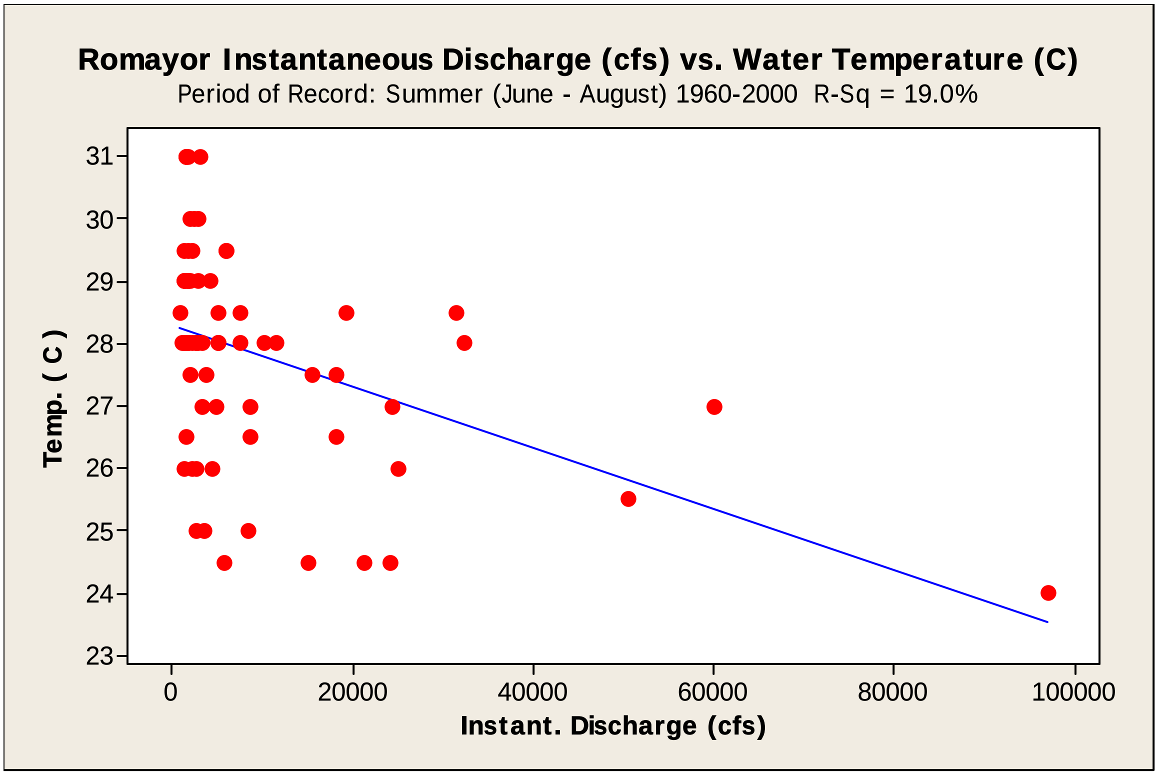


Figure 115. Flow versus summer water temperature at the Trinity River at Romayor 08066500 gage during 1960 through 2000.

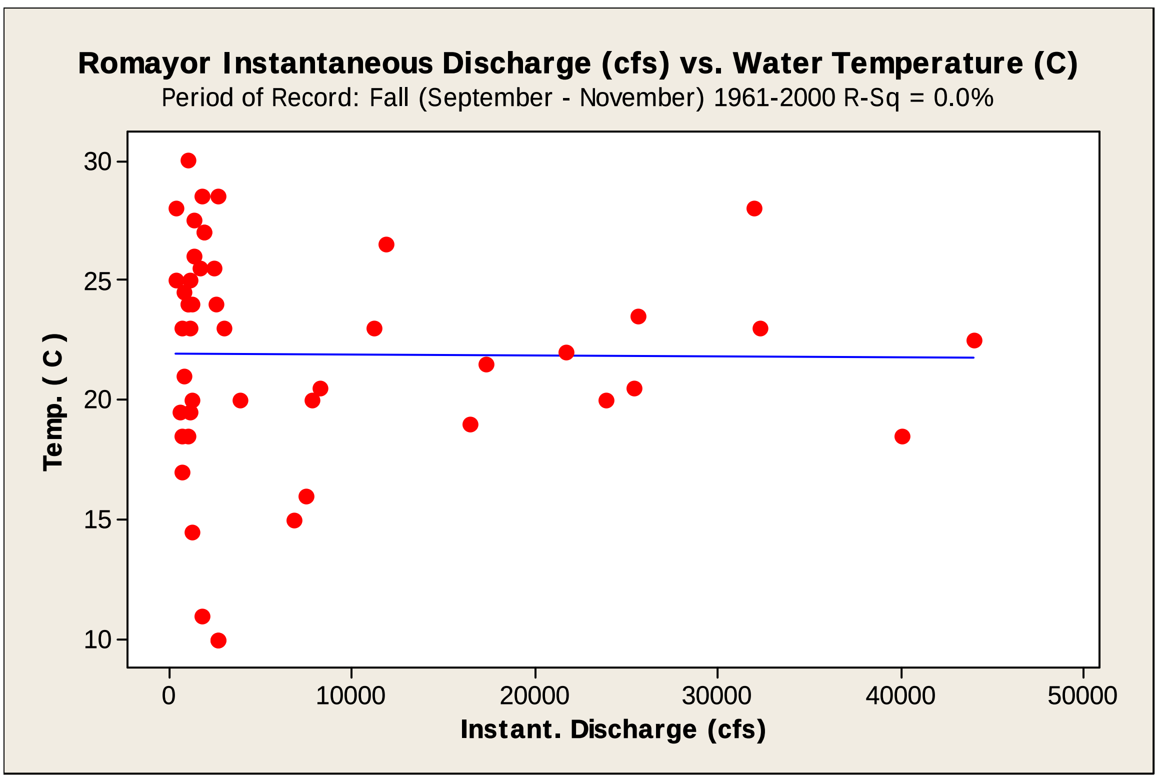


Figure 116. Flow versus fall water temperature at the Trinity River at Romayor 08066500 gage during 1961 through 2000.

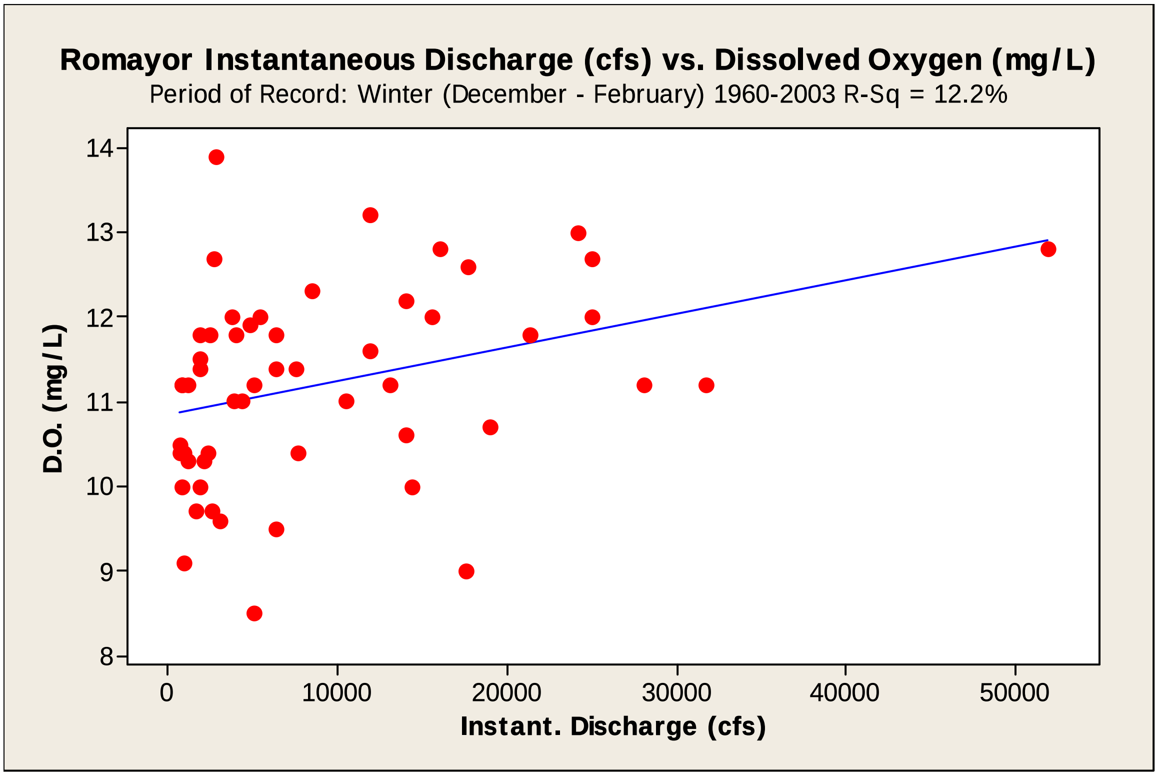


Figure 117. Flow versus winter dissolved oxygen at the Trinity River at Romayor 08066500 gage during 1960 through 2003.

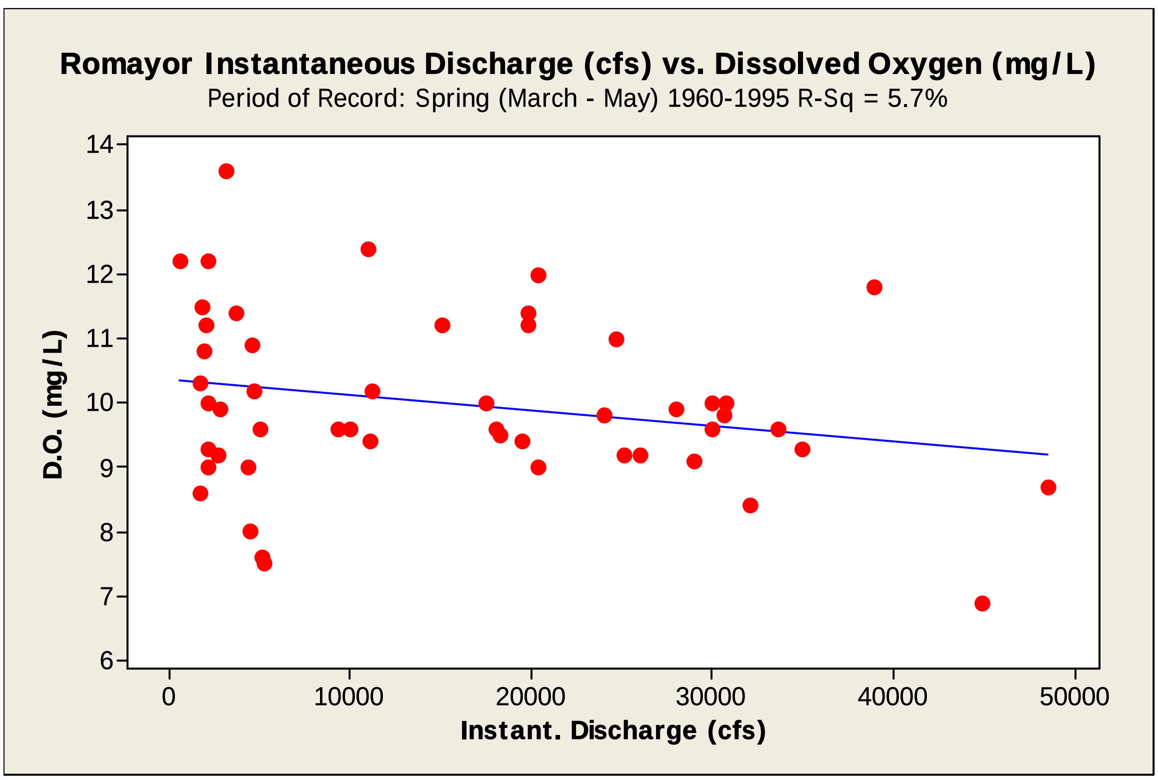


Figure 118. Flow versus spring dissolved oxygen at the Trinity River at Romayor 08066500 gage during 1960 through 1995.

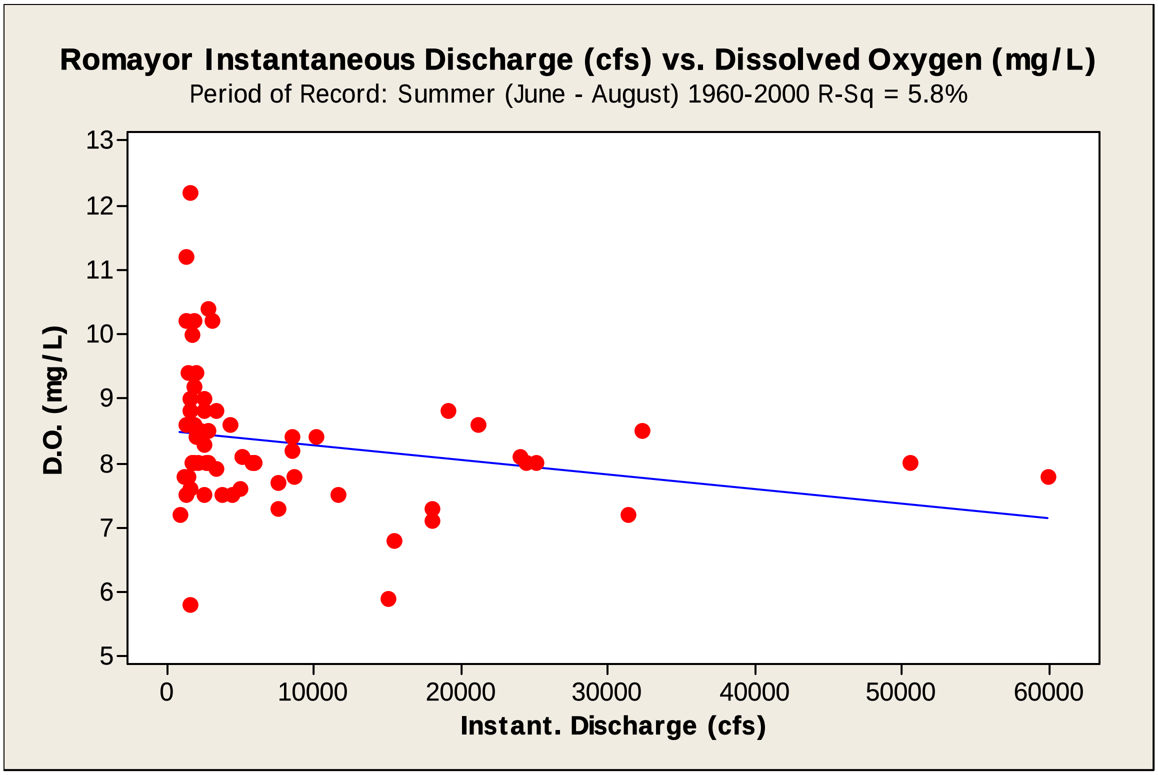


Figure 119. Flow versus summer dissolved oxygen at the Trinity River at Romayor 08066500 gage during 1960 through 2000.

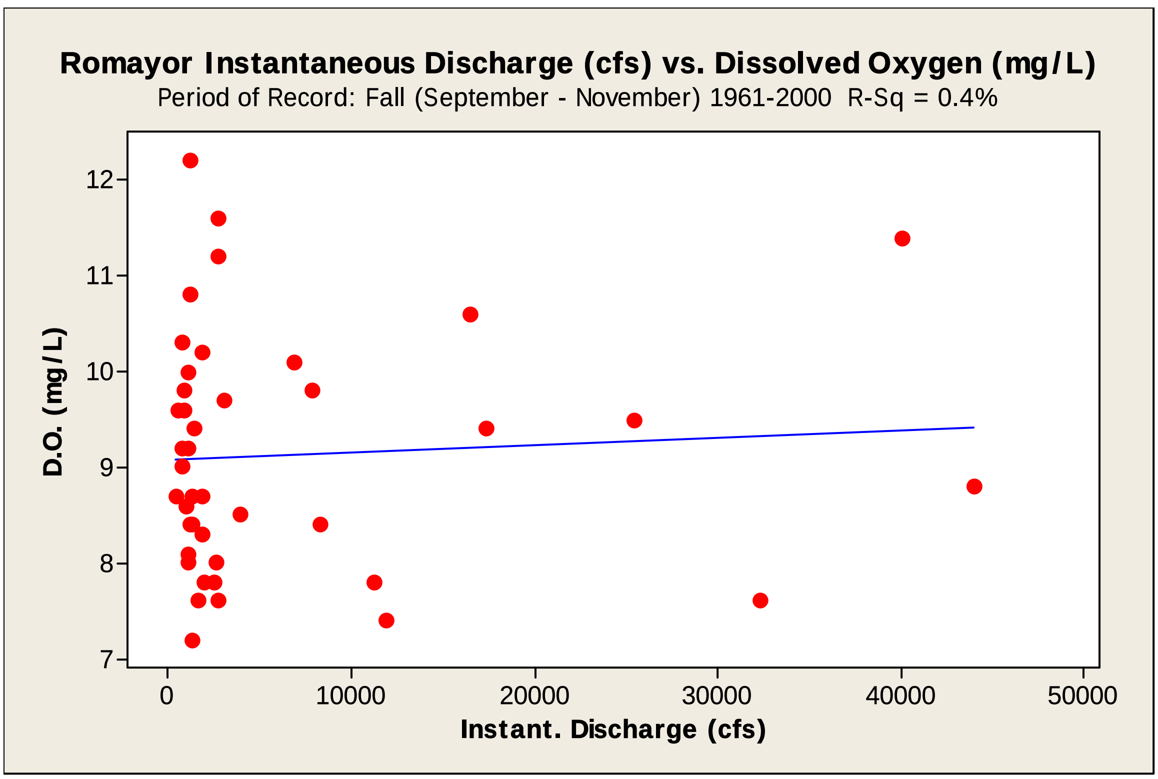


Figure 120. Flow versus fall dissolved oxygen at the Trinity River at Romayor 08066500 gage during 1961 through 2000.

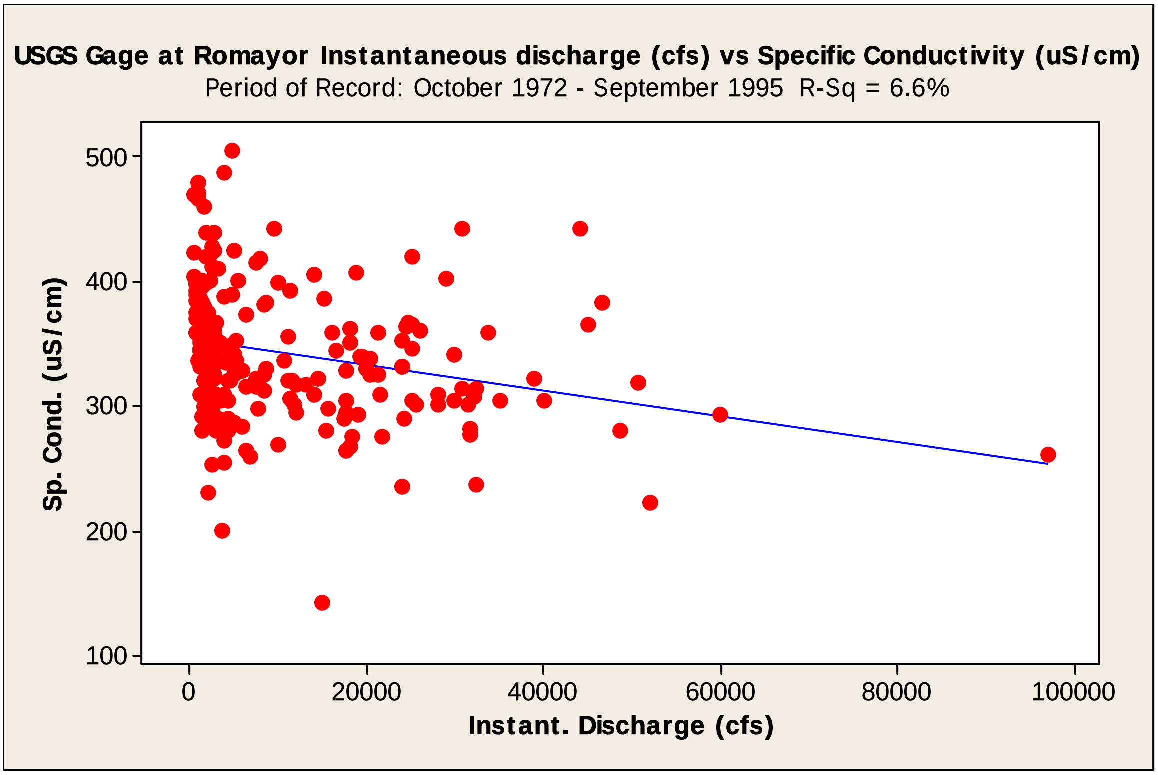


Figure 121. Flow versus specific conductance at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

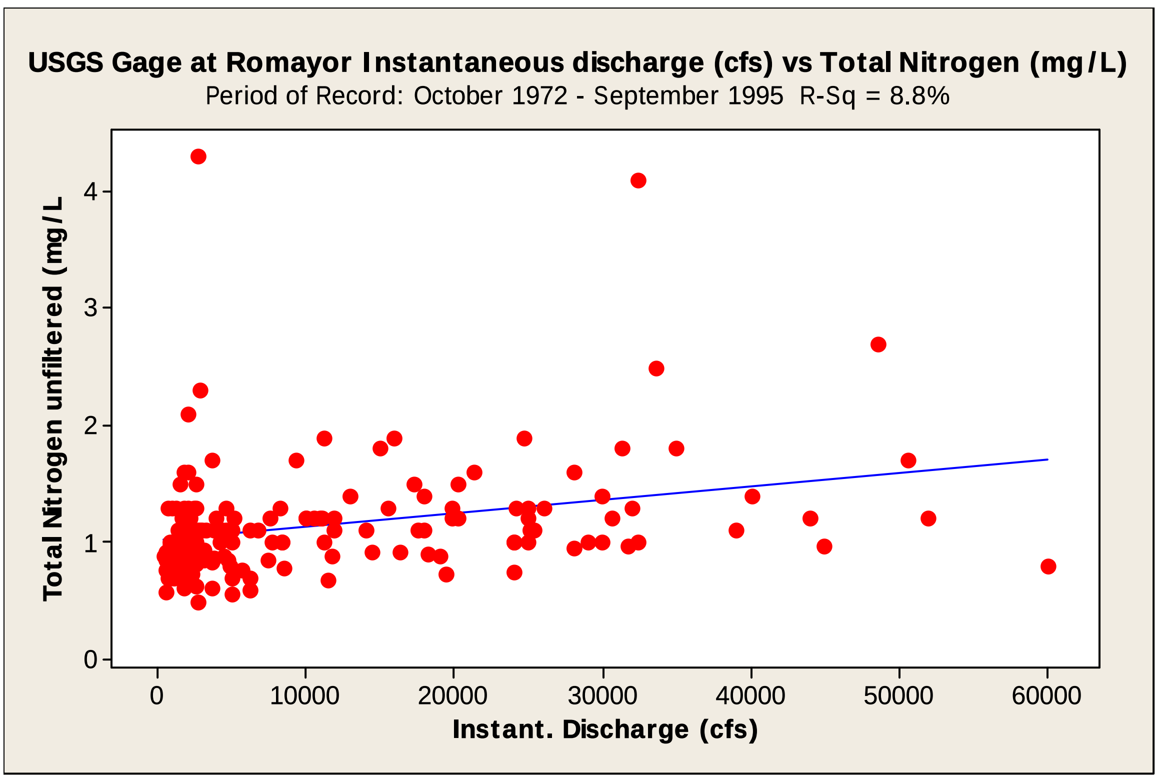


Figure 122. Flow versus specific conductance at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

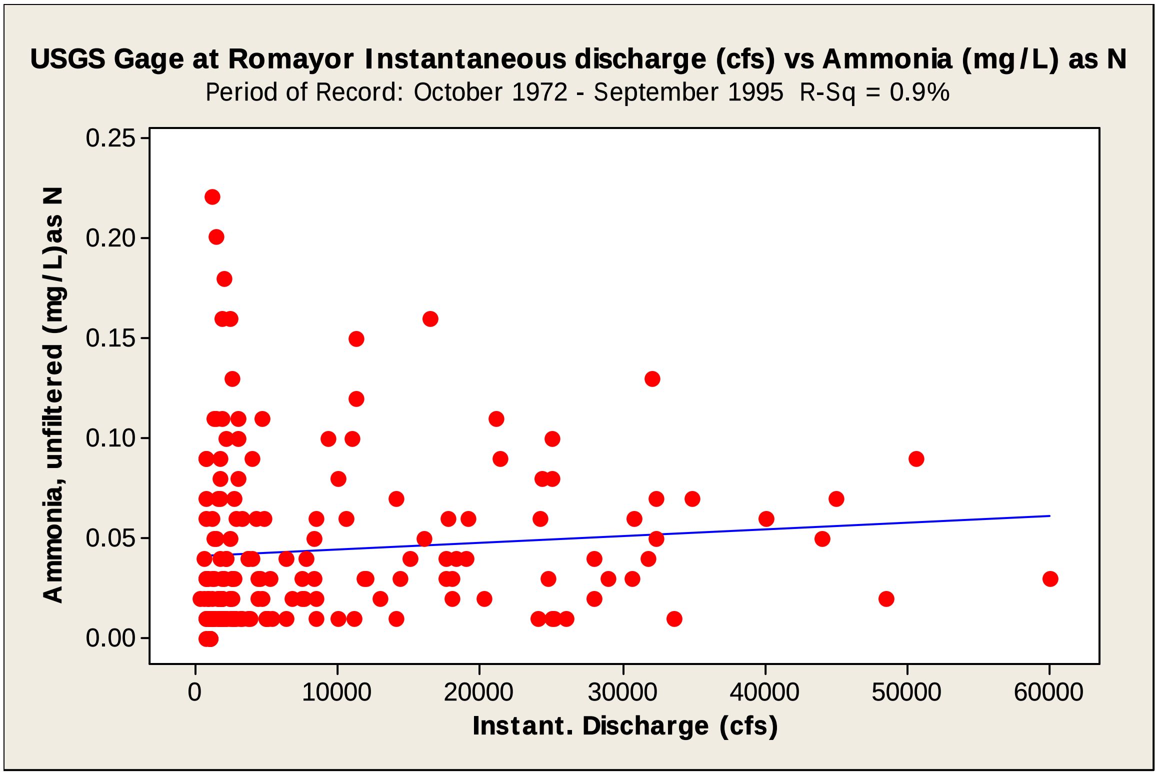


Figure 123. Flow versus ammonia nitrogen at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

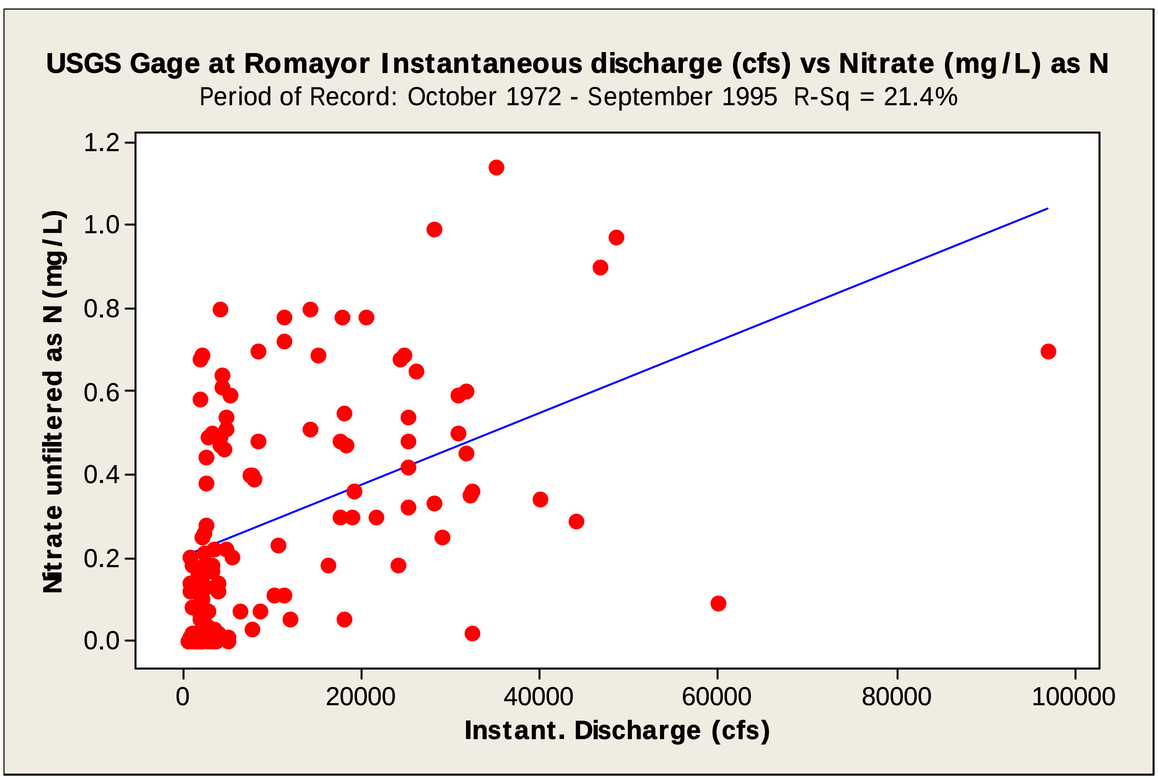


Figure 124. Flow versus nitrate nitrogen at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

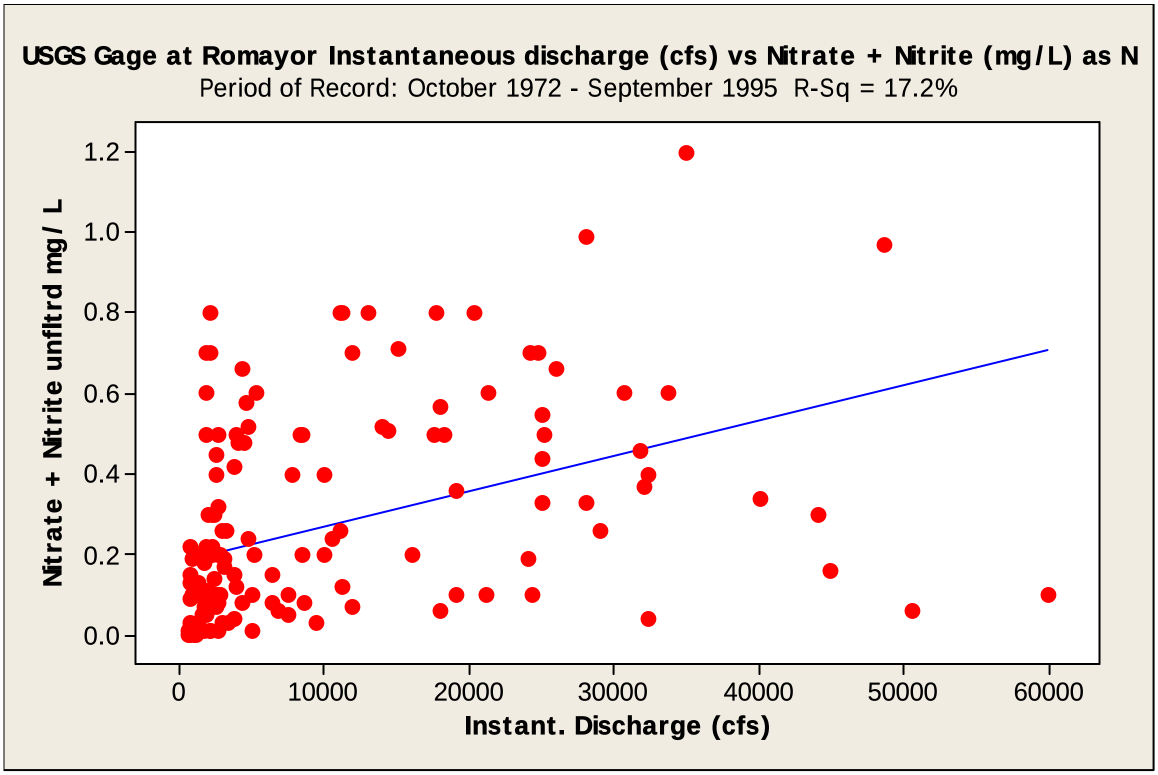


Figure 125. Flow versus nitrate+nitrite nitrogen at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

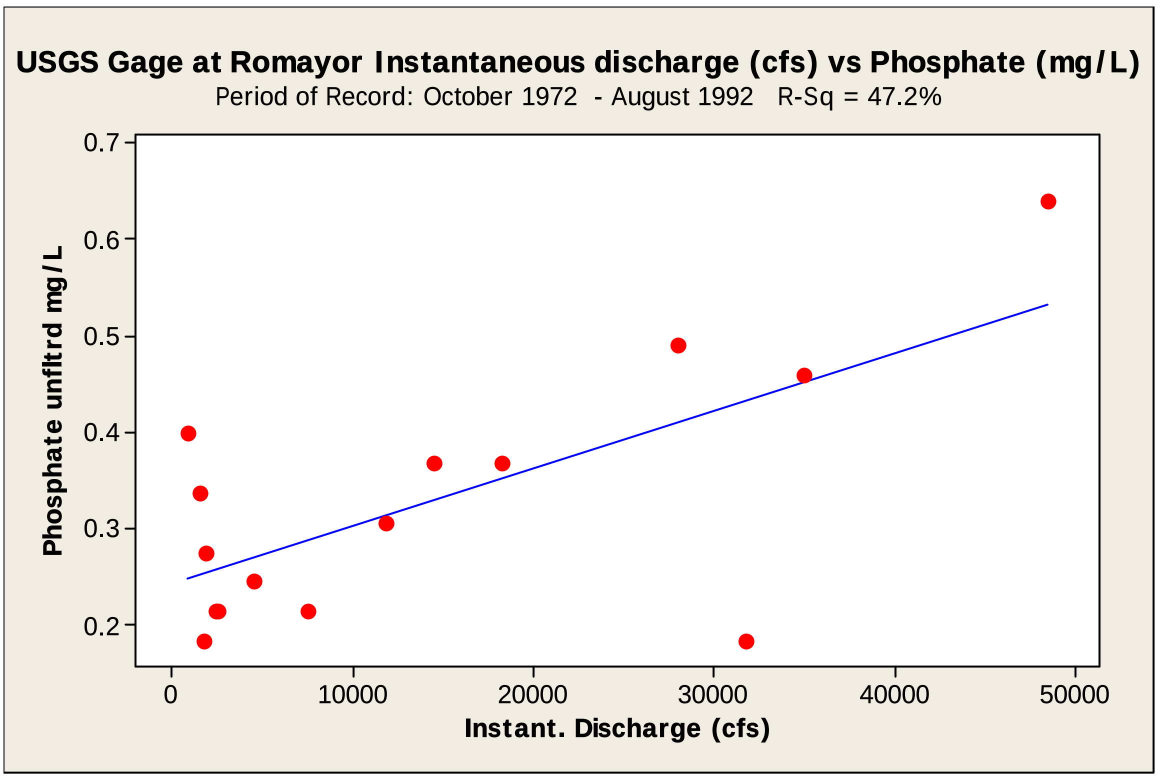


Figure 126. Flow versus phosphate at the Trinity River at Romayor 08066500 gage during 1972 through 1992.

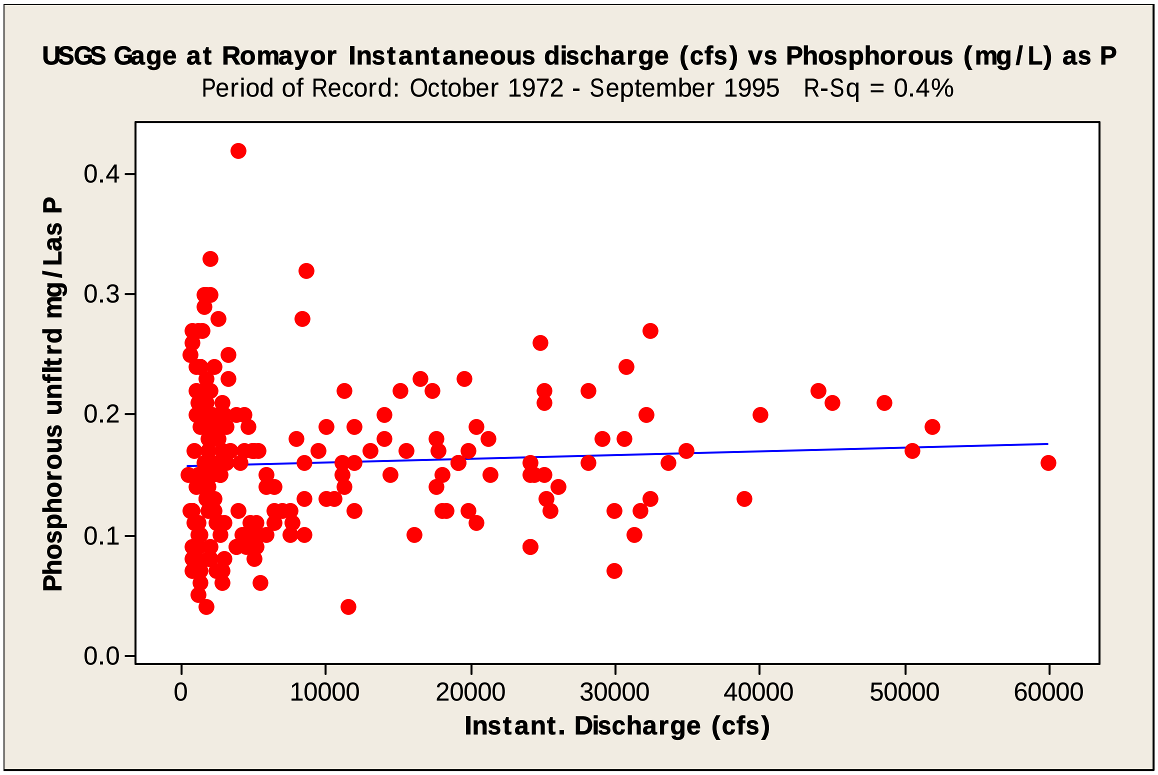


Figure 127. Flow versus phosphorus at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

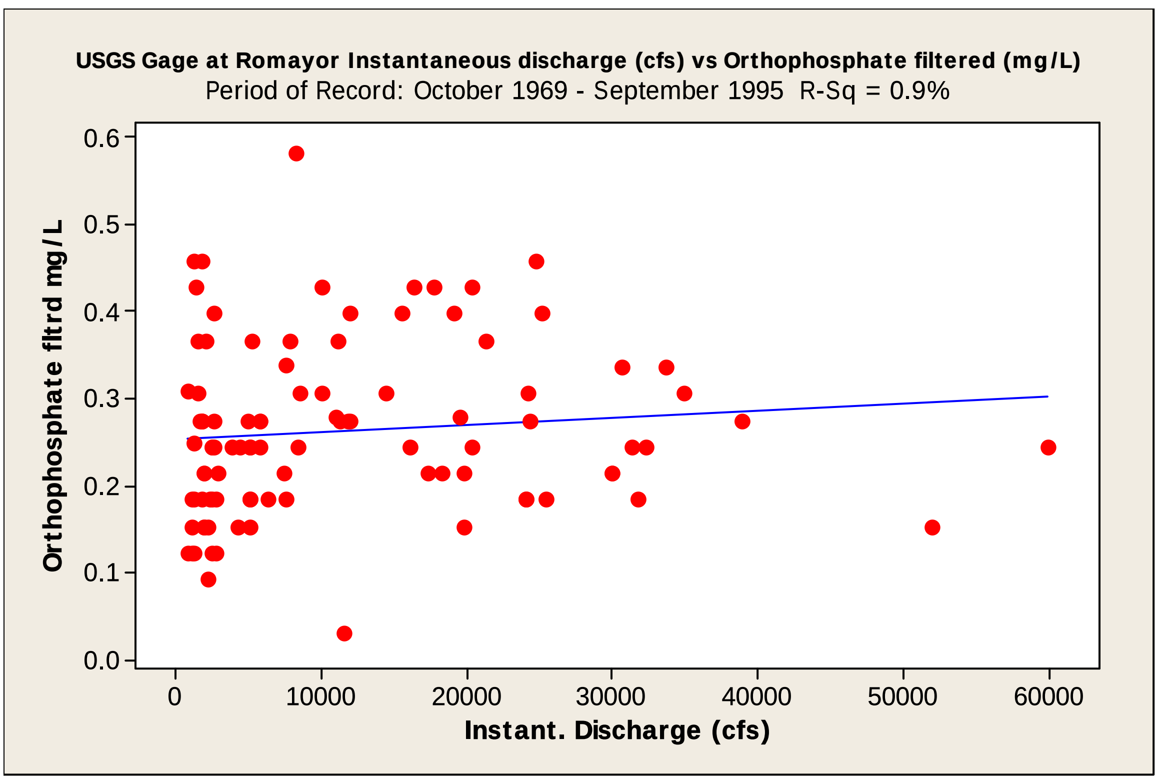


Figure 128. Flow versus orthophosphate at the Trinity River at Romayor 08066500 gage during 1969 through 1995.

Loading estimates for total nitrogen and phosphorus were best fit by a log-log regression model (Figures 129 and 130). By comparing these estimates to those previously generated for the upstream Crockett gage we can easily observe that comparable flow rates below Lake Livingston produced lower loading rates (Figures 106, 108, 129 and 130). For example at 1,000 cfs total nitrogen loads were 12,340 and approximately 2,000 kg/d respectively (Figures 106 and 129). At higher flow rates such as 14,600 cfs we see values decline from approximately 57,000 kg/d to 37,600 kg/d total nitrogen. Similarly at 15,000 cfs maximum total phosphorus levels at the Crockett gage were approximately 18,000 kg/d in contrast to only 6446 kg/d at the downstream Romayor gage. Although there are contributing tributaries between the two gages, these data indicate that Lake Livingston is likely reducing the downstream transport of nutrients to Galveston Bay. USGS data on TSS at the gage sites were limited above and below Lake Livingston. We therefore utilized historical TCEQ data. We observed a general downstream decline in total suspended solids (TSS) within the Trinity River basin (Figures 131 and 132). In general TSS declined downstream from the upper Trinity River (segment 0805) and was lowest downstream of Lake Livingston (0802).

Past Studies – Water Quality

In addition to the historical water quality data obtained from USGS priority gage sites and the TCEQ/CRP water quality monitoring network we also reviewed available studies that were compiled as part of the EIH Trinity River literature review. This included both peer reviewed articles and agency reports. We have plotted the location of these studies on Figure 132. Although there have been numerous studies on water quality and geomorphology in the basin, many are limited to specific issues or projects such as a receiving water assessments aimed at meeting a regulatory requirement, and therefore have limited system wide application. In addition, some studies focused on specific problems that are unlikely to be influenced by instream flow recommendations and/or cannot be significantly influenced or managed by manipulation of flow regimes. This includes persistent organic and metals contaminations related to aerial deposition such as mercury or pesticides. Even though extensive data exists on these subjects we will not spend any time discussing them (Chief Engineers Office 2006; Land and Brown 1996; Twidwell 2000) It should be noted that some of these stressors may in some cases limit aquatic life and may represent a limiting factor on their population viability. Similarly, one of the most cited causes for water quality impairment in the Trinity River basin was violation of recreational use criteria, that is elevated indicator bacteria (Texas Commission on Environmental Quality (TCEQ) 2009). This criteria is for protection of human contact recreation and not aquatic life use. In addition, instream flow criteria development would not be influenced by this water quality standard. The causes of violation of indicator bacteria based standards are varied and complex and include improperly operated wastewater treatment systems, livestock, malfunctioning septic systems, and wildlife.

Based on our review the three water quality variables that are influenced by changes in hydrology and in turn can potentially affect instream and downstream estuarine biological communities, or basin geomorphology are dissolved oxygen, nutrients and sediments. The lack of sediment supply due to dam construction, water diversion, and sea-level rise is a serious problem in some areas, leading to loss of wetlands ((Boesch et al. 1994). Since very few studies have found organisms with a need or even a preference for increased suspended sediment or sedimentation in the field or laboratory we will concentrate our data presentation and analysis on the effects of decreases in sediment supply to estuaries and watersheds (Berry et al. 2003; Newcombe and MacDonald 1991).

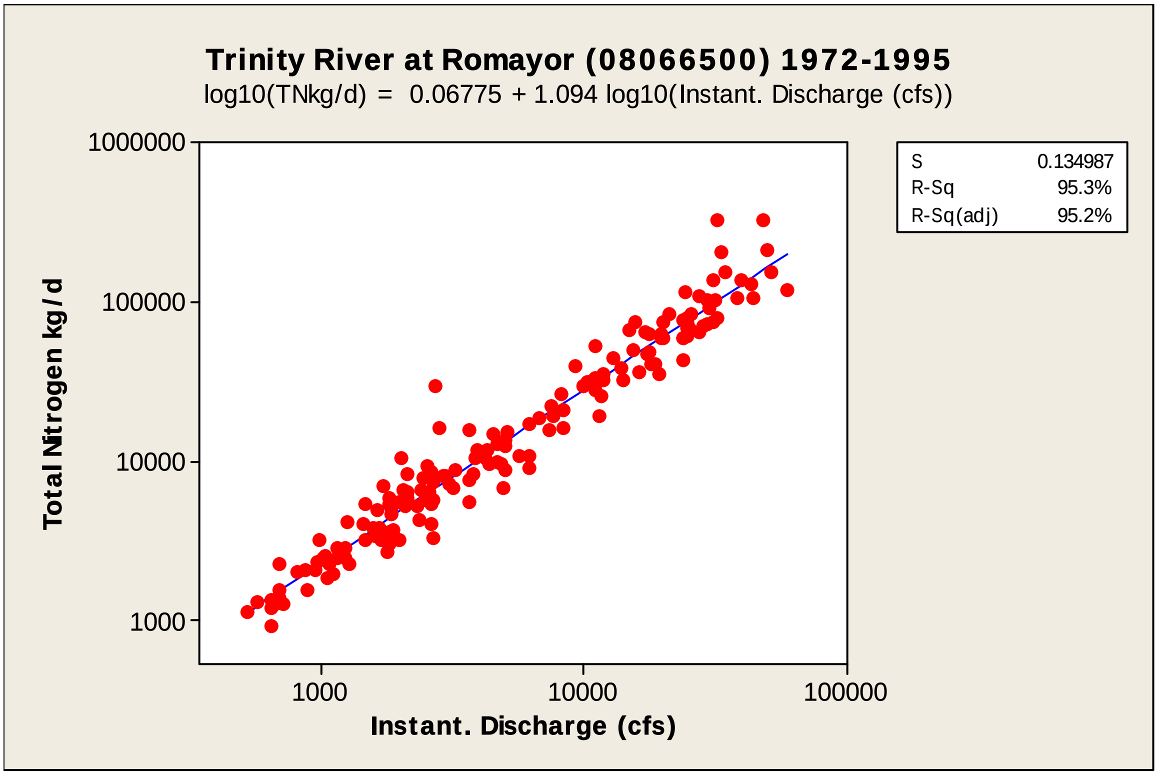


Figure 129. Flow versus total nitrogen loading at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

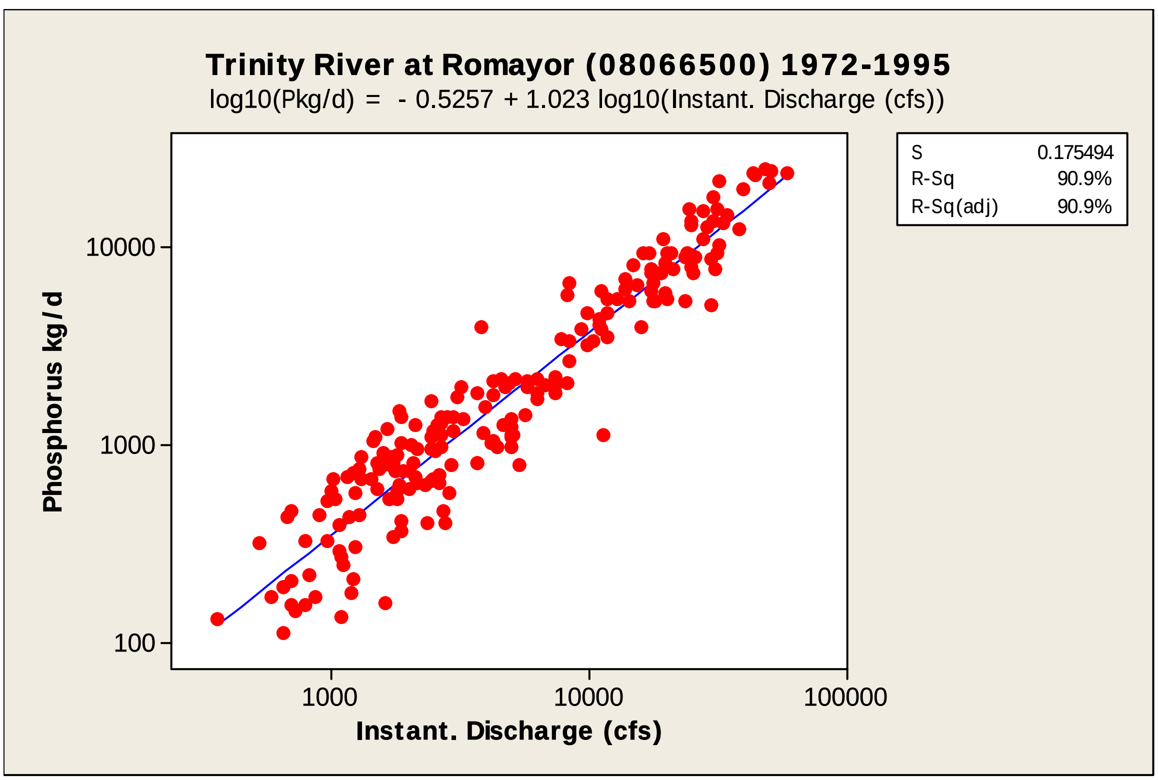


Figure 130. Flow versus total nitrogen loading at the Trinity River at Romayor 08066500 gage during 1972 through 1995.

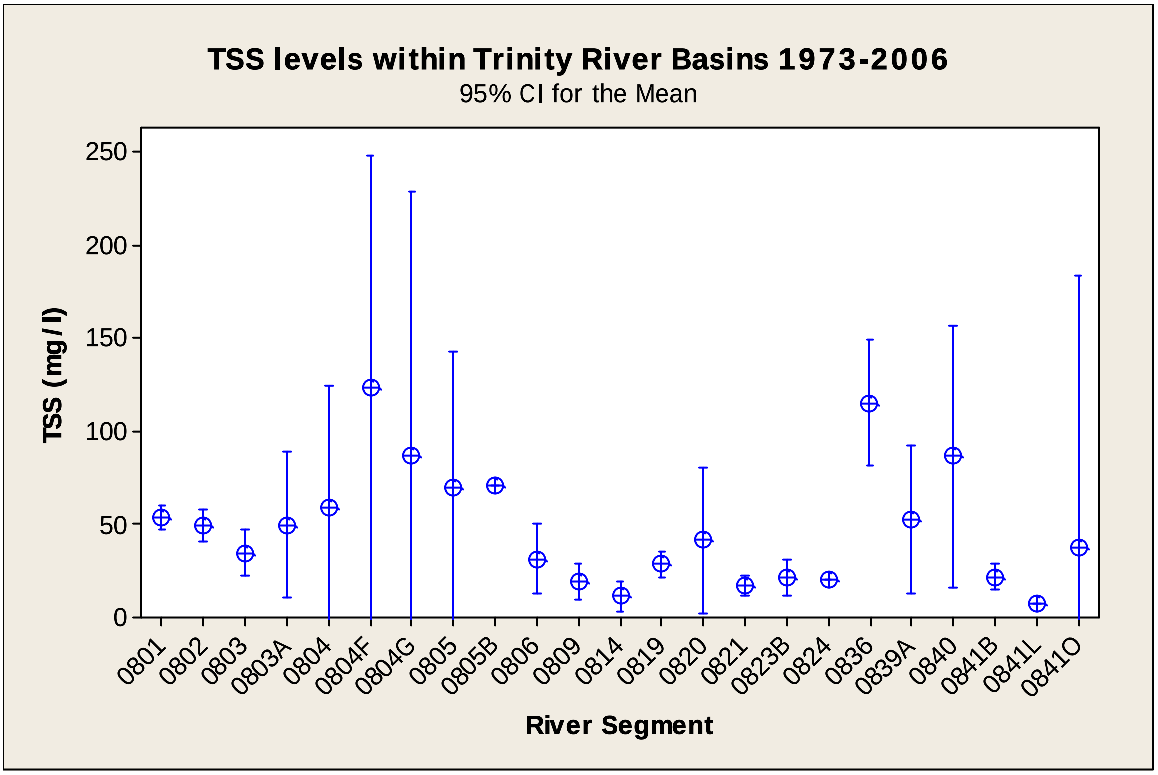


Figure 131. Historical mean and 95% confidence intervals of TSS levels in the Trinity River Basin (source: TCEQ SWQM database; Figure 2).

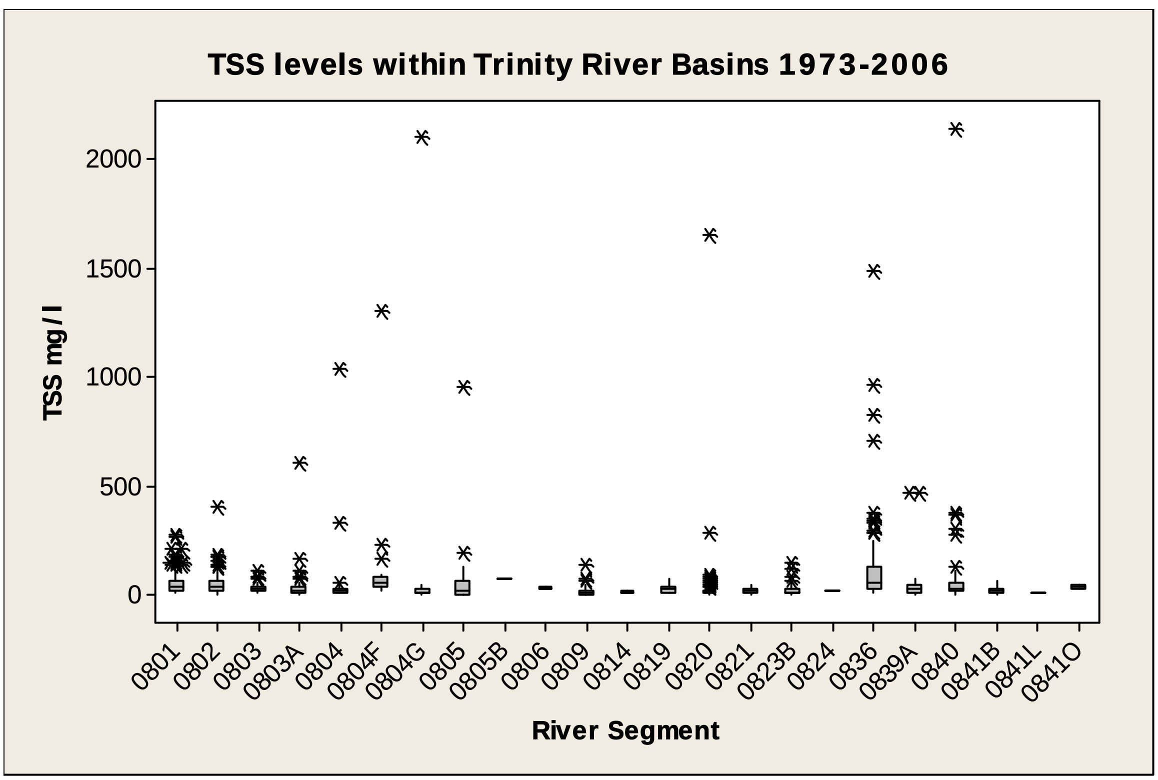


Figure 132. Boxplot depicting historical median and quartiles of TSS levels in the Trinity River Basin (source: TCEQ SWQM database, Map of segments = Figure 2).

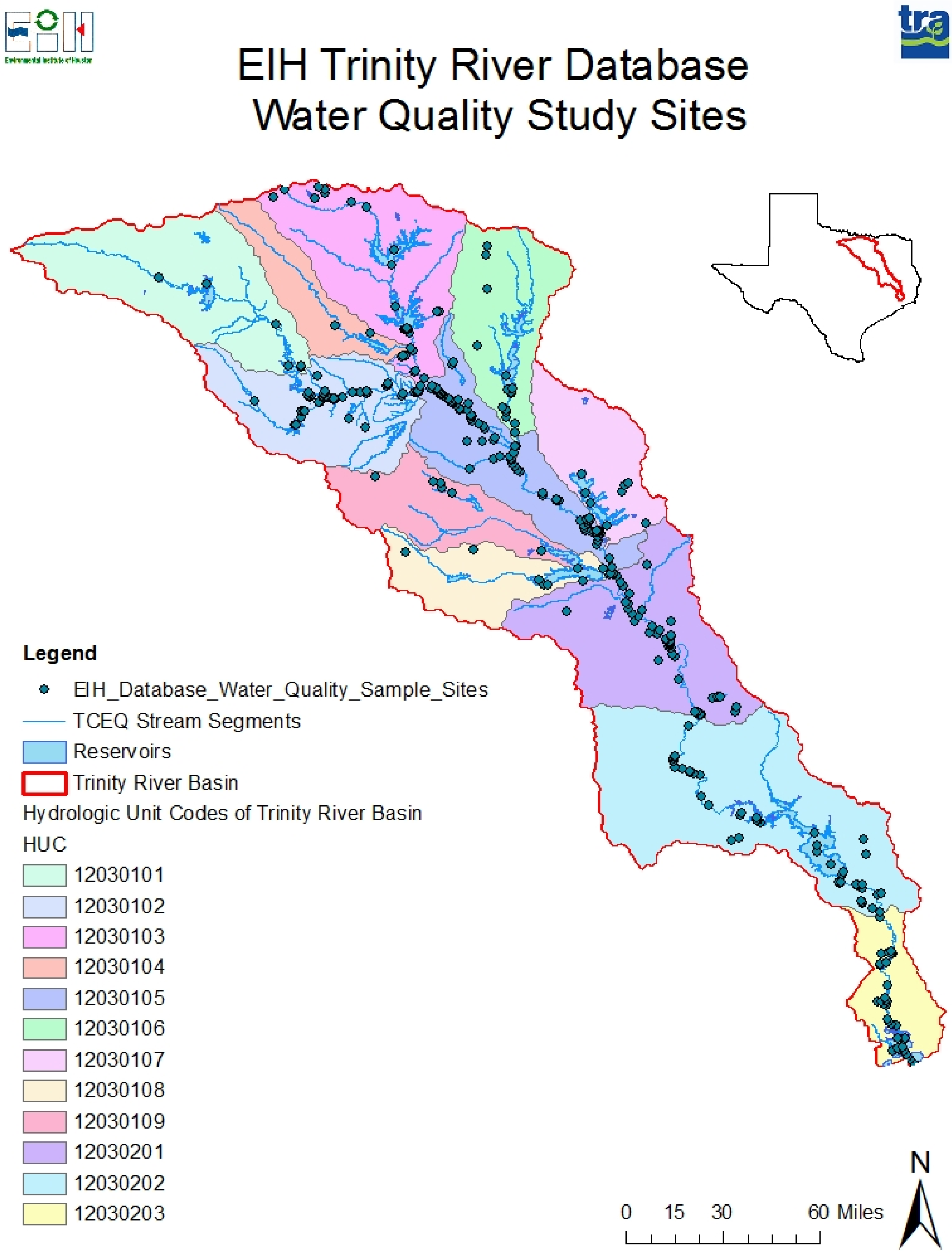


Figure 133. Location of water quality studies historically conducted within the Trinity River basin.

Suspended solids and associated turbidity is quite variable (means levels 125 to <25) within the Trinity Basin but is generally elevated compared to many other streams in the state. The State of Texas does not currently have a numerical turbidity standard for protection of aquatic life. It is highly unlikely though that severe adverse affects would occur to native fish present in the Trinity River under the existing range of turbidity reported. Many warmwater fish species are considered tolerant or adapted to naturally high turbidity levels (Waters 1995). The current species assemblage in the Trinity River has a long evolutionary history in the basin and is probably adapted to the elevated turbidity.

We will first deal with water quality issues affecting instream aquatic communities. The major water quality concern facing aquatic organisms in the mainstem Trinity River and upper tributaries historically has been hypoxia and/or anoxia. In 1925, the Trinity River in the Dallas-Fort Worth area was characterized by the Texas Department of Health as a "mythological river of death."(Browning 1991; Land et al. 1998) With a rapid expansion of industry and population and only primary wastewater treatment beginning in the late 1920s and secondary treatment in the mid-1930s, water-quality conditions in the area were degraded. Conditions did not substantially improve until State and Federal pollution control laws beginning in the early 1970s stimulated efforts to address poor water-quality conditions. For example, The Upper Trinity River Basin Comprehensive Sewage Plan of 1971 resulted in the construction of large, regional wastewater-treatment plants, elimination of many small, industrial and municipal wastewater-treatment plants, and the upgrading of existing wastewater-treatment plants. Advanced wastewater-treatment processes that include nitrification (conversion of ammonia nitrogen to nitrate) were implemented at the new large wastewater-treatment plants that discharge into the Trinity River in the Dallas-Fort Worth area in the late 1980s (Dickson et al. 1991; Land et al. 1998). Large concentrations of ammonia are toxic to fish and other aquatic organisms. Ammonia levels in the Trinity River downstream from Dallas exceeded the TCEQ criterion for dissolved ammonia in freshwater streams and reservoirs (1.0 milligram per liter) consistently until the late 1980s (Land et al. 1998). Since then, the nitrification process used in wastewater-treatment plants has reduced the amount of ammonia nitrogen that is discharged to the river.

During the period between 1970 and 1985, a total of 13 fish kills were documented in the Trinity River from a reach just downstream from Dallas to Lake Livingston in the lower part of the Trinity River Basin (Davis 1987; Dickson et al. 1991; Land et al. 1998). The magnitude and frequency of the fish kills resulted in a depleted fish community, particularly in the reach of the Trinity River immediately downstream from Dallas. An estimated 1.04 million fish died in these 13 kills. Twelve of the 13 fish kills were associated with minor flooding on the Trinity River from rainfall in the Dallas-Fort Worth metropolitan area. According to the Texas Parks and Wildlife Department (TPWD), the probable cause of the kills was the resuspension of bottom sediments and associated organic material during floods that caused an increase in biochemical oxygen demand and a corresponding rapid drop in dissolved oxygen (Davis 1987). Ironically, improvements in water quality during the 1970s set the stage for the fish kills by allowing appreciable fish populations to live in this reach of the Trinity River. Dissolved oxygen, measured as milligrams of oxygen per liter of water, has increased from lows of near zero in the early 1970s to highs of more than 10 milligrams per liter in 1996 (Land et al. 1998) . Notable improvement in dissolved oxygen concentrations in the Trinity River downstream from Dallas began in the mid 1970s and continued through the 1980s and into the 1990s (Schertz et al. 1994). Dissolved oxygen was consistently recorded above the state dissolved oxygen criterion for the support of aquatic life (5.0 milligrams per liter) beginning in the late 1980s. The improvement in dissolved oxygen concentrations is attributable to improvements in wastewater-treatment practices and the corresponding reduction in the discharge of oxygen-demanding materials from wastewater-treatment plants and industry (Dickson et al. 1991).

As early as 1957, TPWD biologists had documented polluted water in the areas below Fort Worth to Trinidad suffered from pollution (Lamb 1957a; Lamb 1957b). In addition, TPWD biologists were responding to fish kills in the West Fork of the Trinity caused by sewage bypasses (Lamb 1957b). (Lamb 1960) describes fish kills caused by “black-rises”. He describes this as an event that residents below Dallas are very familiar with and occurs when rains scour out the accumulation of organic debris that is deposited in the river during periods of low water. When flow is increased this material is resuspended and moves down the river at high concentrations and kills fish. (Lamb 1961) and (Lamb 1962a) further described numerous sewage bypasses causing fish kills downstream of Fort Worth in the Trinity River during 1960-1961. He noted that the heavier than normal rainfall experienced by the Trinity River watershed in 1961-1962 tended to prevent the usual fish kills on the West Fork of the Trinity in Fort Worth (Lamb 1962b). He further reports that by 1963, “the sewage pollution in the West Fork of the Trinity River, in Fort Wort, has continued, but the fish population has been decimated by previous pollutions and it is believed that few fish remain to be killed”(Lamb and Smith 1964). Water quality surveys conducted by the USGS in 1967 revealed poor water quality in the upper Trinity River associated with sewage discharges (Leifeste and Hughes 1967). They cited a 1958-1960 Texas Department of Health Survey which suggested the poor water quality is due to inadequate collection and treatment of sewage and industrial wastes.

As a result of persistent anoxia and hypoxia, the fish community in the Trinity River immediately downstream from Dallas was almost nonexistent in the early 1970s (Land et al. 1998; TPWD 1974). Only four species of fish were collected by the TPWD during 1972-74. They include smallmouth buffalo, gizzard shad, common carp, and yellow bass. Four of the six surveys yielded no fish from this reach of the river. Two of the species, gizzard shad and common carp, generally are classified as tolerant taxa and could be expected to tolerate the water-quality conditions in this reach in the 1970s. Further downstream beyond the confluence with the East Fork of the Trinity conditions were more favorable in areas with increased dissolved oxygen and numbers of fish species ranged between 4 to 13 species per collection (Smith 1974). Dissolved oxygen levels began to increase in the mid 1970s (Schertz et al. 1994). Segments of the Trinity River in this section which supported only limited numbers of certain fish species had greatly improved by late 1974 (Smith 1974). Further downstream near the headwaters of Lake Livingston during this same time period the number of fish species collected had increased to 16 to 22 (Provine 1974).

Within twenty years, the fish community in a reach of the Trinity River downstream from Dallas had markedly improved. Improvement was most evident in the number of fish caught and the number of species, including those that are not tolerant of polluted water. The TPWD collected 11 species of fish from this reach in 1987 (Kleinsasser and Linam 1989; Land et al. 1998). Although the 1987 survey yielded more species than the 1972-74 surveys, the TPWD still considered the species richness low and attributed the condition to the fishes' exposure to ammonia nitrogen and heavy metal toxicity associated with wastewater-treatment plant effluents (Davis 1991; Kleinsasser and Linam 1989).

The USGS conducted fish-community surveys on the reach at Trinity River downstream from Dallas during 1993-95 (Land et al. 1998). The methods used by the USGS were identical to the methods used by the TPWD in 1987. A cumulative total of 25 species of fish were collected in this reach during the 3-year period. Several game species were collected including largemouth bass, white crappie, and white bass. None of these game species were collected in the reach during the 1972-74 or 1987 surveys. Two darter species, bigscale logperch and slough darter, also were collected. The presence of these indigenous species suggests a return of this reach to a more natural condition. Other species characteristic of warm-water southeastern streams including alligator, spotted, and longnose gars and flathead, blue, and channel catfish were frequently collected during the 1993-95 survey. None of the gar or catfish species were reported in the reach downstream from Dallas in the 1972-74 or 1987 TPWD surveys. The change since 1972-74 is a likely consequence of improvements in water quality, particularly improvements in the quality of discharges from wastewater-treatment plants in the Dallas-Fort Worth area (Schertz et al. 1994).

Based on USGS surveys nutrient levels remained unchanged in Trinity River Basin streams between 1974 and 1991 (Land et al. 1998; Van Metre and Reutter 1995). Water-quality trends were evaluated for about 4,800 samples from streams. Concentrations of total nitrogen and phosphorous have not changed significantly from 1974 to 1991 at most sites, although there was a decrease in phosphorous concentrations near Dallas. Spatial variations in chemical concentration in streams are related primarily to point sources and reservoirs. The largest nutrient concentrations occur downstream from Dallas, where streamflow is dominated by treated wastewater. The smallest concentrations occur just downstream from reservoirs, which act as sinks for nutrients. The median concentrations for total nitrogen and total phosphorus for most of the Trinity River below Dallas and below Lake Livingston was 6.0 and 1.3 mg/l N, and 1.6 and 0.1 mg/l P, respectively (Van Metre and Reutter 1995). There continued to be a lack of temporal trends during the period from 1993 to 2003 for nitrates as measured at the Crockett 08065350 gage located above Lake Livingston (Sprague et al. 1009). The State of Texas currently does not have nutrient criteria for rivers and streams. Only narrative criteria are provided, which states "Nutrients from permitted discharges or other controllable sources shall not cause excessive growth of aquatic vegetation which impairs an existing, attainable, or designated use"(TNRCC 2000). The EPA has provided technical guidance on development of appropriate numerical criteria based on regional index sites and streams (EPA 2000). The recommended criteria for he variables we have discussed for the Trinity River are 0.067 mg/l NO_2+NO_3, 0.385-0.507 mg/l TN and 50 ug/l TP. Most of the values we have observed and have been reported in the literature for the Trinity River are above these recommended criteria. It should be noted however that the range of values used to derive these criteria bracket the values observed in the historical record and are quite variable.

Past Studies – Nutrient and Sediment Loading to Galveston Bay

Rivers are major sources of dissolved and suspended nutrients and solids to estuaries in the Gulf of Mexico (Bianchi et al. 1999). Since stream velocity affects the ability to transport sediment, any future management of streamflows could theoretically affect the downstream transport of nutrients and sediments. This has major implications for stream geomorphology and the deltaic environment of the Trinity River. In addition, changes in nutrient inputs into the estuary can change potential primary production within the estuary. Therefore it is necessary to quantify the current and potential loadings associated with changes in streamflow. In addition, since the Trinity River has a major reservoir and dam located (Lake Livingston) near the coast the ability to transport sediments and nutrients has been likely altered based on past studies and data presented in this report. As previously mentioned the median concentrations for total nitrogen and total phosphorus for most of the Trinity River below Dallas and the Trinity River below

Lake Livingston was 6.0 and 1.3 mg/l N, and 1.6 and 0.1 mg/l P, respectively (Van Metre and Reutter 1995). This suggests nutrient levels are reduced as they pass through reservoirs. They specifically estimated loads for three time periods which are presented below in Table 10. The largest reductions occurred in total phosphorus. A focus of their study was to evaluate the influence of Lake Livingston on the downstream transport of phosphorus, nitrogen and suspended solids. They found that all nutrients were generally reduced (Van Metre and Reutter 1995)(Figure 134). The difference in loads observed between these two sites can be attributed to trapping of sediments in Livingston Reservoir. The largest differences in annual suspended sediment loads generally occurred during years of greatest discharge (Figure 134).

Table 10. Mean nutrient loads and mean daily discharge for five priority gage sites in Trinity River Basin estimated by (Van Metre and Reutter 1995).

USGS Gage ID	1974-1979		1984-1989		1974-1989		
	NO2+NO3kg/d	Mean Daily cfs	NO2+NO3kg/d	Mean Daily cfs	Total N kg/d	Total P kg/d	Mean Daily cfs
08049500 West Fork T. River	1,600	565	3,800	777	5,900	2,300	706
08062700 Trinity River @ Trinidad	3,700	2,683	25,100	3,213	32,600	9,800	3,037
08065000 Trinity River near Oakwood	9,000	3,278	Not Estimated	3,213		9,000	3,955
08065350 Trinity River near Crockett	15,800	5,544	24,200	5,579	36,900	10,200	6,038
08066550 Trinity River at Romayor	6,300	8,369	9,700	7,310	24,000	3,600	7,592

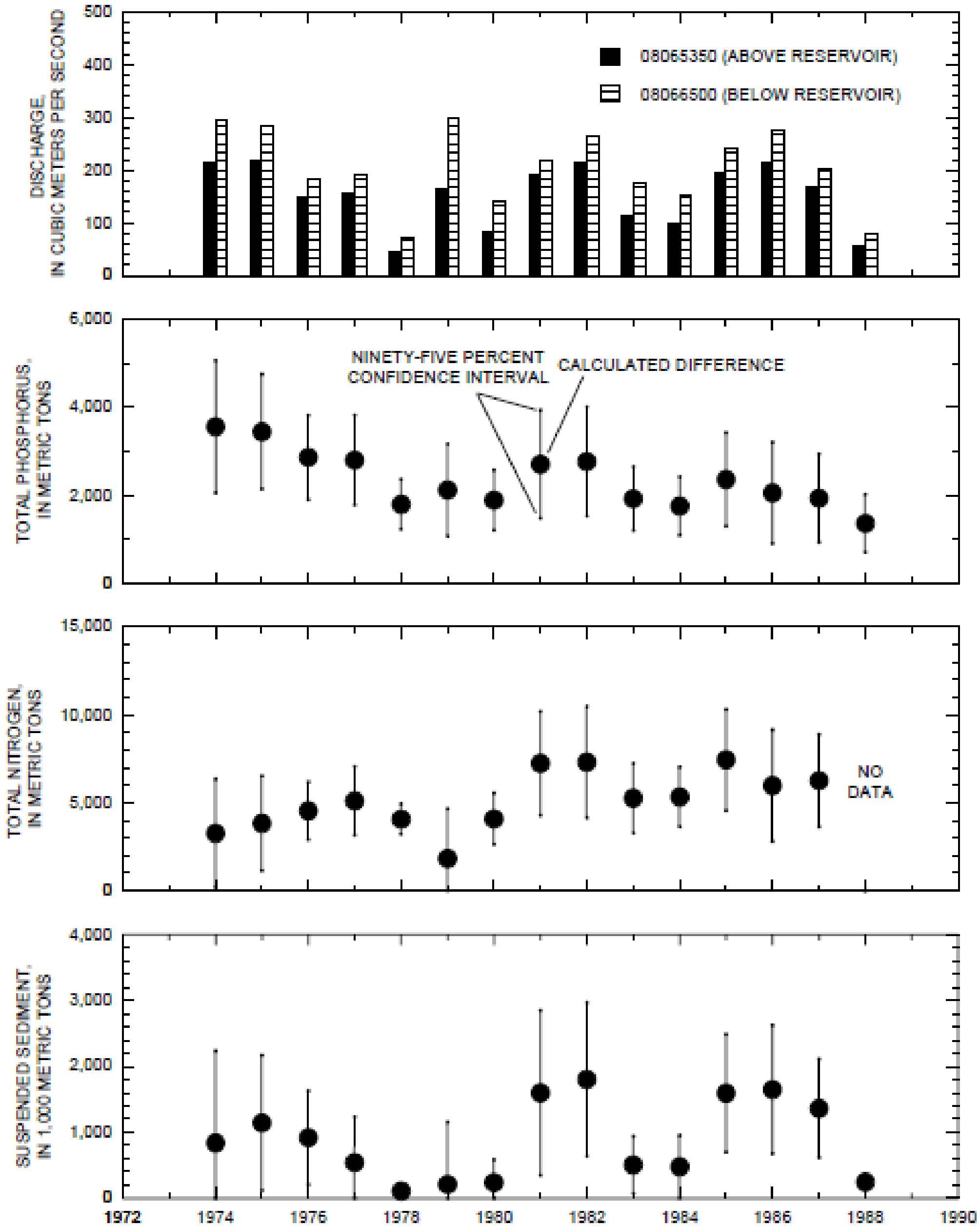


Figure 134. Discharge and difference in nitrogen, phosphorus and sediment loads for sites above and below Livingston Reservoir, 1974-88 (Load differences were calculated by subtracting the loads below Livingston Reservoir from the loads above Livingston Reservoir.) Reprinted from: (Van Metre and Reutter 1995).

(Jensen et al. 2003) reviewed various sources of data on loading into Galveston Bay and summarized pertinent information on the influence of Lake Livingston on nutrient loading (Figures 135-138). He found based on estimates presented in a paper he published in 1991 that the largest point source contribution of nitrogen to Galveston Bay is the Trinity River (Clingenpeel 2002; Jensen et al. 1991) (Figures 135-138). In addition, the construction of Lake Livingston in 1969 had an immediate effect on nitrogen loading to the basin along with enhanced wastewater treatment (Figure 135). He reported that based on Cligenpeel 2002 analysis, loading due to watershed runoff in the Lake separate from the Trinity River had a much greater influence during wet years (Figure 136). He also found, consistent with the TSS trends observed by USGS, that the highest percent reductions in nitrogen and phosphorus occurred during drier years (Jensen et al. 2003; Van Metre and Reutter 1995) (Figure 137). He also concluded that rates of reductions in phosphorus had declined similar to the previous USGS reports but was greatest during wet years suggesting a linkage between reductions in suspended solids and phosphorus (Clingenpeel 2002; Jensen et al. 2003; Van Metre and Reutter 1995)(Figure 138). (Armstrong and Ward Jr. 1993) also provided additional estimates of annual loading of TSS, total nitrogen and total phosphorus as part of an overall contaminants loading study of Galveston Bay (Figures 139-141). They found that Trinity River loads were often up to 10 times greater than any other tributary within the system. The Trinity River during 1968 to 1988 contributed 63, 65 and 58% of the tributary loads of TSS, TN and TP (Armstrong and Ward Jr. 1993). When compared to all sources including other tributaries, point source discharges within the local basin and non-point source runoff estimates in the local watershed, the Trinity River was the most dominant source of total suspended solids and total nitrogen (Armstrong and Ward Jr. 1993).

Past Studies – Sediment and Geomorphology

We had previously conducted a literature review which involved assembling recent and pertinent geomorphology studies within the Trinity River watershed (Figure 142). We examined these publications to evaluate pertinent information on important channel processes including additional studies on suspended sediment transport. From these studies we selected a few key studies that deal with important aspects of hydrology and sediment transport and channel formation.

(Slattery and Phillips 2007) recently conducted a study on the influence of Lake Livingston on the downstream transport and fluvial dynamics of sediment below the dam. Their research study focused on documenting the effects of the Lake Livingston dam on downstream sedimentation processes, in particular the delivery of sediment to the lower Trinity River, Trinity Bay estuary and Galveston bay. Some of the main objectives of that study included identifying the major sediment sources for the Trinity River delta and Trinity Bay, evaluate the effects of various human and natural controls on sediment transport and storage in the lower Trinity River, evaluating the effects of channel slope, flow, and water withdrawals from the Trinity River on sediment transport capacity in the lower River They conducted their study in part because there have been very few studies on the on the effects of the impoundment on the downstream tributaries. These tributaries have been noted for contributing significant inputs of energy (flow) and mass (sediment) to the mainstem system. Based on their analysis of stream discharge data in the lower Trinity basin they ruled out modifications in the discharge regime as a significant cause of change in lower river geomorphology.

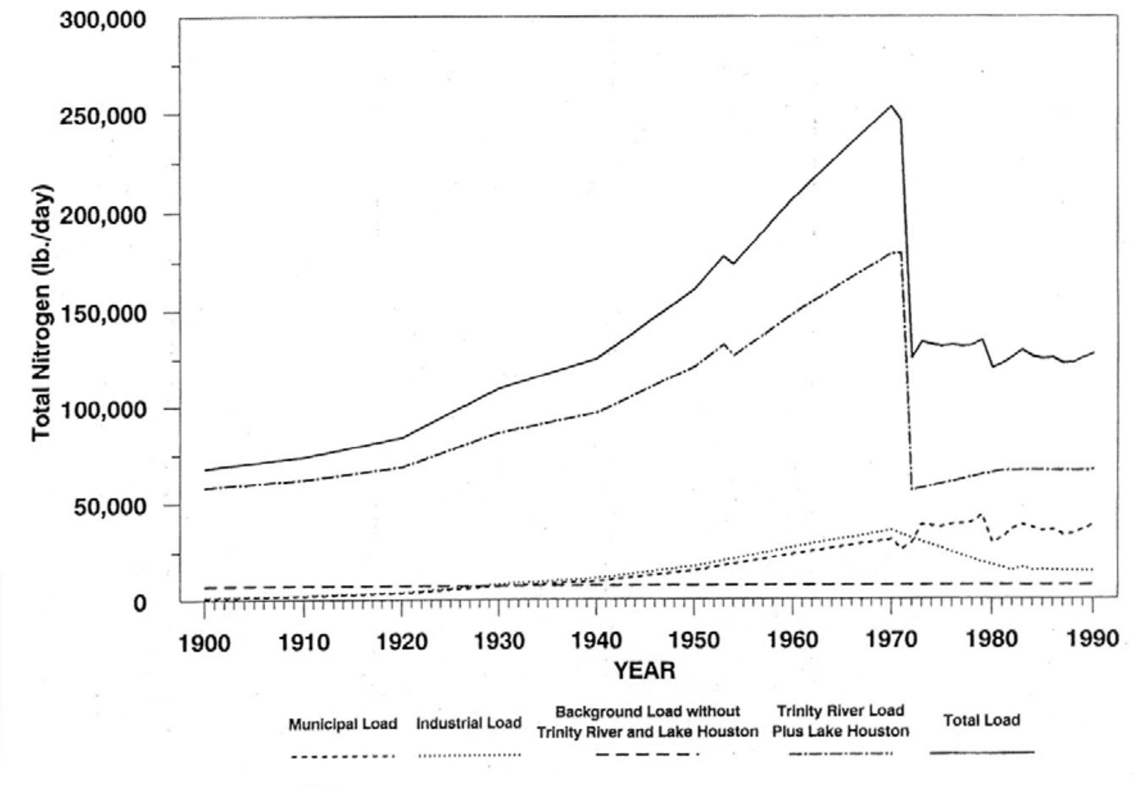


Figure 135. Historical Estimates of nitrogen loads. Source: (Jensen et al. 1991).

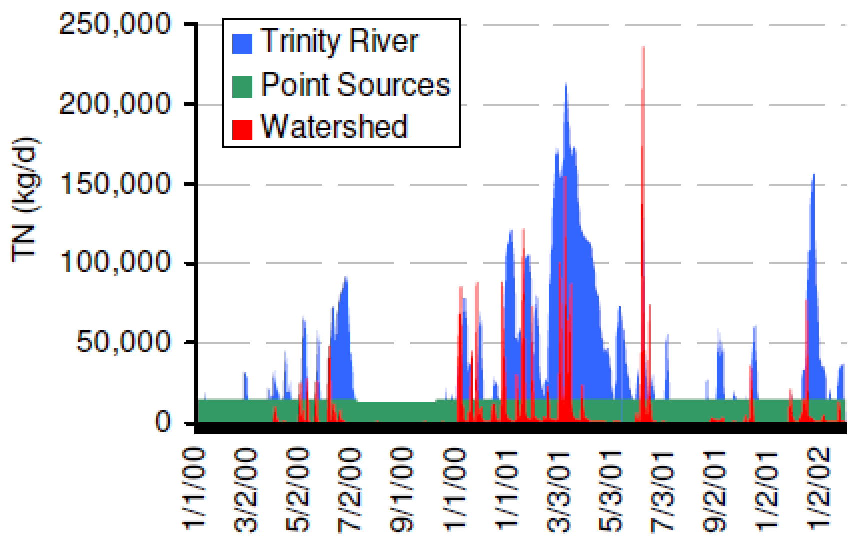


Figure 136. Total nitrogen loads estimated presented and cited by (Jensen et al. 2003). Original source: (Clingenpeel 2002)

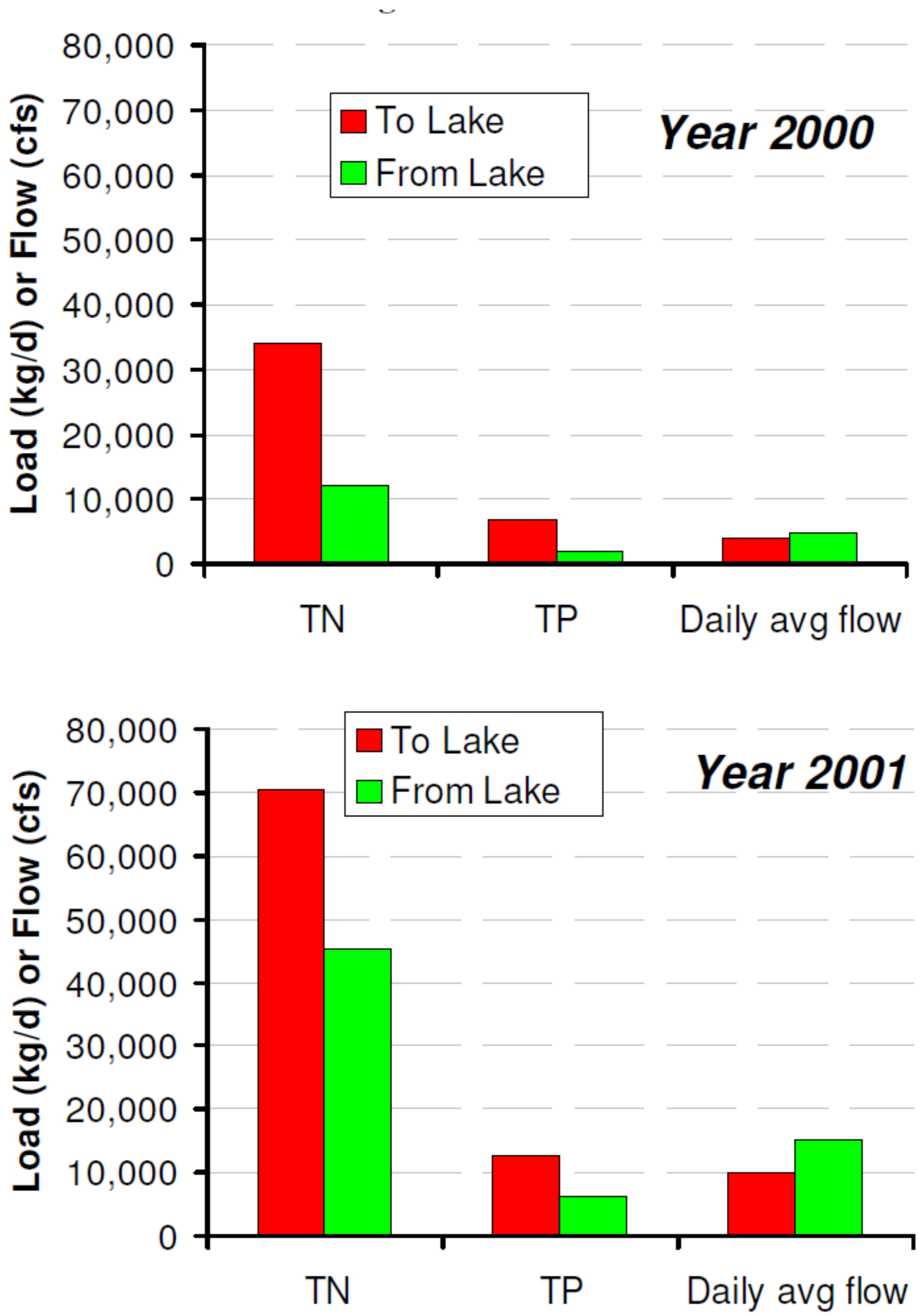


Figure 137. Average Daily Loads of total nitrogen and total phosphorus to and from Lake Livingston. From: (Jensen et al. 2003).

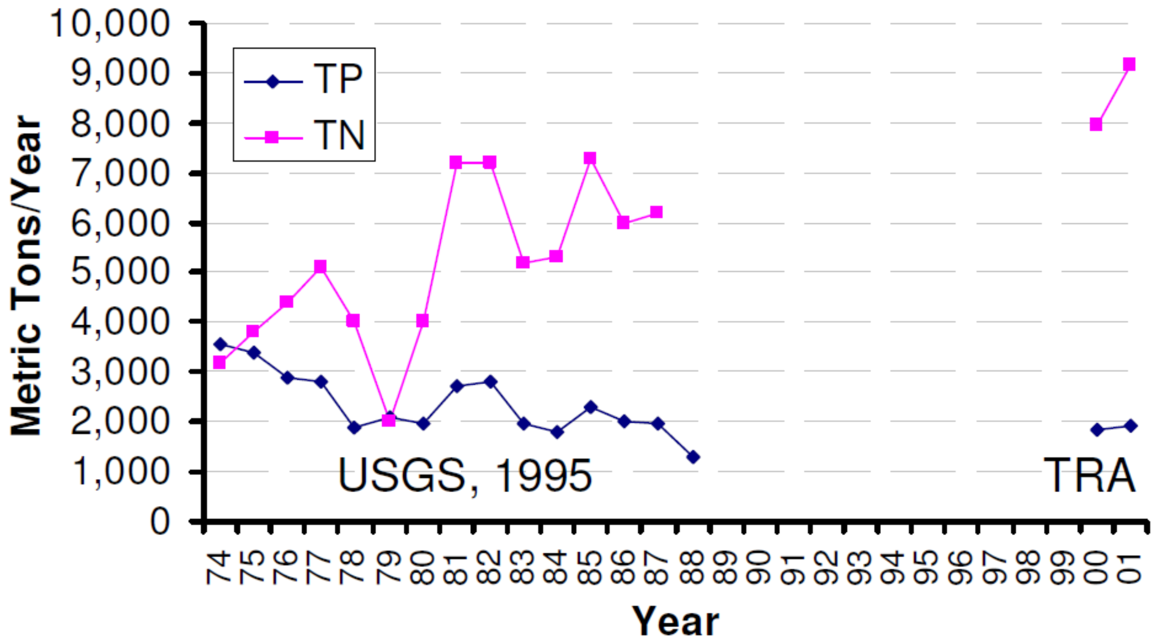


Figure 138. Comparisons between total nitrogen and phosphorus removal. Sources: (Clingenpeel 2002; Jensen et al. 2003)

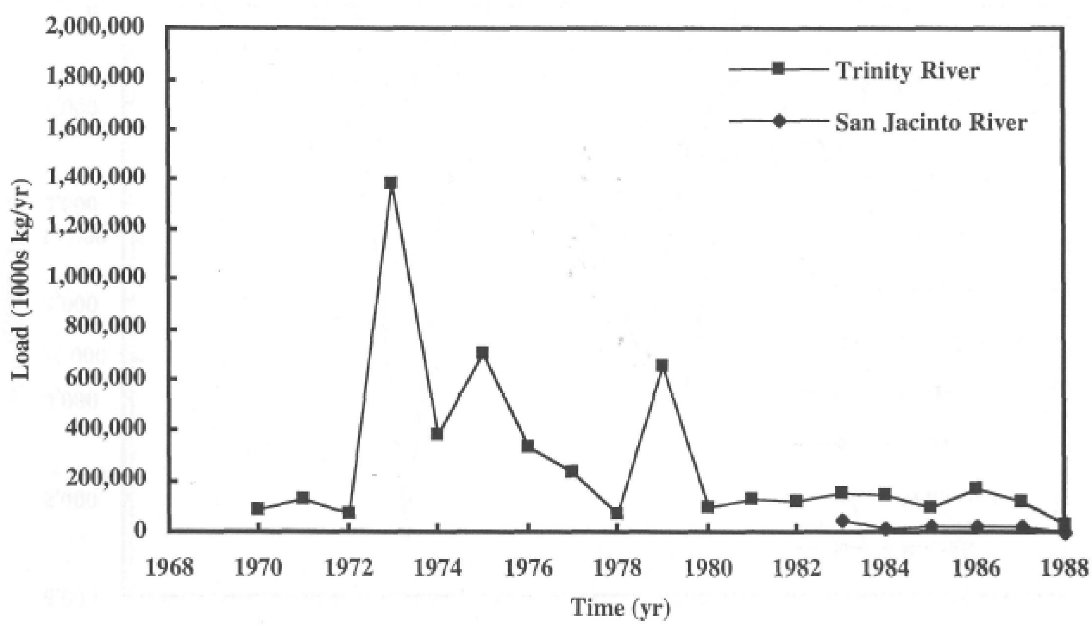


Figure 139. Estimated loads of total suspended solids into Galveston Bay from the Trinity River at Romayor and from the San Jacinto River from 1969 through 1988. Source: (Armstrong and Ward Jr. 1993)

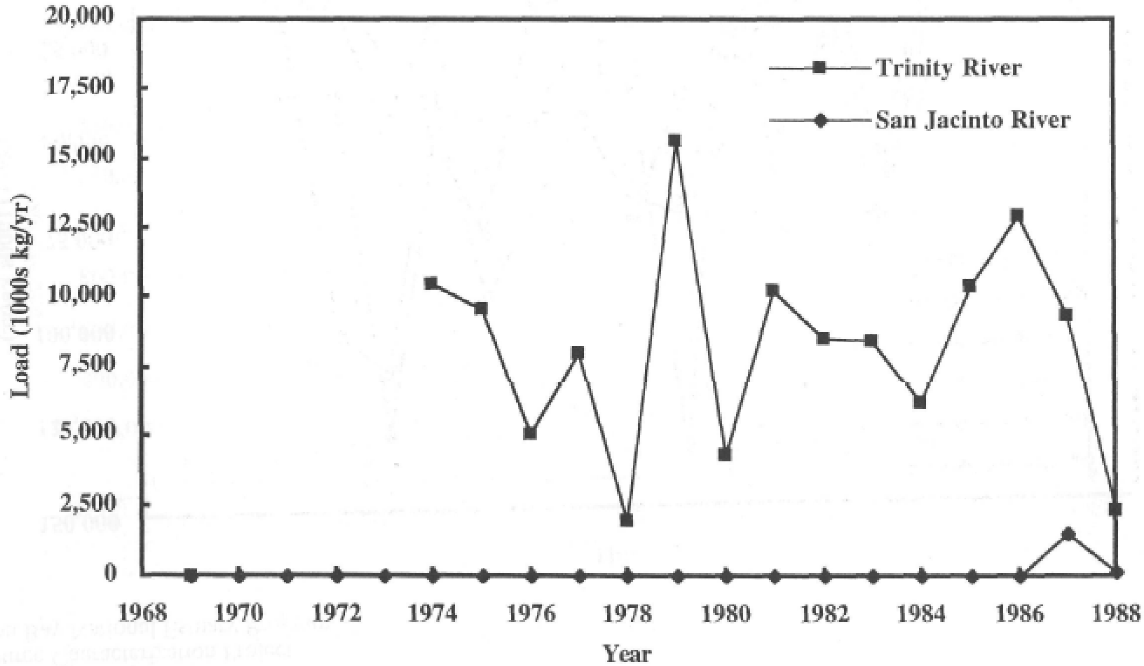


Figure 140. Estimated loads of total nitrogen into Galveston Bay from the Trinity River at Romayor and from the San Jacinto River from 1969 through 1988. Source: (Armstrong and Ward Jr. 1993)

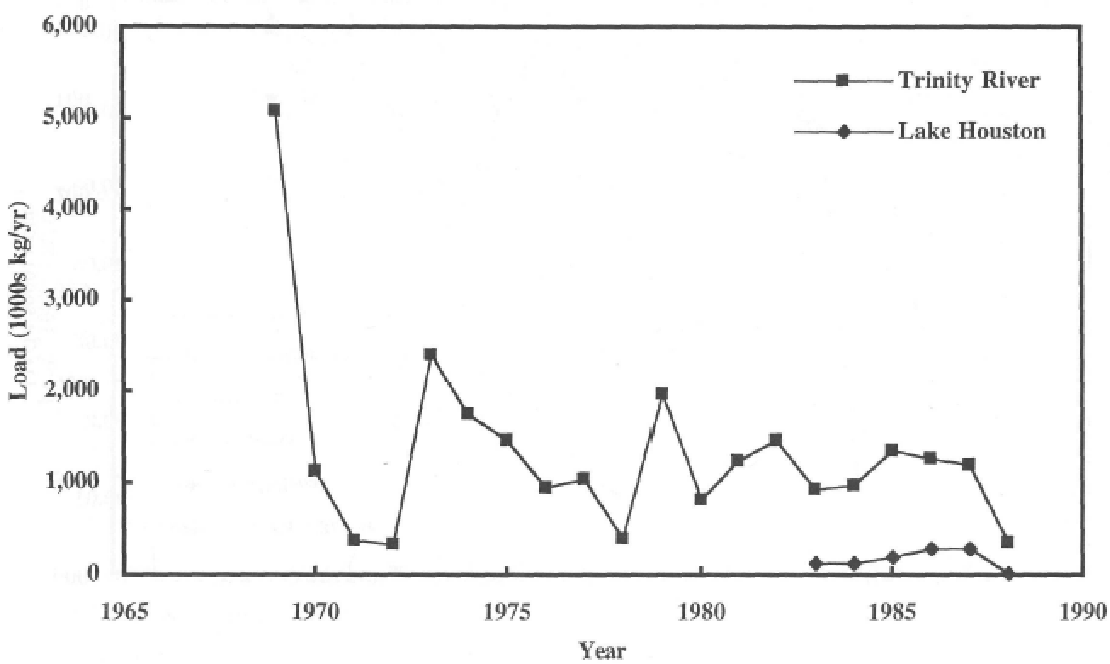


Figure 141. Estimated loads of total phosphorus into Galveston Bay from the Trinity River at Romayor and from the San Jacinto River from 1969 through 1988. Source: (Armstrong and Ward Jr. 1993)

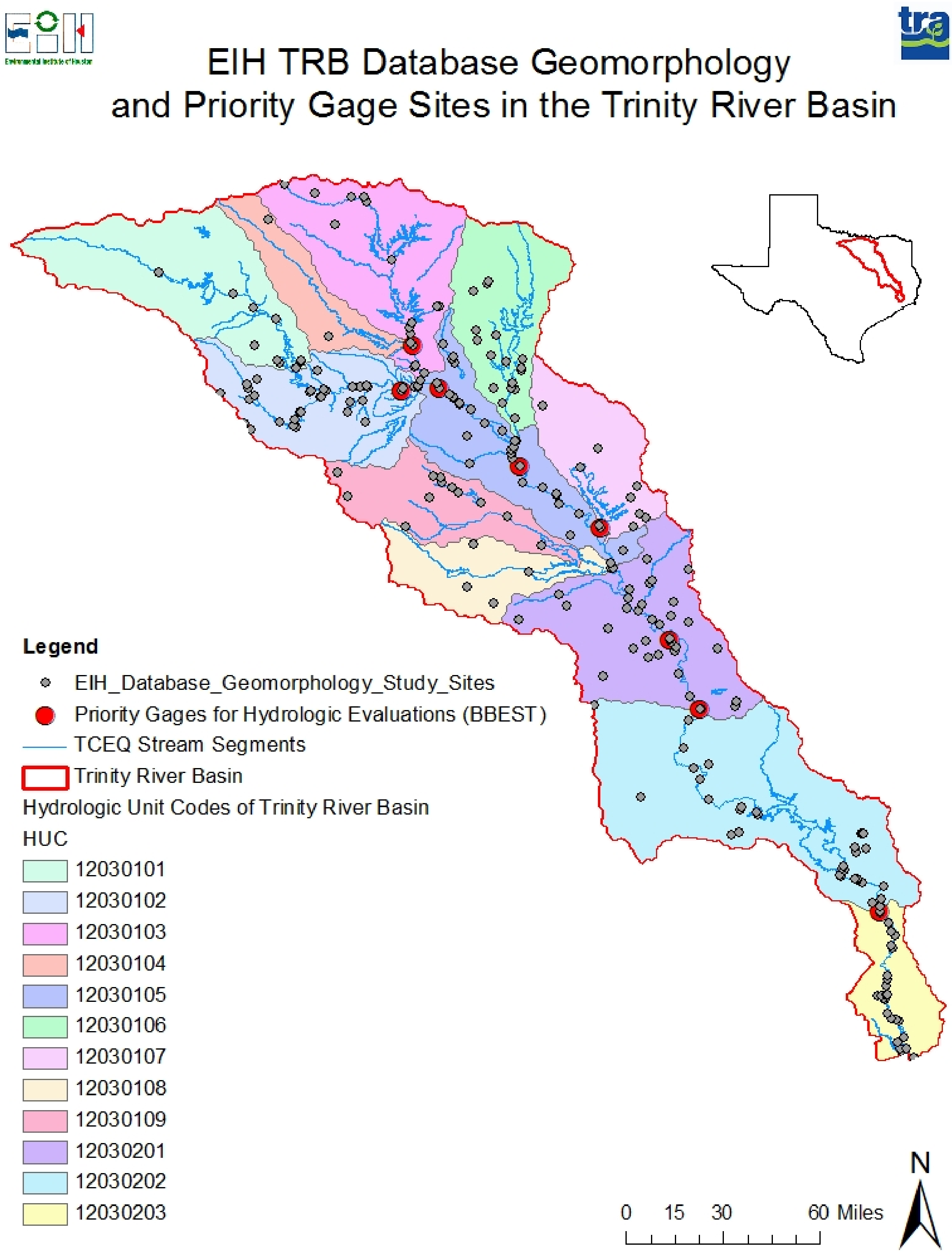


Figure 142. Location of geomorphology study sites based on recent Trinity literature review.

They concluded that the two gauged tributaries below the dam (Long King Creek (LKC) and Menard Creek) along with the three stations on the Trinity River (Goodrich, Romayor and Liberty) do not show any indication of post-dam alterations in flow. On the mainstem, slightly elevated flows in the post-dam period can be attributed to higher than - average precipitation during this corresponding period (Slattery and Phillips 2007). They observed that even though no general change in flow regime is associated with the dam, flood waves are slowed as they pass through Lake Livingston. Thus, tributary flows are out of phase with the Trinity River. Subsequently, the tributaries peak sooner. When the tributaries are carrying their maximum sediment loads to the mainstem, the Trinity has not yet reached its maximum transport potential, and deposition occurs. While changes in the characteristics of the LKC delta have occurred, a delta did exist prior to 1968 and the dam emplacement. As Trinity flows increase, stream power increases, transporting portions of the recently deposited alluvium. While the Trinity flow increases, tributary flows are decreasing, creating backwater flooding. They found evidence of backwater deposits occurs on the delta surfaces at the mouths of LKC and MC (Slattery and Phillips 2007).

(Slattery and Phillips 2007) defined a critical zone as a boundary between different channel responses, channel and valley morphologies, and sediment transport and storage regimes. Earlier studies conducted on the channel morphological responses of the Trinity River to Livingston Dam were reported by (Phillips et al. 2005). Using seven cross-sections from just downstream of the dam to Romayor, about 52 km downstream, they showed morphological evidence of channel scour and/or widening in response to the dam. At the Romayor site, they observed exposed bedrock in the channel, indicating recent scour. This was observed in the channel a short distance downstream of Romayor. However, they did not see any evidence of scour at the cross-sections examined 8 km downstream of Romayor. They also did not see any morphological response to the dam at ten cross-sections between Romayor and Trinity Bay (Phillips et al. 2005). Analysis of suspended sediment transport data from gaging stations at Romayor, located about 8 km upstream of the critical zone, and Liberty, about 45 km downstream, show pronounced differences in sediment transport regimes (Phillips et al. 2004). They estimated that the mean annual sediment yield at Romayor is nearly 3.4 million t yr-1, with a specific yield of 76 t km-2 yr-1. At Liberty, by contrast, the numbers are less than 69,000 t yr-1 and 1.6 t km-2 yr-1. Additionally, while the Romayor station shows a clear reduction in sediment transport following closure of the Livingston Dam, there is no evidence of any change at Liberty (Phillips et al. 2004). They concluded that downstream of Liberty low stream power and ample accommodation space creates a sediment storage bottleneck such that little upstream sediment was reaching the lower reaches of the river even before the dam was constructed. (Phillips et al. 2005) concluded that beyond 60 km downstream of the dam the Trinity River is characterized by extensive sediment storage and reduced conveyance capacity, so that even after dam construction sediment supply still exceeds transport capacity. Downstream of this point sea-level rise and backwater effects from the estuary are more important physical controls. (Phillips et al. 2004) pinpointed the transition in sediment storage regimes at what is called the critical zone in this paper, just downstream of a Deweyville palaeomeander scar, at a point where floodplain elevation generally decreases, width increases, and numerous modern oxbow lakes appear. They found that the reaches up- and downstream of the critical zone also differ significantly in sinuousity, slope, and stream power. Cross-sectional stream power at any given reference flow is 4.5 to 33 times greater at Romayor compared to Liberty, despite the higher discharges downstream, and unit stream power is 20 to 100 times higher upstream of the critical zone (Phillips and Slattery 2006b). The difference is mainly attributable to slope, as channel bed slopes are 25 times steeper upstream of Romayor.

(Phillips and Slattery 2007) concluded that there is no systematic downstream pattern of increases of decreases in the discharge, stream power, or water surface slope of the lower Trinity River. Discharge in the river channel likely decreases downstream due to coastal backwater effects in the lowermost reaches and due to diversion of flow into valley-bottom depressions during high flows. Decreased stream power and slope in the lower reaches is consistent with earlier findings of limited fluvial sediment delivery to the coastal zone (Phillips and Slattery 2007). Their study reinforced the notion that coastal plain rivers may be more complex with sediment transport and flows being controlled by complex topography.

(Phillips 2007) studied the status and various factors influencing geomorphic equilibrium in Southeast Texas rivers. They state that studies directly examining morphological effects downstream of dams in the region have generally found a "hungry water" scour zone downstream of the dam, which extends relatively short distance (< 55 km) downstream, with limited impacts on sediment transport or storage further downstream, due to a combination of sediment supplied by the downstream stream bed and bank erosion in the scour zone, tributary and local sediment inputs downstream of the dams, and the fact that the systems were transport-limited and overloaded with sediment (relative to transport capacity) before dam construction (Phillips and Slattery 2006a; Phillips and Slattery 2007). In the lowermost Trinity and Sabine Rivers the effects of Holocene sea level, antecedent topography, and inherently limited stream power overwhelm the potential effects of any upstream change in sediment supply, including dams (Phillips and Slattery 2007; Phillips and Slattery 2008). They conclude that these factors plus the fact that incision is generally down (or close) to resistant bedrock, suggests that further downstream propagation of dam effects is unlikely and relaxation time equilibrium (RTE) has been achieved. Relaxation time equilibrium (RTE) implies that changes in response to a disturbance or to new boundary conditions have run their course, or at least slowed to negligible rates.

Recent studies of the upper Trinity River Basin suggest that the Trinity River is highly fragmented in comparison to other Texas Rivers (Chin et al. 2008). The authors used a stream fragmentation metric (km of river per number of dams) as one measure of hydrological modification. In addition, they utilized reservoir storage as another metric. They argue that the amount of reservoir storage represents the amount of water held behind a dam instead of being allowed to flow downstream naturally , thus serving as a primary indicator of the potential disruption to the hydrologic cycle. Dams on the other hand pose physical barriers to the flow of water and sediment where they occur. So that dammed river networks are composed of disconnected channel segments between dams. They argue that these two factors contribute to river habitat degradation by altering microhabitat quality and changing aquatic community composition (Chin et al. 2008). When they applied these metrics they found that the Trinity River exhibits the highest degree of river fragmentation and hence has a high degree of hydrological alteration within the State of Texas. The majority of these dams were however smaller dams located on average about every 44 km of river length. The author recommends therefore that smaller dams should be emphasized in mitigating environmental impacts associated with the fragmentation of river landscapes including the degradation of aquatic habitat and movement of sediment as well as aquatic species (Chin et al. 2008).

Based on these studies it is very evident that the construction of Lake Livingston has had an influence on the downstream transport of sediments and nutrients. Reductions in nitrogen, phosphorus and suspended solids have occurred since the impoundment in 1969. However, since nutrient loading from urban sources have increased during this period it is difficult to evaluate the overall impacts on the estuary in terms of primary productivity. However, based on the studies of (Phillips and Slattery 2007) the impacts on downstream sediment transport on the estuary are probably minimal due to the upstream placement of the dam far upstream of the estuary and the natural reduced sediment transport capacity of the river at a point below the dam, but still far above the estuary. The capacity of the river to transport sediment is diminished due to low stream gradients, increased distribution to back water areas, meandering and natural attenuation due to tidal action. The loss sediment load near the dam represents a quantity that under natural conditions would have seldom reached the estuary. The river however reaches a new equilibrium and replenishes this lost load from the lower river before entering the estuary.

Focal Species Matrix and Potential Flow Relationships

Our literature survey identified numerous fish collections and taxa spanning the entire watershed and all sub-watersheds and ecoregions (Figures 143-145). The location of these collections spans numerous land use types including urban areas near Dallas Fort Worth, forested areas, and prairies and pastures (Figure 146). There was a clear gradient in number of species collected with highest numbers on the mainstem river and major tributaries being collected above and below the Dallas Fort Worth area (Figure 145). Fish collections started in the mid-1950s and continued through 2000s (Figure 147 and 148) However, fish collecting activity appeared to be largely absent during the mid-1970's through mid-1980's. (Figure 147 and 148). We have no immediate explanation for this pattern. However, it does appear that earlier collections were associated with fisheries studies conducted primarily in reservoirs (Figure 148). The period during the early 1970s was marked by such poor water quality that few fish survived in the upper portions of the Trinity River. As water quality improved fish would move into areas but would soon perish when oxygen levels dropped due to additional "black rises". The transition to more river studies occurred during the period of time when agencies and cities began to aggressively assess and deal with impacts caused by organic pollution in the Trinity River. The source of much of this pollution was believed to come from faulty sanitary sewer collection systems and improperly designed wastewater plants. During this time numerous "black-rises" were reported downstream of the Dallas-Fort Worth area. It was believed that this was largely due to resuspended untreated organic waste with high biological oxygen demand that was released after heavy spring rains and rising river levels (Dickson et al. 1991). By the late 1980's water quality had begun to improve due to improvements in wastewater treatment and new regional treatment capacity (Wells 1991). However, (Anderson et al. 1995) described major shifts in fish communities in the Trinity Basin between 1953 and 1986, with reductions in catfish, darter species and increases in tolerant silversides and *Gambusia affinis.* They indicated that one of the major causes of these declines were the construction of dams and exotic species introductions.

Based on the results of our cluster analysis we generated a dendrogram depicting species with similar life history attributes (Figure 149). Fish species with similar traits were placed into one of six community guilds (Table 11). We then checked to see if at least one candidate "focal" species occurred in each of the community guilds and could therefore theoretically serve as indicator species as well. We did find at least one focal species in each guild (Table 4). Fish guild 1 consisted of water quality tolerant invertivores and piscivores consisting of open substratum and nest spawners. The focal species found in this group was the alligator gar. Species in guild 2 consisted mainly of moderately water quality tolerant invertivores who are exclusively open substratum spawners. The focal species found in this group was the blackspot shiner.

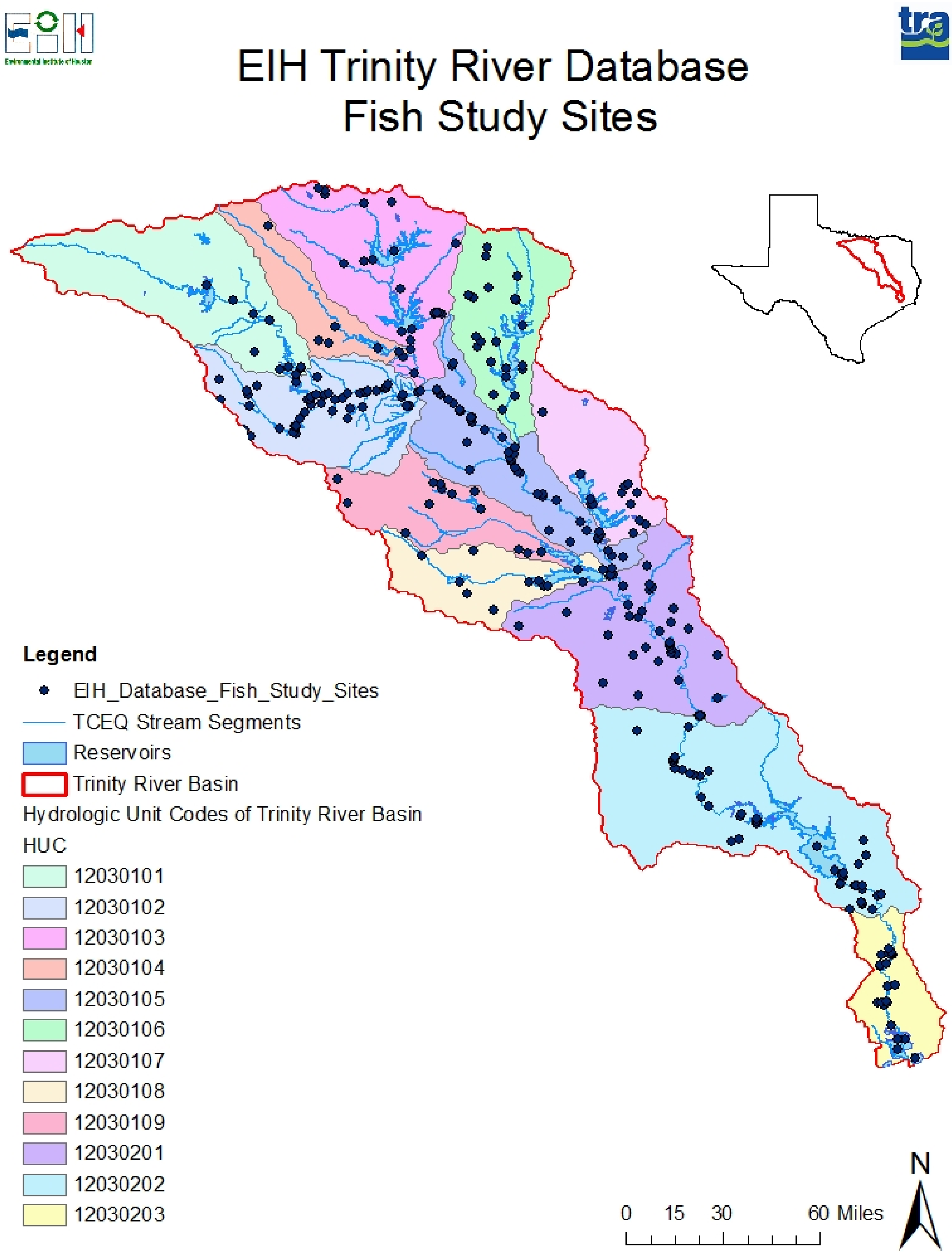


Figure 143. Location of published and unpublished fish studies archived in the EIH Trinity River database that were used to document the historical distribution of fish species in the Trinity River basin.

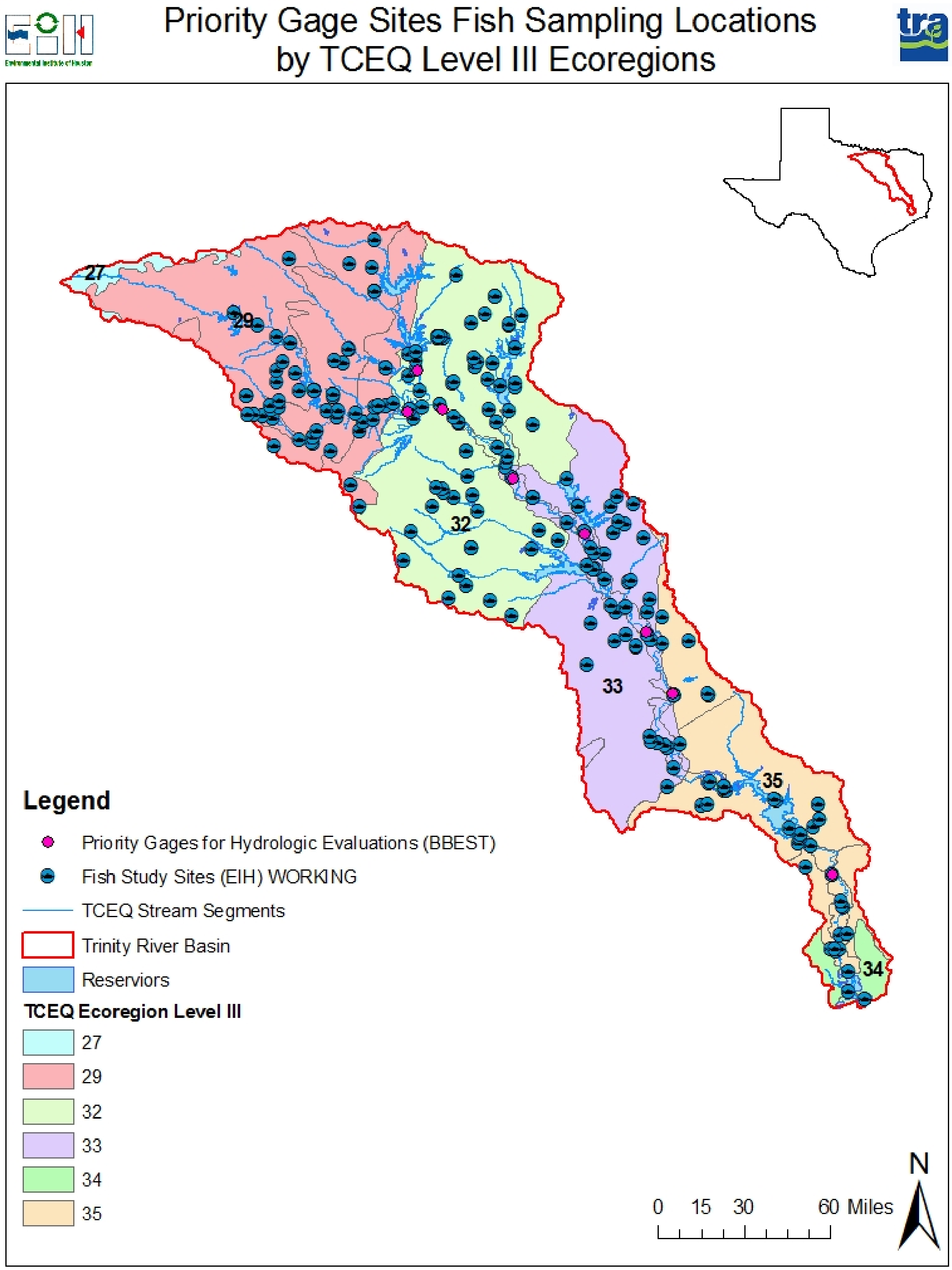


Figure 144. Fish collections by Ecoregion.

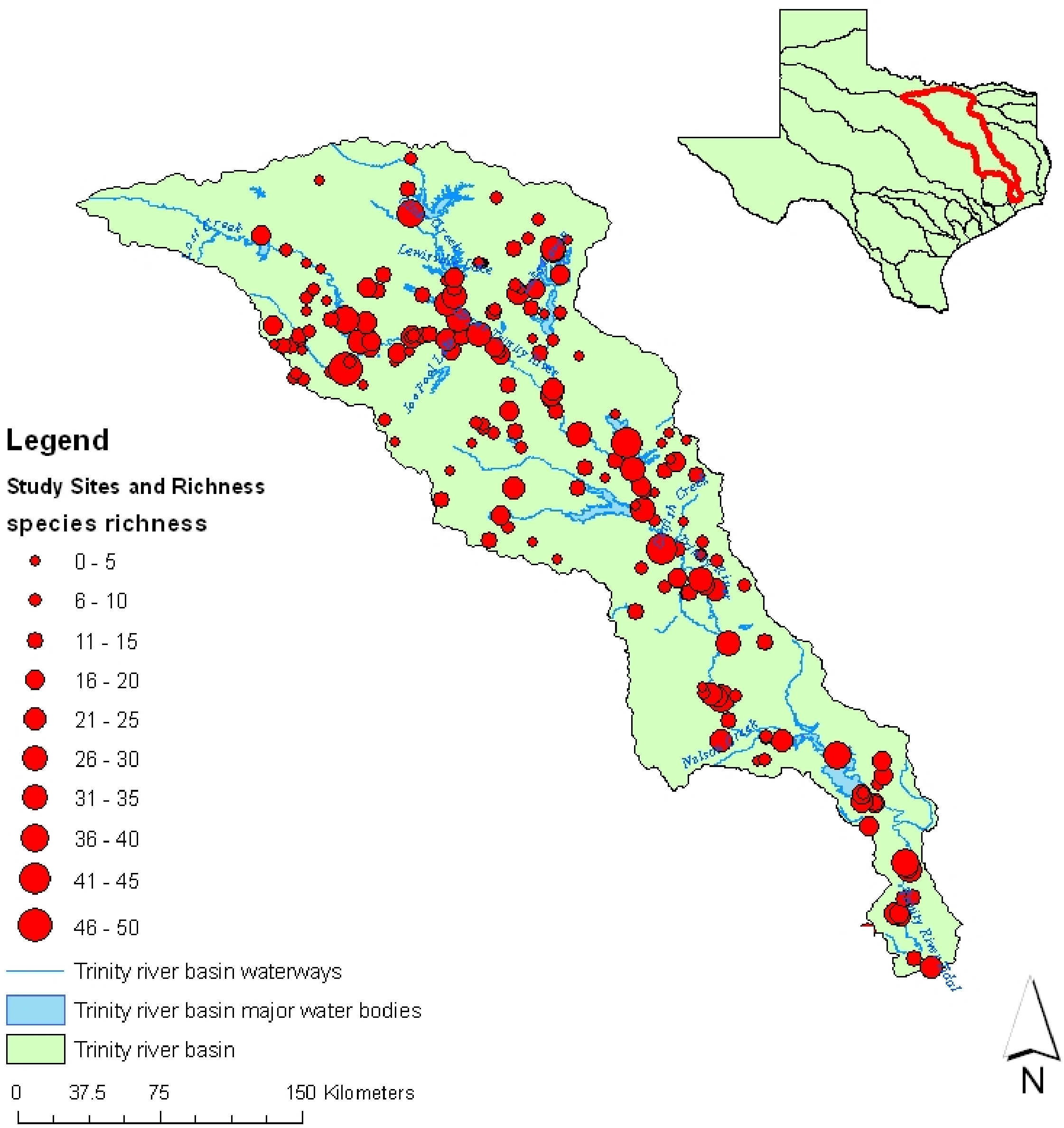


Figure 145. Numbers of fish taxa reported during each study within the Trinity River basin.

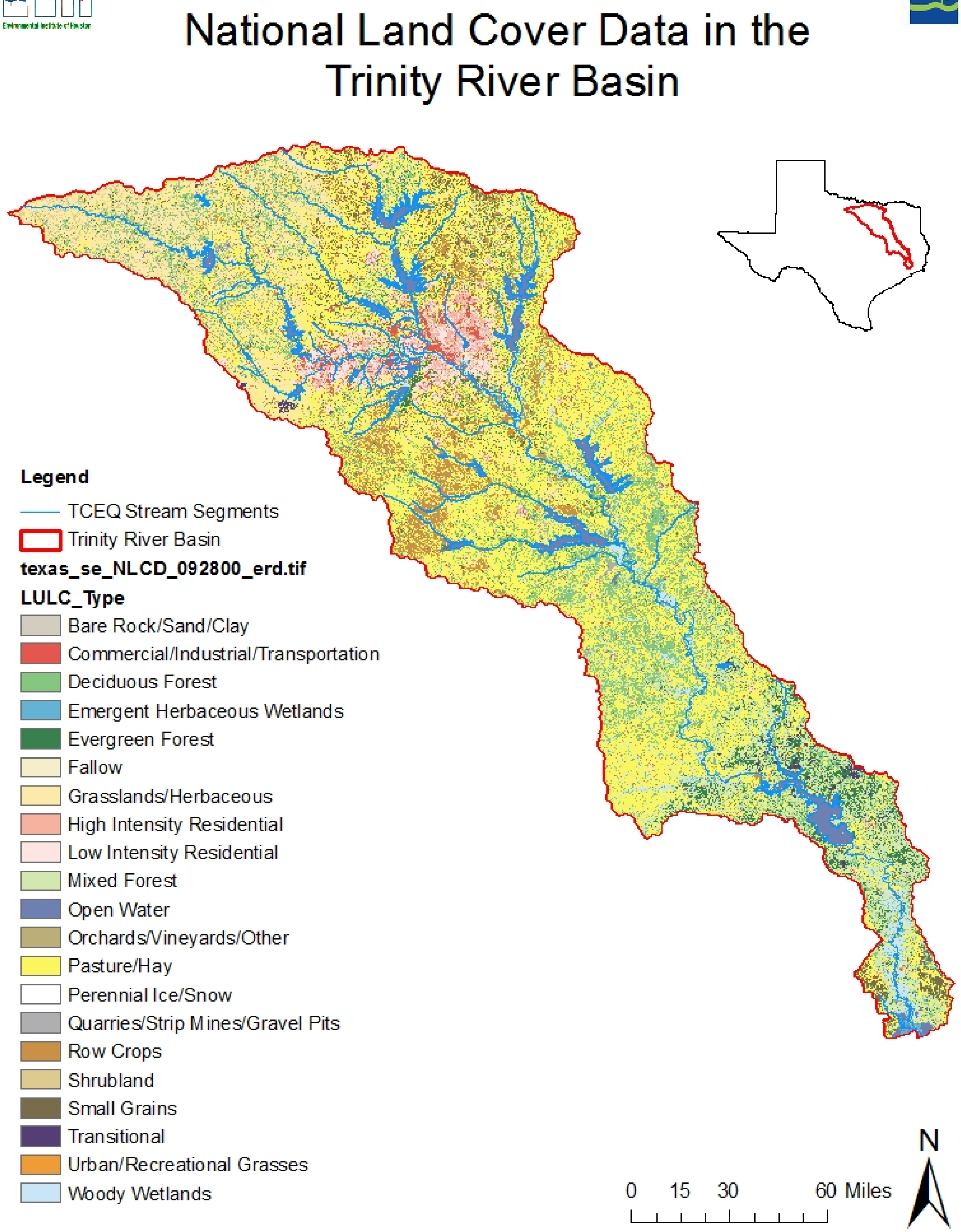


Figure 146. Major land use categories present in the Trinity River basin.

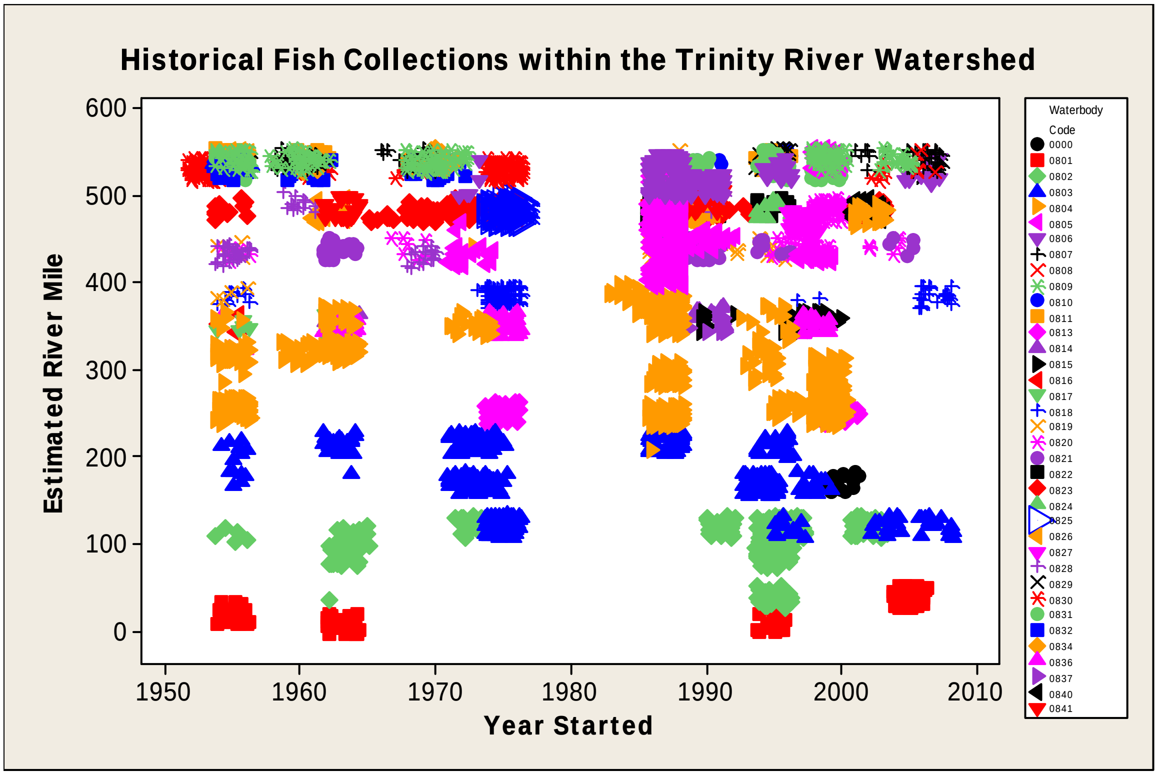


Figure 147. Location of fish collections obtained from literature review. Waterbody code is the TCEQ segment number (see Table 2). Code 0000 denotes collections from uncertain locations or tributaries without a TCEQ segment number. Data includes collections from fish kills and reservoirs.

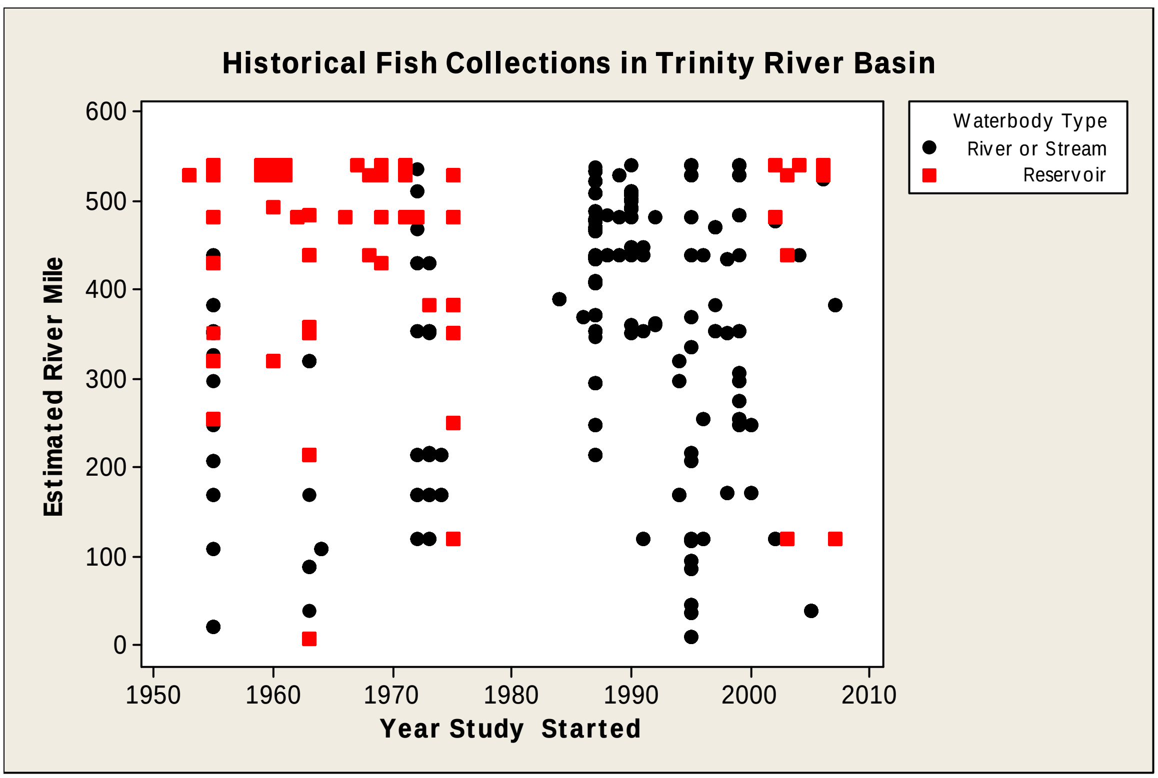


Figure 148. Location of fish collections obtained from literature review. Data from reservoirs and fish kills included.

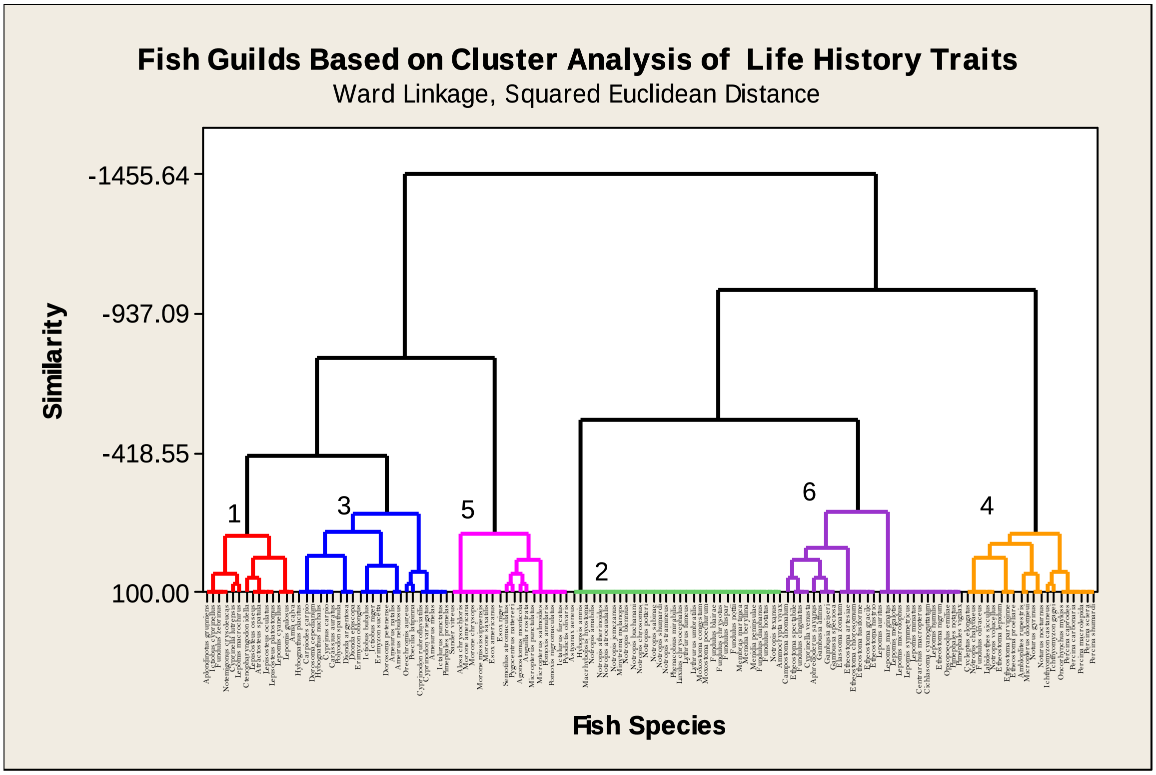


Figure 149. Fish guilds estimated from cluster analysis of life history characteristics including trophic level, water quality tolerance and reproductive behavior. (Balon level 1).

Table 11. Fish community guilds identified using cluster analysis.

SPECIES	COMMON NAME	FAMILY	Trophic	Tolerance	Balon Level 1	TPWD Focal Species	Cluster
Aplondinotus grunniens	**freshwater drum**	**Sciaenidae**	**IF**	**T**	**A1**	**TR**	1
Ctenopharyngodon idella	grass carp	Cyprinidae	H	T	A1	no	1
Ictiobus cyprinellus	bigmouth buffalo	Catostomidae	IF	T	A1	no	1
Fundulus zebrinus	plains killifish	Fundulidae	IF	T	A1	no	1
Lepisosteus osseus	longnose gar	Lepisosteidae	P	T	A1	**SJR**	1
Atractosteus spatula	**alligator gar**	**Lepisosteidae**	**P**	**T**	**A1**	**TR**	**1**
Lepisosteus oculatus	spotted gar	Lepisosteidae	P	T	A1	no	1
Lepisosteus platostomus	shortnose gar	Lepisosteidae	P	T	A1	no	1
Notemigonus crysoleucas	golden shiner	Cyprinidae	IF	T	A1	no	1
Cyprinella lutrensis	red shiner	Cyprinidae	IF	T	A2	no	1
Lepomis cyanellus	green sunfish	Centrarchidae	P	T	B2	no	1
Lepomis macrochirus	bluegill	Centrarchidae	IF	T	B2	no	1
Lepomis gulosus	warmouth	Centrarchidae	P	T	B2	no	1
Amia calva	bowfin	Amiidae	P	T	B2	no	1
Astyanax aeneus	Mexican tetra	Characidae	IF	N	A1	no	2
Hybopsis amnis	pallid shiner	Cyprinidae	IF	N	A1	**SJR**	2
Macrhybopsis hyostoma	shoal chub	Cyprinidae	IF	N	A1	no	2
Notropis amabilis	Texas shiner	Cyprinidae	IF	N	A1	no	2
Notropis atherinoides	emerald shiner	Cyprinidae	IF	N	A1	no	2
Notropis atrocaudalis	**blackspot shiner**	**Cyprinidae**	**IF**	**N**	**A1**	**TR&SJR**	**2**
Notropis jemezanus	Rio Grande shiner	Cyprinidae	IF	N	A1	no	2
Minytrema melanops	spotted sucker	Catostomidae	IF	N	A1	no	2
Notropis blennius	ghost shiner	Cyprinidae	IF	N	A1	no	2
Notropis buchanani	ghost shiner	Cyprinidae	IF	N	A1	no	2
Notropis chrosomus	rainbow shiner	Cyprinidae	IF	N	A1	no	2
Notropis potteri	chub shiner	Cyprinidae	IF	N	A1	no	2
Notropis sabinae	Sabine shiner	Cyprinidae	IF	N	A1	no	2
Notropis shumardi	**silverband shiner**	**Cyprinidae**	**IF**	**N**	**A1**	**TR**	2
Notropis stramineus	sand shiner	Cyprinidae	IF	N	A1	no	2
Phenacobius mirabilis	suckermouth minnow	Cyprinidae	IF	N	A1	no	2
Luxilus chrysocephalus	striped shiner	Cyprinidae	IF	N	A1	no	2
Lythrurus fumeus	ribbon shiner	Cyprinidae	IF	N	A1	**SJR**	2
Lythrurus umbratilis	redfin shiner	Cyprinidae	IF	N	A1	no	2
Moxostoma congestum	gray redhorse	Catostomidae	IF	N	A1	no	2
Moxostoma poecilurum	blacktail redhorse	Catostomidae	IF	N	A1	**SJR**	2
Fundulus blairae	western starhead topminnow	Fundulidae	IF	N	A1	no	2
Fundulus chrysotus	golden topminnow	Fundulidae	IF	N	A1	no	2
Fundulus dispar	starhead topminnow	Fundulidae	IF	N	A1	no	2
Fundulus nottii	bayou topminnow	Fundulidae	IF	N	A1	no	2
Membras martinica	rough silverside	Atherinopsidae	IF	N	A1	no	2
Menidia beryllina	inland silverside	Atherinopsidae	IF	N	A1	no	2
Menidia peninsulae	tidewater silverside	Atherinopsidae	IF	N	A1	no	2
Fundulus diaphanus	banded killifish	Fundulidae	IF	N	A1	no	2
Fundulus notatus	blackstripe topminnow	Fundulidae	IF	N	A1	no	2
Notropis texanus	weed shiner	Cyprinidae	IF	N	A1	no	2
Ammocrypta vivax	scaly sand darter	Percidae	IF	N	A1	no	2
Hybognathus placitus	plains minnow	Cyprinidae	O	T	A1	no	3
Carpiodes carpio	river carpsucker	Catostomidae	O	T	A1	no	3
Dorosoma cepedianum	gizzard shad	Clupeidae	O	T	A1	no	3
Erimyzon oblongus	creek chubsucker	Catostomidae	O	N	A1	**SJR**	3
Hybognathus nuchalis	Mississippi silvery minnow	Cyprinidae	O	T	A1	no	3
Ictiobus bubalus	smallmouth buffalo	Catostomidae	O	N	A1	no	3
Ictiobus niger	black buffalo	Catostomidae	O	N	A1	no	3
Polyodon spathula	**paddlefish**	**Polyodontidae**	**O**	**I**	**A1**	**TR**	**3**
Dionda argentosa	Manatial roundnose minnow	Cyprinidae	O	I	A1	no	3
Dionda episcopa	roundnose minnow	Cyprinidae	O	I	A1	no	3
Cyprinus carpio	common carp	Cyprinidae	O	T	A1	no	3
Erimyzon sucetta	lake chubsucker	Catostomidae	O	N	A1	no	3
Carassius auratus	goldfish	Cyprinidae	O	T	A1	no	3
Dorosoma petenense	threadfin shad	Clupeidae	O	N	A1	no	3
Oreochromis aureus	blue tilapia	Cichlidae	O	T	B1	no	3
Cyprinodon rubrofluviatilis	Red River pupfish	Cyprinodontidae	O	T	B2	no	3
Cyprinodon variegatus	sheepshead minnow	Cyprinodontidae	O	T	B2	no	3
Ameiurus melas	black bullhead	Ictaluridae	O	T	B2	no	3
Ameiurus natalis	yellow bullhead	Ictaluridae	O	N	B2	no	3
Ameirus nebulosus	brown bullhead	Ictaluridae	O	N	B2	no	3
Ictalurus punctatus	channel catfish	Ictaluridae	O	T	B2	no	3
Pimephales promelas	fathead minnow	Cyprinidae	O	T	B2	no	3
Poecilia latipinna	sailfin molly	Poeciliidae	O	T	C2	no	3

Table 11. Continued.

SPECIES	COMMON NAME	FAMILY	Trophic	Tolerance	Balon Level 1	TPWD Focal Species	Cluster
Cycleptus elongatus	blue sucker	Catostomidae	IF	I	A1	no	4
Notropis chalybaeus	ironcolor shiner	Cyprinidae	IF	I	A1	no	4
Fundulus olivaceus	blackspotted topminnow	Fundulidae	IF	I	A1	no	4
Labidesthes sicculus	brook silverside	Atherinopsidae	IF	I	A1	no	4
Notropis volucellus	mimic shiner	Cyprinidae	IF	I	A1	no	4
Ichthyomyzon castaneus	chestnut lamprey	Petromyzontidae	P	I	A2	no	4
Ichthyomyzon gagei	southern brook lamprey	Petromyzontidae	None	I	A2	no	4
Oncorhynchus mykiss	rainbow trout	Salmonidae	IF	I	A2	no	4
Percina caprodes	logperch	Percidae	IF	I	A2	no	4
Percina carbonaria	Texas logperch	Percidae	IF	I	A2	no	4
Percina macrolepida	bigscale logperch	Percidae	IF	I	A2	no	4
Percina sciera	**dusky darter**	**Percidae**	**IF**	**I**	**A2**	**TR**	**4**
Percina shumardi	river darter	Percidae	IF	I	A2	no	4
Etheostoma lepidum	greenthroat darter	Percidae	IF	I	B1	no	4
Etheostoma parvipinne	goldstripe darter	Percidae	IF	I	B1	no	4
Etheostoma proeliare	cypress darter	Percidae	IF	I	B1	no	4
Ambloplites rupestris	rock bass	Centrarchidae	P	I	B2	no	4
Micropterus dolomieui	smallmouth bass	Centrarchidae	P	I	B2	no	4
Noturus gyrinus	tadpole madtom	Ictaluridae	IF	I	B2	no	4
Noturus nocturnus	freckled madtom	Ictaluridae	IF	I	B2	**SJR**	4
Sander vitreus	walleye	Percidae	P	N	A1	no	5
Alosa chrysochloris	skipjack herring	Clupeidae	P	N	A1	no	5
Morone americana	white perch	Moronidae	P	N	A1	no	5
Morone chrysops	**white bass**	**Moronidae**	**P**	**N**	**A1**	**TR**	**5**
Morone mississippiensis	yellow bass	Moronidae	P	N	A1	no	5
Morone saxatilis	striped bass	Moronidae	P	N	A1	no	5
Esox americanus	redfin pickerel	Esocidae	P	N	A1	no	5
Esox niger	chain pickerel	Esocidae	P	N	A1	no	5
Semotilus atromaculatus	creek chub	Cyprinidae	P	N	A2	no	5
Pygocentrus nattereri	red piranha	Characidae	P	N	B1	no	5
Micropterus punctulatus	spotted bass	Centrarchidae	P	N	B2	no	5
Micropterus salmoides	**largemouth bass**	**Centrarchidae**	**P**	**N**	**B2**	**TR**	**5**
Pomoxis annularis	white crappie	Centrarchidae	P	N	B2	no	5
Pomoxis nigromaculatus	black crappie	Centrarchidae	P	N	B2	no	5
Ictalurus furcatus	**blue catfish**	**Ictaluridae**	**P**	**N**	**B2**	**TR**	**5**
Pylodictis olivaris	flathead catfish	Ictaluridae	P	N	B2	SJR	5
Agonostomus monticola	mountain mullet	Mugilidae	O	N	CAT	no	5
Anguilla rostrata	American eel	Anguillidae	P	N	CAT	no	5
Campostoma anomalum	central stoneroller	Cyprinidae	H	N	A2	no	6
Etheostoma spectabile	orangethroat darter	Percidae	IF	N	A2	no	6
Fundulus cingulatus	Banded topminnow	Fundulidae	IF	N	A2	no	6
Cyprinella venusta	blacktail shiner	Cyprinidae	IF	N	A2	no	6
Elassoma zonatum	banded pygmy sunfish	Elassomatidae	IF	N	B1	no	6
Etheostoma artesiae	redspot darter	Percidae	IF	N	B1	no	6
Etheostoma chlorosomum	bluntnose darter	Percidae	IF	N	B1	no	6
Etheostoma fusiforme	swamp darter	Percidae	IF	N	B1	no	6
Etheostoma gracile	slough darter	Percidae	IF	N	B1	no	6
Etheostoma histrio	harlequin darter	Percidae	IF	N	B1	no	6
Lepomis auritus	redbreast sunfish	Centrarchidae	IF	N	B2	no	6
Lepomis marginatus	dollar sunfish	Centrarchidae	IF	N	B2	no	6
Lepomis megalotis	**longear sunfish**	**Centrarchidae**	**IF**	**N**	**B2**	**TR**	**6**
Lepomis microlophus	redear sunfish	Centrarchidae	IF	N	B2	no	6
Lepomis symmetricus	bantam sunfish	Centrarchidae	IF	N	B2	no	6
Lepomis miniatus	redspotted sunfish.	Centrarchidae	IF	N	B2	no	6
Centrarchus macropterus	flier	Centrarchidae	IF	N	B2	no	6
Cichlasoma cyanoguttatum	Rio Grande cichlid	Cichlidae	IF	N	B2	no	6
Lepomis humilis	orangespotted sunfish	Centrarchidae	IF	N	B2	no	6
Etheostoma nigrum	johny darter	Percidae	IF	N	B2	no	6
Opsopoeodus emiliae	pugnose minnow	Cyprinidae	IF	N	B2	no	6
Pimephales notatus	bluntnose minnow	Cyprinidae	IF	N	B2	no	6
Pimephales vigilax	bullhead minnow	Cyprinidae	IF	N	B2	no	6
Aphredoderus sayanus	pirate perch	Aphredoderidae	IF	N	C1	no	6
Gambusia affinis	western mosquitofish	Poeciliidae	IF	N	C2	no	6
Gambusia geiseri	largespring gambusia	Poeciliidae	IF	N	C2	no	6
Gambusia speciosa	Tex-Mex gambusia	Poeciliidae	IF	N	C2	no	6

Explanation for various codes used in Table 11 provided in Table 4. Focal species nominated by TPWD and presented at BBEST meeting in August 2009 are in bold.

Species in guild 3 were all omnivores who exhibited a wide range of tolerances to poor water quality and exhibited a variety of spawning behavior including open substrate spawning, nest spawning and internal fertilization. The focal species located in this group was the paddlefish, which is classified as an omnivore, intolerant to poor water quality, and an open substratum spawner over gravel and rocks.

Guild 4 mainly consisted of invertivores which were intolerant and exhibited a range of reproductive traits including open substrate spawning, brood hiding, substrate choosers and nest spawning. Dusky darter was the only focal species found in this group.

Fishes in guild 5 consisted of predatory species with neutral water quality tolerance which exhibited open substrate and nest spawning. Two focal species were found in this group including the white bass (an open substrate spawner) and largemouth bass (a nest spawner). The final group 6 consisted mainly of invertivores with intermediate tolerance to water quality, who largely exhibited nest spawning. The longear sunfish was the only focal species in this group.

Focal species distributions, including data independently summarized by Dr. Hendrickson were plotted against river mile, HUC codes and TCEQ segments by year (Figures 150, 151, 152 and 153). Based on our compiled data most records of focal fish species occurred between river mile 200 and 400 in TCEQ waterbody segments 0802 through 0805 (Figures 150 and 151). However, some species ranged from river mile 84 to 550 (Figure 152).

Focal species distributions were also plotted against reported stream flows and years when both variables were measured (1987-2007). Focal fish species were primarily observed between flows ranging from 0 to 20 cfs. These recorded occurrences were not associated with an instream flow study and are not meant to imply any preferred flow regime (Figure 150). However, at a minimum it does provide a baseline to compare conditions under which fish have been collected. In addition, many of these species distribution overlapped the location of priority gage sites that will be used for hydrological analysis (Figure 150 and 151). Data compiled by the Fishes of Texas Project documented in some cases extensive temporal and spatial distributions of some species (e.g. largemouth bass and longear sunfish)(Figure 153)(Hendrickson 2009). Distributions of fish documented during our literature survey are similar to their findings (Figures 152 and 153). However some species such as paddlefish were not encountered in their study. His data also suggests that most accounts of blue catfish were restricted to the lower river while freshwater drum were encountered in the upper river (Figure 153

Individual Species Accounts and Hydrological Relationships

Aplodinotus grunniens (Freshwater drum)

Aplodinotus grunniens (freshwater drum) were generally collected throughout the basin during lower recorded flows (Figures 150-156). Many collections occurred very close to the priority gage sites. Freshwater drum is considered a large river fish species which serves as a host for at least six species of mussel glochidia including one species of concern, the Rock Pocketbook (Table 5). The primary literature on the ecology of freshwater drum in Texas has been summarized by (Bonner 2009).

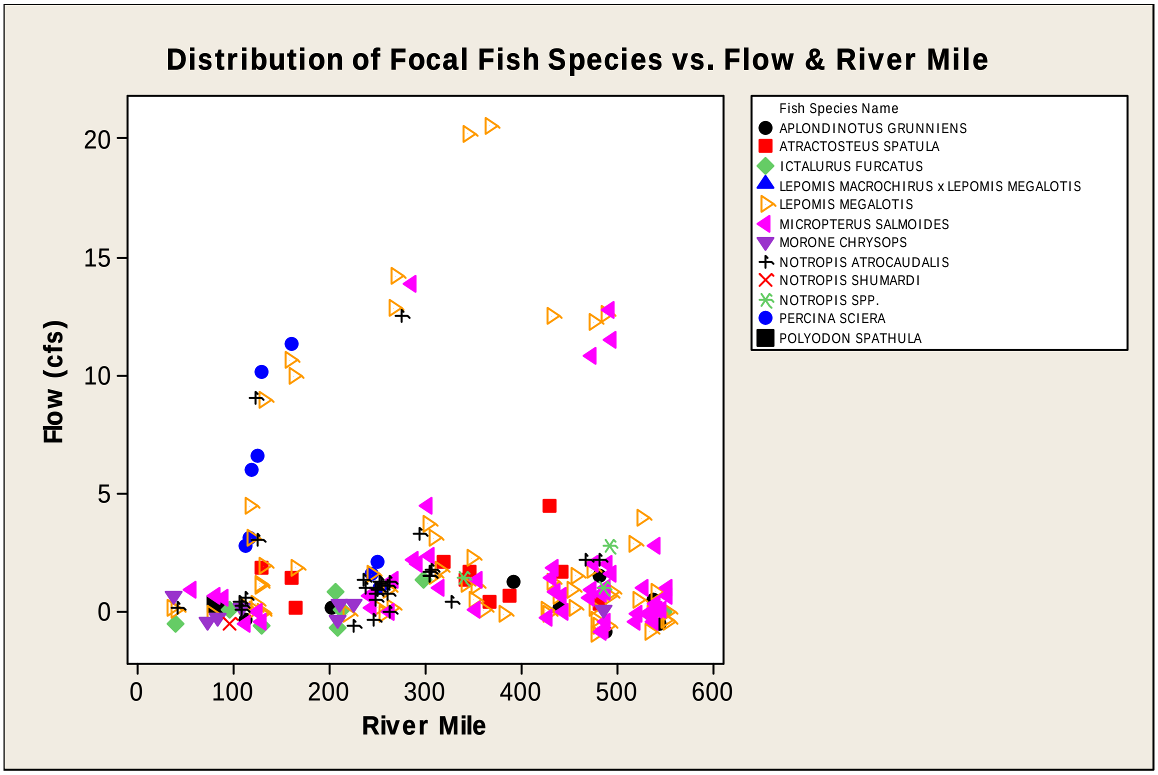


Figure 150 . Occurrence of focal fish species and associated flow measurements. Excludes fish kill and reeservoir data. Period of record 1989 to 2007. (jitter added to data display)

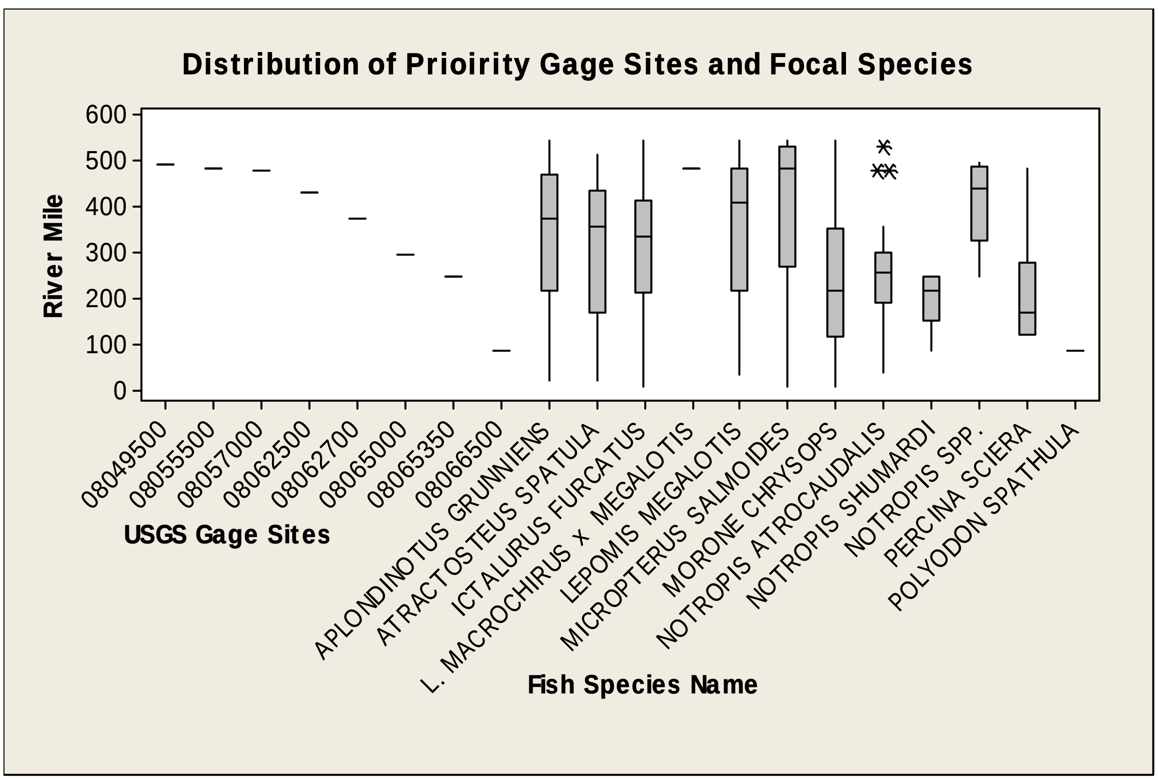


Figure 151 . Distribution of focal fish species based on literature review within the Trinity River Basin. Period of record 1953-2007 (excluding reservoir sites).

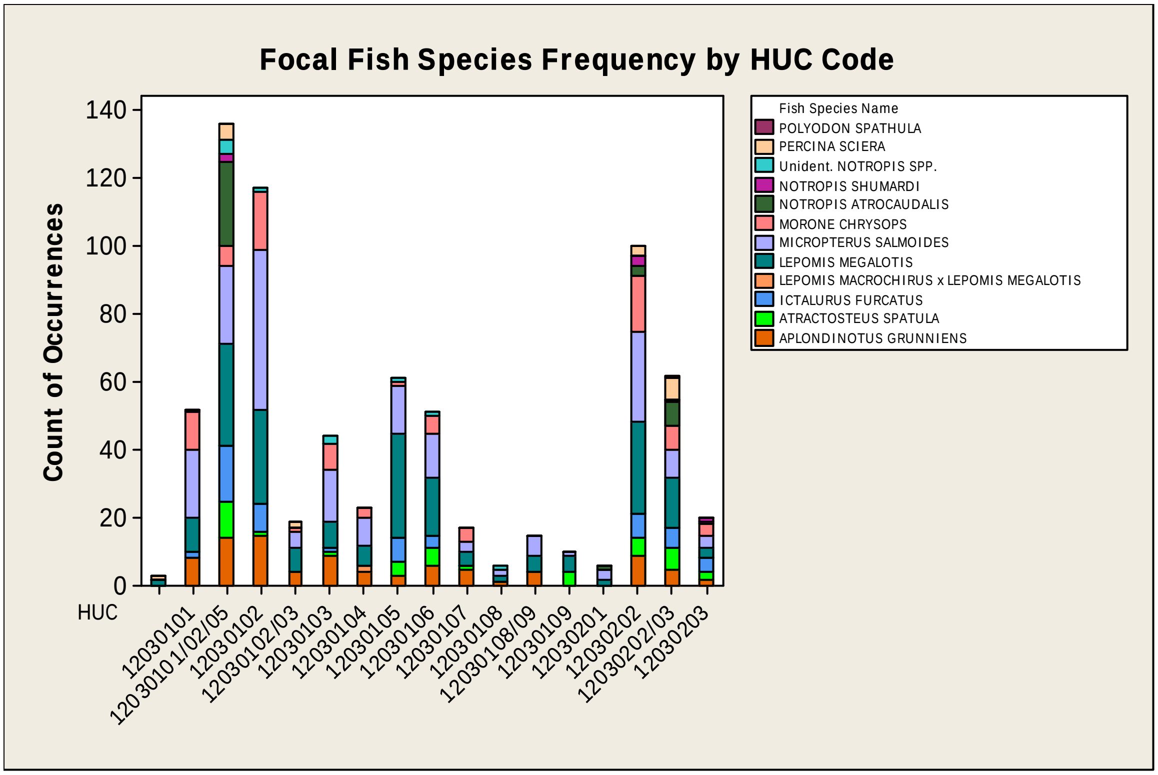


Figure 152. Distribution of focal fish species within the Trinity River Basin by year and HUC codes. Period of record 1953-2007. Includes data from fish kill investigations and reservoirs. Multiple HUC listing due to transcription from TCEQ codes.

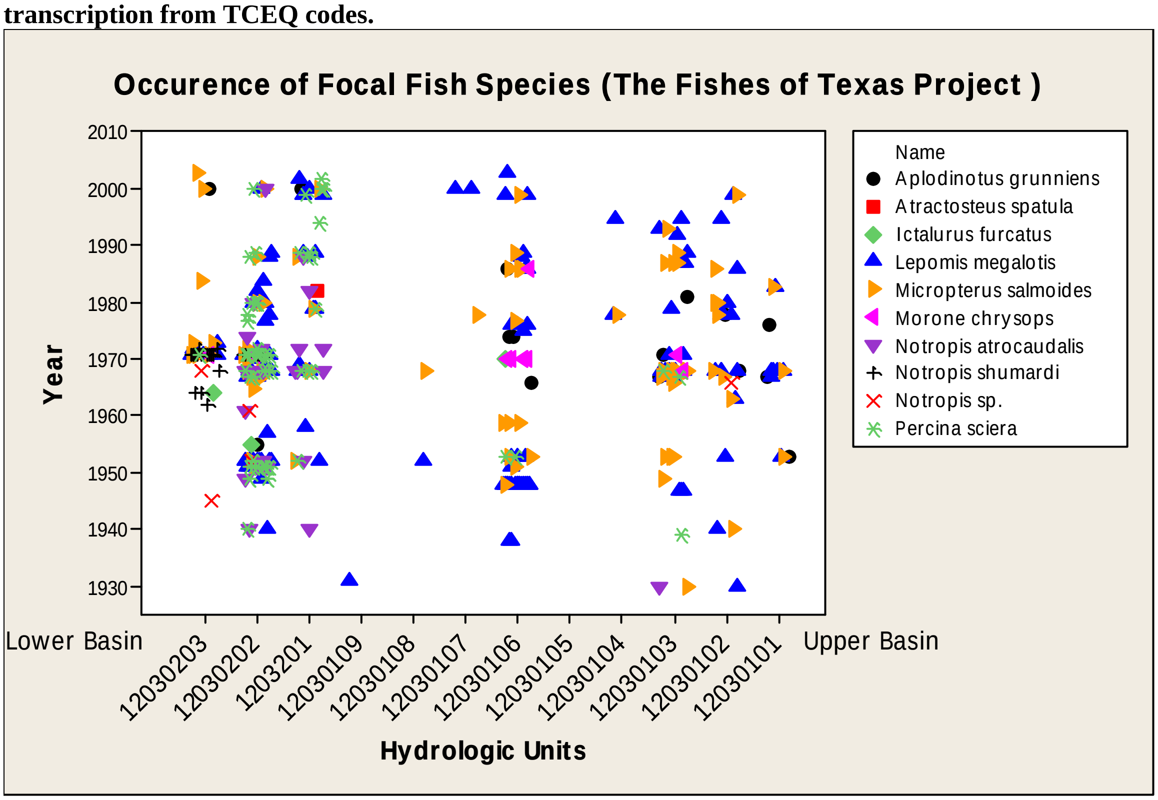


Figure 153. Distribution of focal fish species within the Trinity River Basin by year and HUC codes. Based on data provided by D. Henrickson "Fish of Texas Project". Period of record 1930 to 2004.

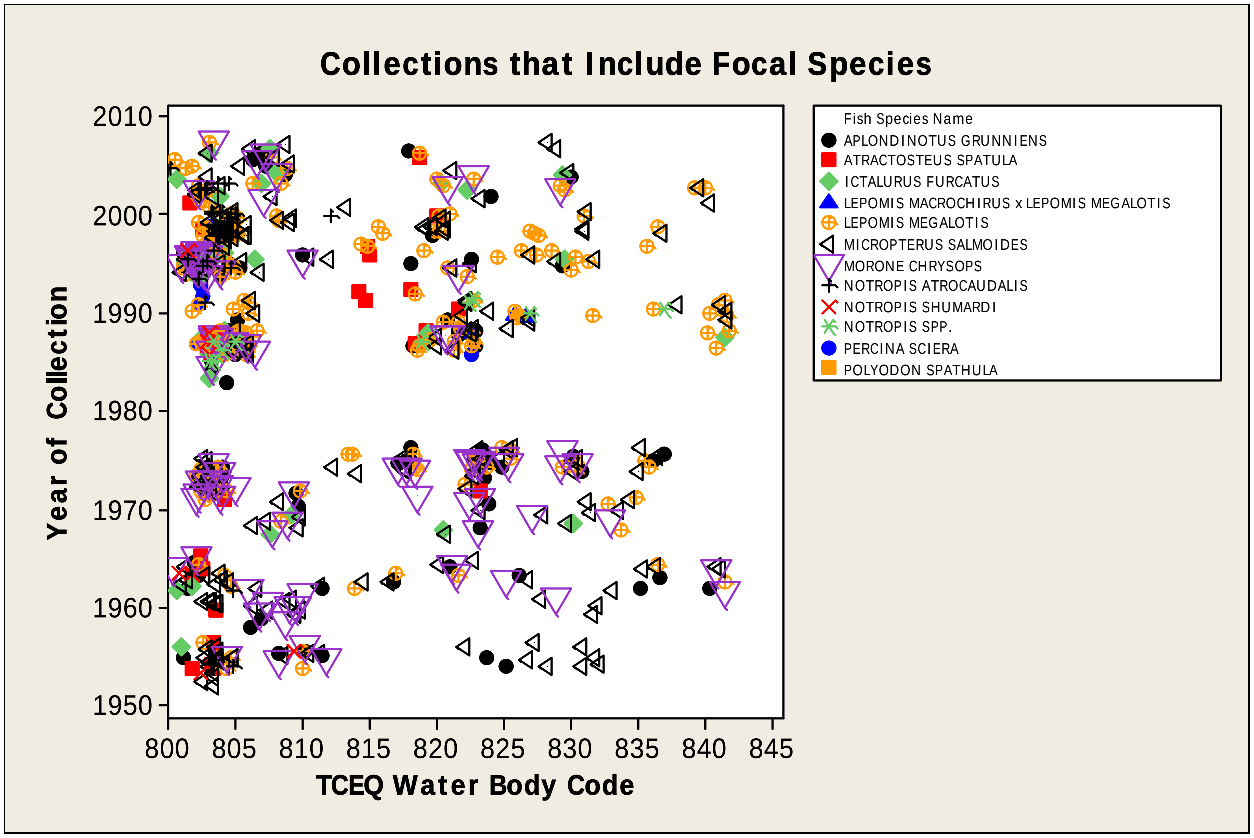


Figure 154. Distribution of focal fish species within the Trinity River Basin by year and TCEQ waterbody code. Period of record 1953-2007. Includes data from fish kill investigations and reservoirs. (jitter added to data display).

Much of the following data below was extracted from this study. Freshwater drum are typically found in a range of habitats ranging from turbid to clear lakes and rivers (Bonner 2009). It is usually found associated with benthic habitats of large, shallow bodies of water up to 40-60 feet deep. In large rivers, fish may move distances of at least 161 km. Individual freshwater drum have been observed to become distressed when water temperatures exceed 25.6°C, and when dissolved oxygen concentrations remain low over an extended period. Spawning season for freshwater drum occurs in May and June, usually when water temperatures range between 18-26°C (Bonner 2009). Spawning apparently occurs in open water. This species is considered a non-guarders, open substratum spawners or pelagophils which produces numerous buoyant eggs (Tables 3 and 4) (Simon 1999a). Hatching occurs in 1-2 days and the larvae drift for 1-2 days before settling to the bottom and begin feeding (Winemiller et al. 2005). This species is considered a riverine (flow) dependent species and a generalist (Herbert and Gelwick 2003a; Schramm Jr. 2005; Winemiller et al. 2005). Species may not be that dependent on access to aquatic habitats in the floodplain. The species probably benefit from extended periods of low flow during the summer to promote benthic secondary production. The freshwater drum has flow requirements for spawning and dispersal of early life stages very similar to paddlefish (Winemiller et al. 2005).

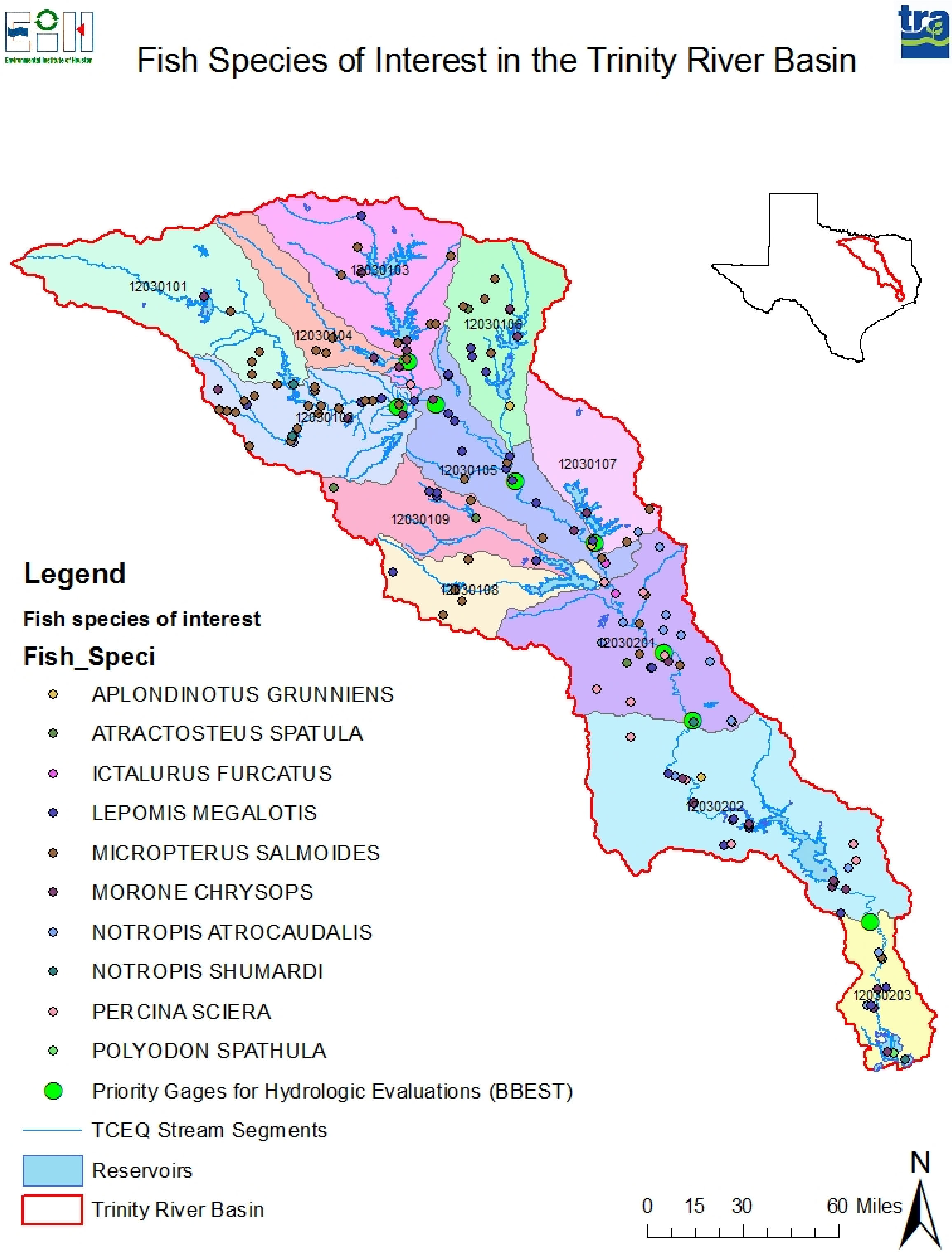


Figure 155. Spatial distribution of focal fish species in relation to priority gage sites within Trinity River basin. Period of record 1953-2007.

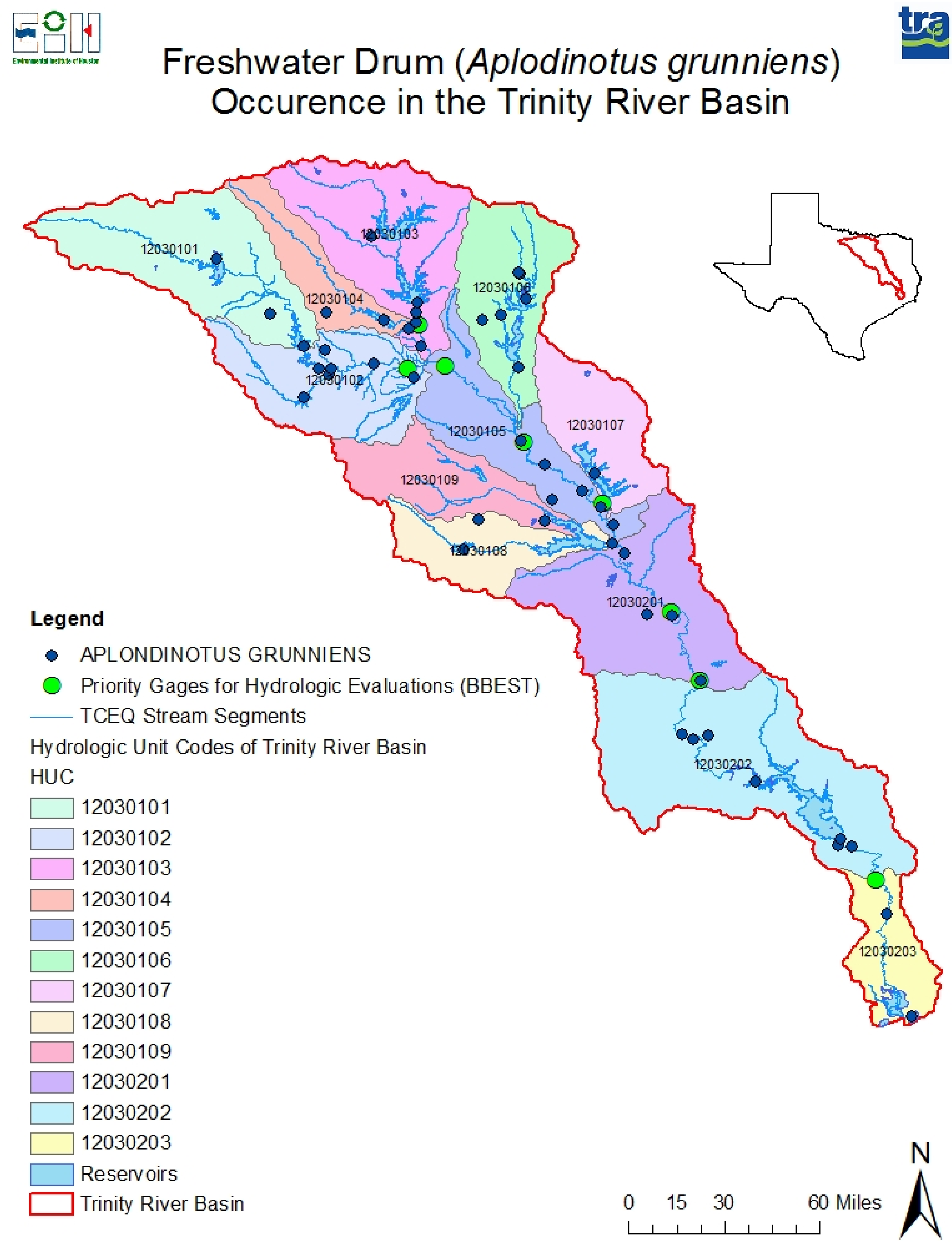


Figure 156. Spatial distribution of freshwater drum in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

Atractosteus spatula (alligator gar)

Alligator gars were found throughout the watershed at lower flows (Figures 150-155, 157). In some cases they were also collected in the vicinity of priority gages. The primary literature on the ecology of alligator gar in Texas has been summarized by (Bonner 2009). Much of the data below was extracted from his web site. Alligator gar is considered a species of concern in Texas (Table 3)(Hubbs et al. 2008). It inhabits large river systems and is dependent upon backwater and floodplain habitats for reproduction. It is a top level piscivore (Table 3) (Linam and Kleinsasser 1998). It is generally associated with near surface habitats in slack water and backwater habitats of rivers (Bonner 2009). It prefers pool, pool-bank snag, pool-channel snag, pool-snag complex, pool-edge, and pool-vegetation habitat. It has been collected from deep, frequently connected oxbow lakes; and has significantly higher abundance in oxbow habitats during wet years (Bonner 2009). Typically specimens collected from oxbows are juveniles (409- 810 mm), while only adults (1474-1850 mm) are captured in the river channel (Bonner 2009). However, this may be due in part to large individuals escaping capture in oxbow sampling. Adults may move into oxbows during flooding to exploit abundant prey, returning to the river channel later. Factors including enhanced foraging, growth and survival may influence juveniles to remain in oxbows for extended periods (Bonner 2009). The spawning season most likely extends from April to June in Texas based on observed activity in Louisiana and Oklahoma (Bonner 2009). Alligator gar are considered phytophils, specifically plant material nesters that have adhesive eggs and free embryos that attach to plants by cement glands (Bonner 2009; Simon 1999a). Furthermore they are classified as nonguarders; open substratum spawners. They are long lived species living up to 50 years. No other specific data on instream flow requirements for Texas populations or elsewhere were encountered. No data was found on possible host relationships with mussel species of concern.

Ictalurus furcatus (blue catfish)

Blue catfish were found throughout the watershed at lower flows (Figures 150-155, 158). Blue catfish are large river species with adults inhabiting the main river and juveniles being found in tributaries. It is considered a sportfish in Texas. Blue catfish are migratory and prefer open waters of large reservoirs and main channels, backwaters, and flowing rivers with strong current where water is normally turbid (Graham 1999). Declines in blue catfish have been documented and appear to be associated with stream channelization, snag removal and depressed oxygen (Graham 1999). They appear to be more sensitive to hypoxia than channel catfish. The primary literature on the ecology of blue catfish in Texas has been summarized by (Bonner 2009). In Texas, blue catfish usually inhabit larger rivers and streams (Bonner 2009). It is typically found in rivers and streams containing swift chutes and pools of noticeable current, and over bottom areas that contain silt-free sand, gravel and rubble substrates (Bonner 2009). Based on published literature and TPWD coastal fisheries data it will also enter estuaries and upper Galveston Bay during freshets. It has been found in salinities between 3.7 to 15 ppt (Bonner 2009; Graham 1999). Blue catfish is considered an indicator species for lower salinity regimes in Galveston Bay. Blue catfish spawn between April and June at water temperatures of 21-25 degrees C (Bonner 2009). Males construct nests in cavities often in pools and backwaters (Simon 1999a). It is classified as a guarder, nest spawners or speleophils or hole nester (Table 3) (Simon 1999). A nest is constructed and cared for by the parents until the young hatch. Blue catfish can live at least 14 years but their life expectancy is likely over 20 (Bonner 2009). No other specific data on instream flow requirements for Texas populations or elsewhere were encountered.

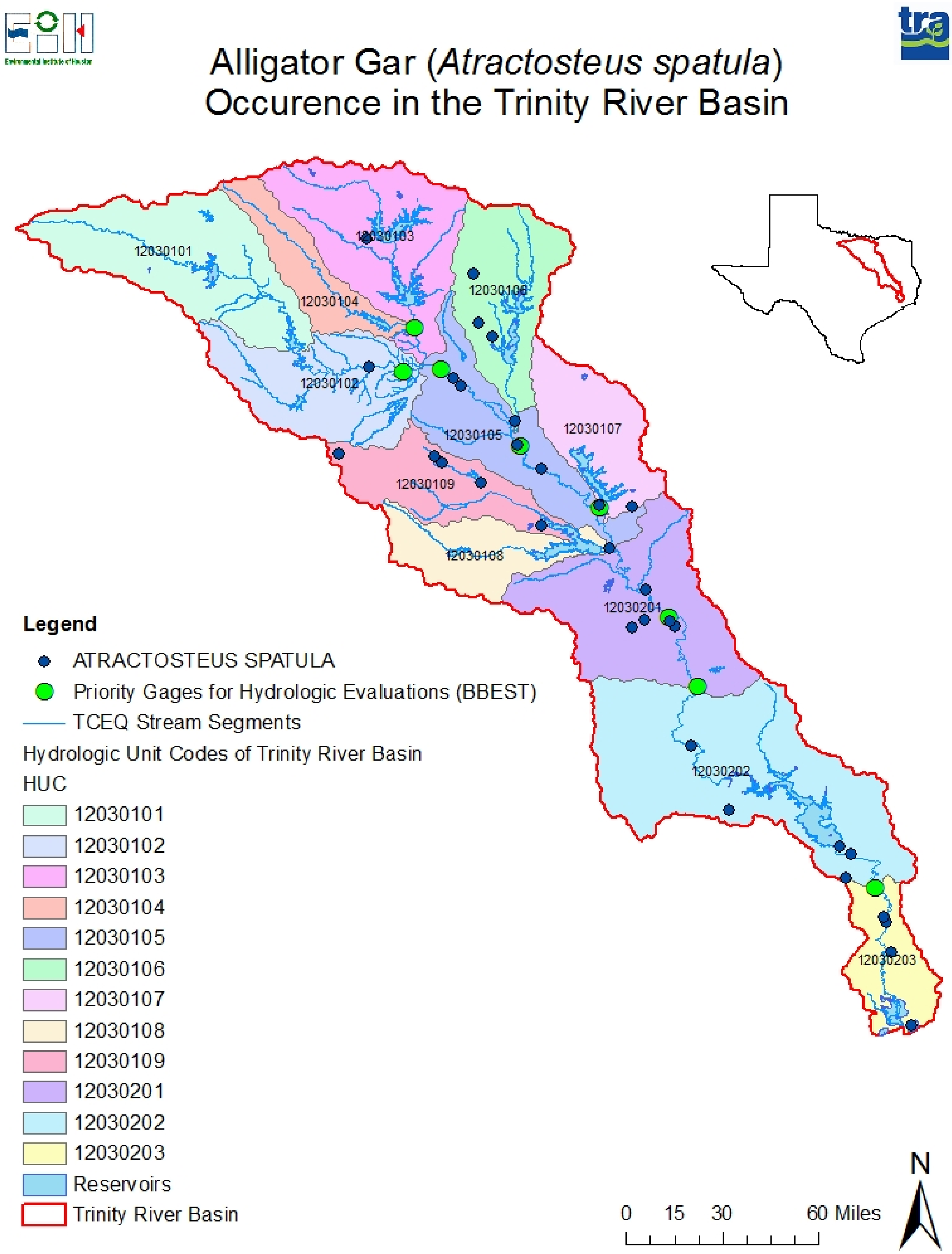


Figure 157. Spatial distribution of alligator gar in relation to priority gage sites within the Trinity River Basin. Period of Record 1953-2007.

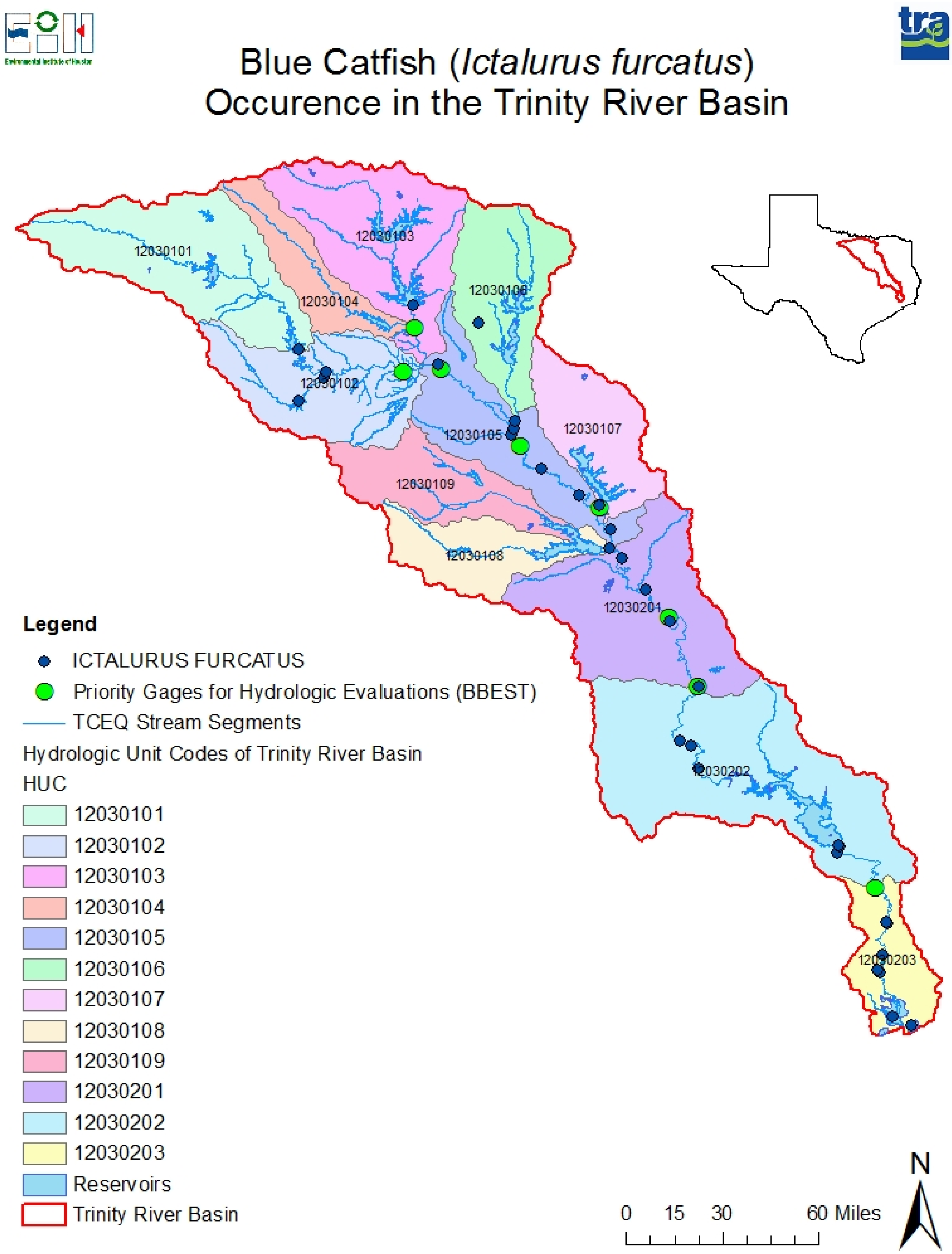


Figure 158. Spatial distribution of blue catfish in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

Lepomis megalotis (longear sunfish)

Longear sunfish was one of the most common species collected throughout the watershed based on historical records (Figures 150-155, 159). They were captured over a larger range of flows and were generally the one of the few species collected above 10 cfs. In addition, this species was generally more abundant in the upper portion of the watershed. Many collections occurred very close to the priority gage sites (Figures 154). A comprehensive synthesis of the ecology of the species is provided by (Warren 2009). The primary literature on the ecology of longear sunfish in Texas has been summarized by (Bonner 2009). Longear sunfish inhabits both main stem rivers and tributaries in pools and backwater areas. It is an invertivore (Simon 1999a)(Table 1). They are reported to serve as potential hosts for at least two species of mussel glochidia (Table 5). Longear sunfish are typically found in reservoirs and small streams (Bonner 2009). They are abundant in clear, small upland streams with rocky or sandy bottoms and permanent or semi-permanent flows with pools ((Warren 2009). In previous studies in Mississippi, longear sunfish habitat averaged 61 cm deep and had slow current flow (5.2 cm/s) and possessed a silt, mud or sand substratum (Bonner 2009). This species generally shows little movement in streams; however, when movements do occur they are more often downstream than upstream and average approximately 17 km. Longear sunfish spawning occurs during the late spring and early summer (Bonner 2009). Spawning may occur at discrete intervals from late May to August between 22 and 31 C (Warren 2009). This species is considered a polyphil, that is utilizing miscellaneous substrate and material for nest building and producing adhesive eggs that are either attached or occur in clusters (Table 3)(Simon 1999a). Spawning has been reported in shallow water with gravel bottom, shallow water and little current (Bonner 2009). Flood events and potentially associated lowered water temperatures can delay initiation of spawning and result in high nest abandonment and decreased brood survival (Warren 2009). It is believed that longear sunfish can live up to 6 years in southern areas (Bonner 2009). Longear sunfish were most often found in pools (velocity 0.07 to 0.29 m/s) (Edwards 1997). (Schramm Jr. 2005) classified longear as a backwater dependent species. (Bio-West Inc 2008) grouped this species into the shallow pool/backwater guild. No other specific data on instream flow requirements for Texas populations or elsewhere were encountered.

Micropterus salmoides (largemouth bass)

Largemouth bass was one of the most common species collected throughout the watershed based on historical records (Figures 150-155, 160). It inhabits both the main stem Trinity River and tributaries in pool and backwater areas. It is considered a nest builder and piscivore (Table 3). Furthermore it is considered on the most popular freshwater sportfish in Texas. Largemouth bass were one of the most common species collected in the Trinity River. They were captured over a large range of flows and were generally one of the few species encountered above 10 cfs. Largemouth bass were encountered more frequently in the upper portion of the watershed (Figure 160). Many collections occurred very close to the priority gage sites. Largemouth bass are reported to serve as a host for at least 4 species of mussel glochidia (Table 5) The primary literature on the ecology of largemouth bass in Texas has been summarized by (Bonner 2009). A comprehensive synthesis of the ecology of the species is provided by (Warren 2009).

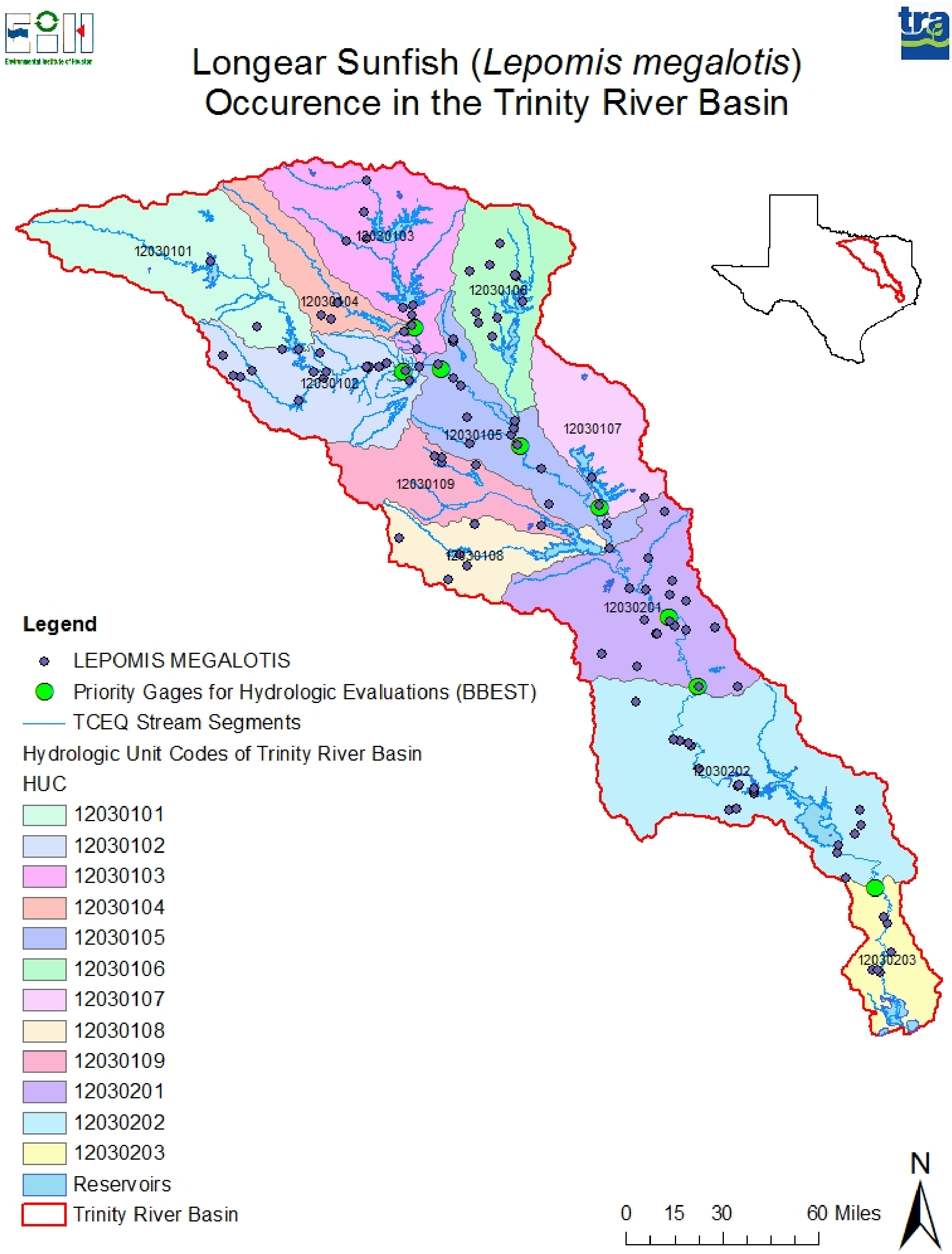


Figure 159. Spatial distribution of longear sunfish in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

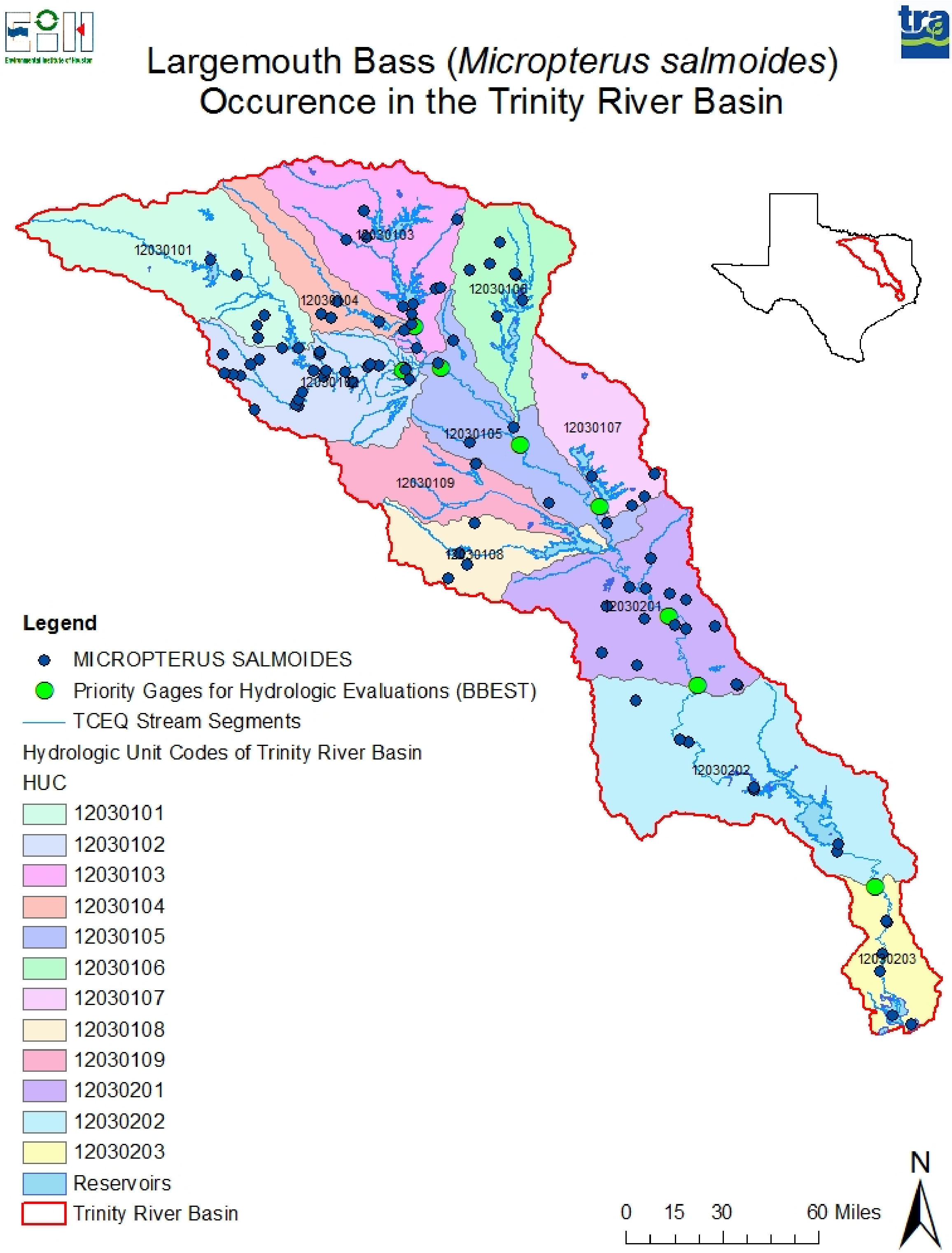


Figure 160. Spatial distribution of largemouth bass in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

Largemouth bass are found in lakes, ponds, reservoirs, backwaters, and slow-moving rivers and streams. They appear to prefer clear, quiet waters with aquatic vegetation but can survive in a wide variety of mesohabitats. In riverine habitats young and adults are most common in deep pools or low-velocity habitats near undercut banks, instream wood, overhanging and aquatic vegetation, or other cover (Warren 2009). The spawning season for largemouth bass occurs in late winter or early spring (mid March to May), when water temperatures rise to about 15.5 degrees C and continuing over a temperature range of 15-24 degrees C (Bonner 2009; Warren 2009). Largemouth bass often next in backwater areas lacking current, either stream margins, oxbows or floodplain lakes (Winemiller et al. 2005). Largemouth bass are considered polyphils utilizing miscellaneous substrate and material to create nests that receive adhesive eggs that are either attached or occur in clusters (Simon 1999a) Largemouth bass guard their nests. The male guards nest for several weeks after spawning. Largemouth bass can tolerate warm (<= 38.5 C) temperatures, but are limited by colder water (<10C), and can tolerate low dissolved oxygen > 3.0 mg/l (Warren 2009).

A habitat suitability index (HSI) model that addresses instream flow needs for riverine largemouth bass has been published by USFWS (Stuber et al. 1982)(Figure 161). According to the authors, the models are applicable throughout the natural range of largemouth bass in lower 48 states of North America with its greatest applicability in southern states. Several riverine habitat variables were identified as useful metrics for defining suitable habitat for largemouth bass including percent pool and backwater area, percent bottom cover, water level fluctuation, dissolved oxygen, pH range, temperature, turbidity, salinity, and substrate, current velocity and stream gradient (Stuber et al. 1982). Suitable levels of these variables that would support and/or provide critical life functions including food, cover, water quality and reproduction were defined. Several of these including percent pool and backwater area, water level fluctuation and current velocity are directly affected by hydrology (Stuber et al. 1982). For example rivers possessing greater than 55% pool and backwater areas during average summer flows are considered the best conditions for providing food. Minimum dissolved oxygen levels in pools that are frequently above 8.0 mg/l are considered ideal water quality conditions. Ideal average water level fluctuations during the growing season for adults and juveniles should be less than 3 meters (Stuber et al. 1982). The ideal maximum water level fluctuation during spawning should be close to zero for embryos. The average water level fluctuation during growing season for fry should be no more than 1 meter (Stuber et al. 1982). Average current velocities at 0.6 depths during summer should be less than 6 cm/sec for adult and juveniles. Maximum current stream velocities at 0.8 depths within pools and backwater during spawning should be less than 3.0 cm/sec during the spawning period. Average current velocity at 0.6 depths during the summer for fry rearing should be 0.8 cm/sec during the summer to optimize survival and growth. These metrics, along with the other less flow dependent variables, are used in the construction of a total HSI that can used in the Habitat Evaluation Procedure (HEP) and/or Instream Flow Incremental Approach (IFIM) physical habitat simulation model (PHABSIM), or similar approaches, to define and describe how overall habitat and quality vary with flow. A copy of this document with associated suitability index curves is provided with this report. In order to appropriately apply these HIS metrics, all of the metrics should be evaluated simultaneously in order to properly evaluate how habitat fluctuates with flow regime.

(Schramm Jr. 2005) classified largemouth bass as a backwater dependent species. (Bio-West Inc 2008) grouped this species into the shallow pool/backwater guild. (Winemiller et al. 2005) evaluated this species for use in setting instream flow targets in the Big Cypress Caddo Lake system (Figure 162).

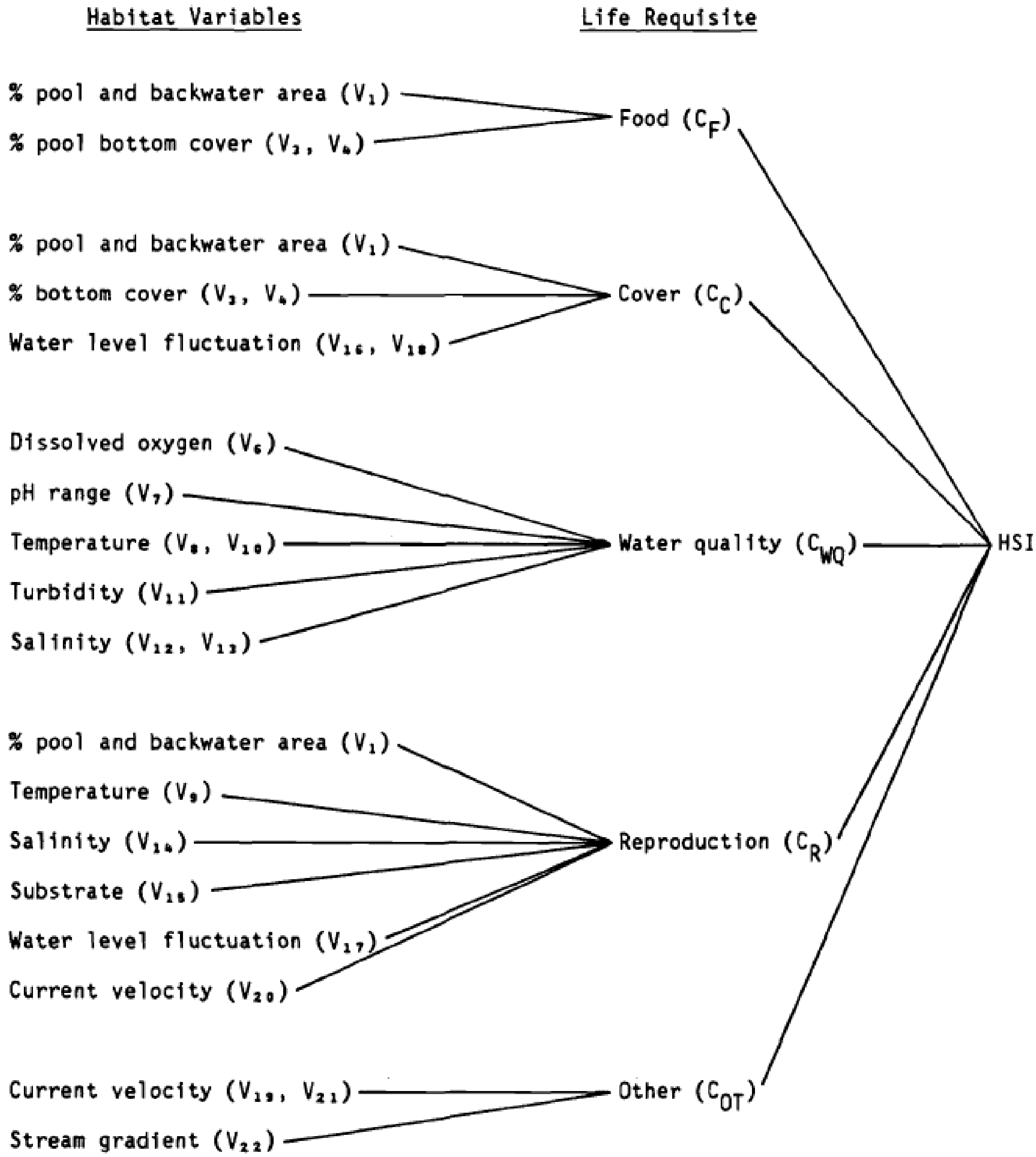


Figure 161. Conceptual structure for riverine model for largemouth bass (Stuber et al. 1982).

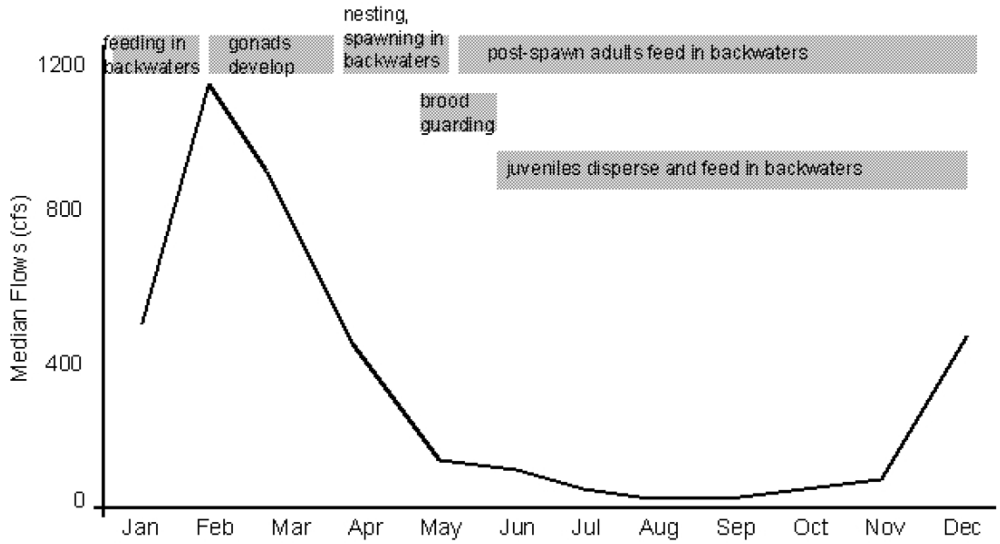


Figure 162. Largemouth bass (backwater dependent species) life cycle in relation to seasonal flow (portrayed relative to pre-1957 median flows in Big Cypress Bayou). Source: (Winemiller et al. 2005)

Morone chrysops (white bass)

White bass was collected throughout the watershed based on historical records (Figures 150-155, 163). It inhabits both the main stem Trinity River and reservoirs. Many collections occurred very close to the priority gage sites. White bass typically inhabits main stem rivers and are considered migratory. They are considered sportfish within Texas and many states. White bass are also reported to serve as a host for at least three species of mussel glochidia (Table 5). The primary literature on the ecology of white bass in Texas has been summarized by (Bonner 2009). This species is abundant in lakes and reservoirs, being more common in clear versus turbid waters (Bonner 2009). The spawning season extends from mid-March to late May at water temperatures of 12-20 degrees C (Bonner 2009). White bass are open substratum spawners and phytolithophils (nonobligatory plant spawner that deposit eggs on submerged items) which have late hatching larvae with cement glands (Table 3). The larvae have moderately developed respiratory structures, and are photophobic (Bonner 2009). Most phytolithophils reproduce in clear water on submerged plants or, if not available, on other submerged items such as logs, gravel, and rocks in shallow (< 3m) water (Balon 1975; Balon 1981; Simon 1999a). Spawning usually occurs in small tributary streams or wave-swept points or shoals within reservoirs (Bonn 1952; Riggs 1955). The species is a nonguarders (Simon 1999a). The species forms spawning groups consisting of several males following a ripe female. The female then rises to the surface releasing her eggs which may be fertilized by several males that have remained in close proximity to her. The demersal adhesive eggs then sink to the bottom, attaching to rocks, boulders, plants, or other surfaces. The species is considered a potamodromus species that homes, often forming unisexual schools that migrates to spawning sites on shoals and in streams in the spring(Bonner 2009). Fish move upstream in early spring, when water temperatures are above 7-13°C, with males preceding females onto spawning grounds by at times at least a month. The net movement during these spawning runs occurs from either large rivers or reservoirs into small streams for spawning.

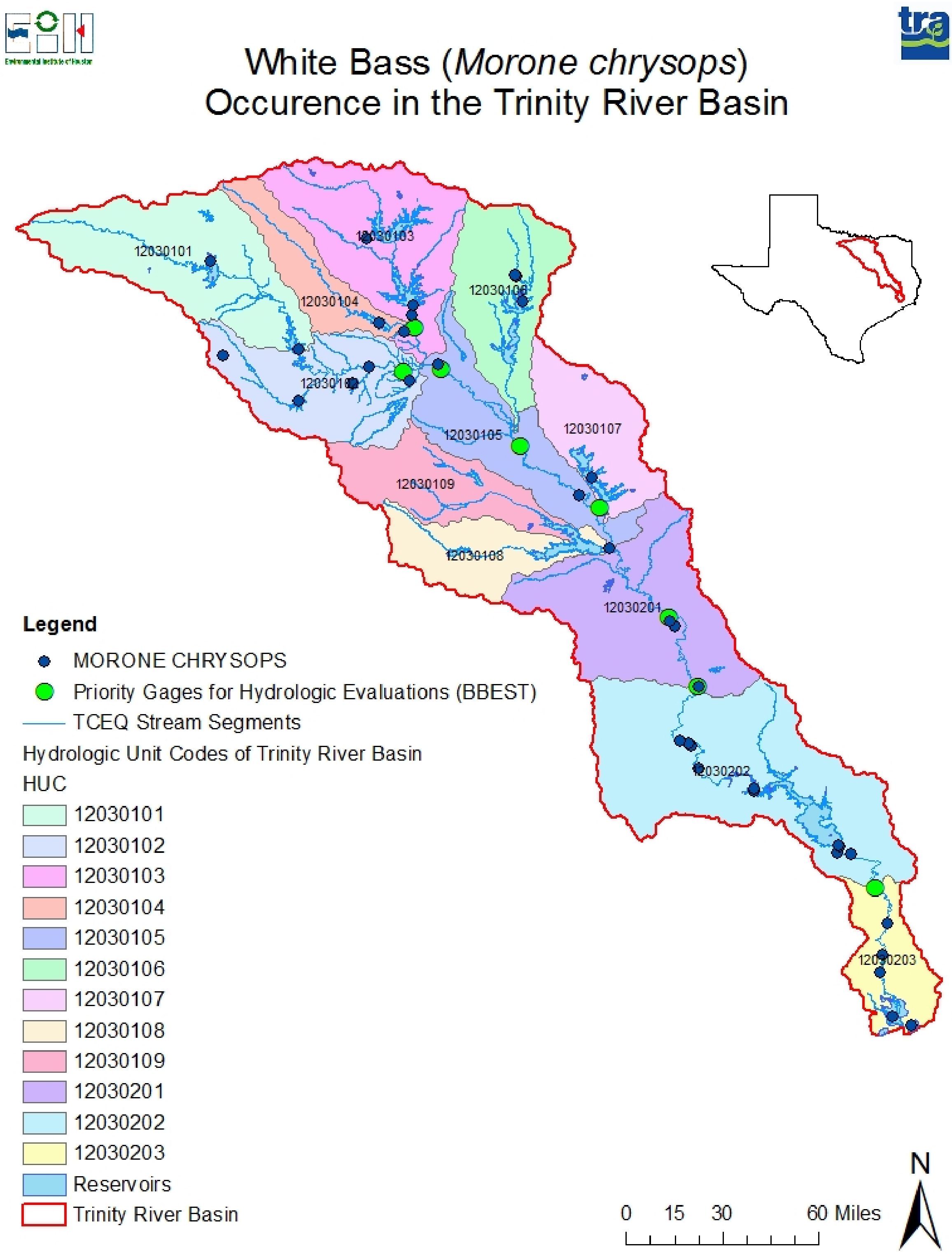


Figure 163. Spatial distribution of white bass in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

A habitat suitability index (HSI) model that addresses instream flow needs for white bass has been published by USFWS (Hamilton and Nelson 1984)(Figure 164). According to the authors, the models are applicable throughout the natural range of white bass in lower 48 states of North America with its greatest applicability in southern states. Several riverine habitat variables were identified as useful metrics for defining suitable habitat for white bass including forage fish, water level change, temperature, length: depth ratio, stream order, percent low velocity area, day-degrees and substrate index. Suitable levels of these variables that would support and/or provide critical life functions including food and reproduction were defined. Several of these including water level change, percent low velocity area and temperature are directly affected by hydrology. For example rivers possessing between 25 and 75% surface area with a surface current velocity $\leq$ 0.4 m/sec provide the best habitat for this species. This can include deep pools, behind structure or off channel pools. Another metric is the maximum water level change from the onset of white bass spawning to the hatching of fry. The ideal value is zero which declines linearly to -4.0 meters. Another metric is average weekly water temperature during spawning and incubation. The ideal range is 15 to 17 C (Hamilton and Nelson 1984). These metrics, along with the other less flow dependent variables, are used in the construction of a total HSI that can used in the Habitat Evaluation Procedure (HEP) and/or Instream Flow Incremental Approach (IFIM) physical habitat simulation model (PHABSIM), or similar approaches, to define and describe how overall habitat and quality vary with flow. A copy of this document with associated suitability index curves is provided with this report.

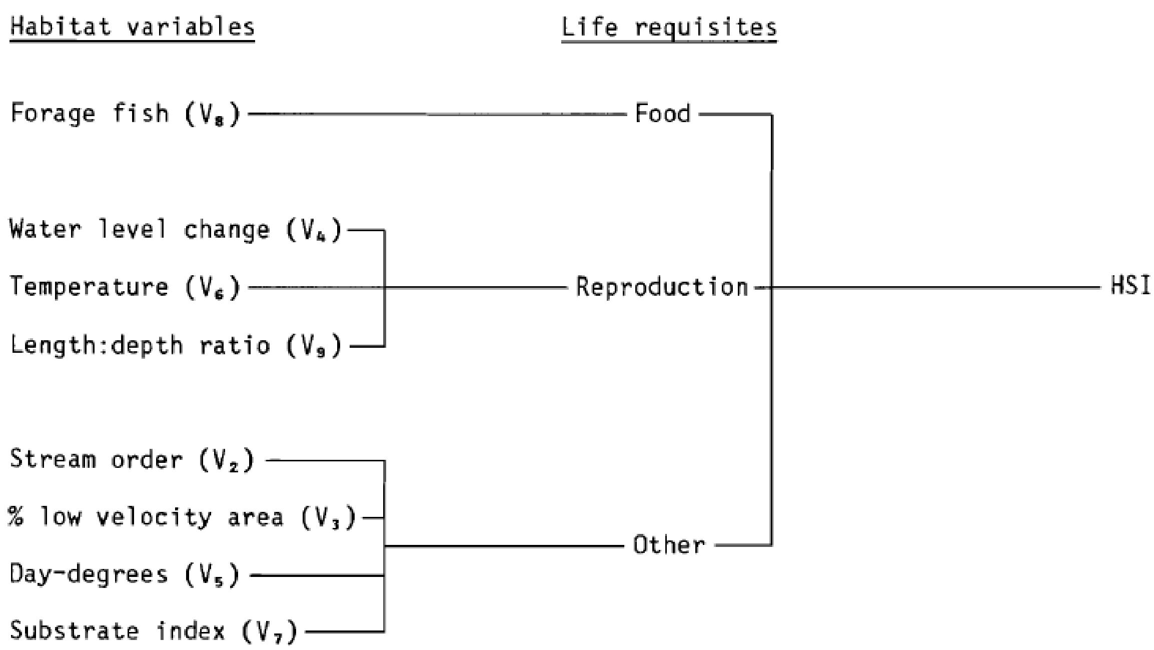


Figure 164. Conceptual structure for riverine model for white bass.

Notropis atrocaudalis (blackspot shiner)

Blackspot shiner was collected primarily in the middle and lower portion of the watershed based on historical records (Figures 150-155, 165). Only three of the priority gage sites in the middle and lower Trinity River were located near historical collections. Based on historical records Blackspot shiner was collected at various flows less than 12 cfs in the Trinity River (Figure 150). Blackspot shiner was recommended as a focal species by TPWD because it is a species of concern (Table 3) (Hubbs et al. 2008). The primary literature on the ecology of blackspot shiner in Texas has been summarized by (Bonner 2009). Blackspot shiner inhabits small to moderate size tributary streams. It is usually more abundant near headwaters. The species classified as a fluvial specialist (Bonner 2009). It is found in runs and pools over all types of substrates, generally avoiding areas of backwater and swiftest currents. In Banita Creek, TX, blackspot shiner were found at mean depths ranging from 0.19 to 0.29 m, and mean current velocities ranging from 0.13 to 0.30 m/s (Bonner 2009). The species most commonly occurs in small seepage-fed hill streams with sandy bottoms, where it is closely associated. The blackspot shiner spawning season occurs from April through June in open water, most likely producing multiple batches of eggs throughout the season. This species is most likely a pelagophils (broadcast spawner)(Balon 1981; Bonner 2009). Juveniles of this species may undergo movement between downstream sites to upstream sites up to 15 km (Bonner 2009). The species is believed to live up to 2 years. (Herbert and Gelwick 2003a)classified this species as a fluvial specialist. No other specific data on instream flow requirements for Texas populations or elsewhere were encountered.

Notropis shumardi (silverband shiner)

Silverband shiner has been collected infrequently throughout the watershed based on historical records (Figures 150-155, 166). It was collected primarily in the lower and upper portions of the watershed at lower flow (< 5 cfs) (Figures 150 and 166). It occurred only near two of the priority gage sites. According to TPWD silverband shiner is considered a species of concern and sensitive to alterations in stream flow and is a species of concern (Table 3) (Hubbs et al. 2008). The primary literature on the ecology of silverband shiner in Texas has been summarized by (Bonner 2009). Silverband shiner is found large rivers as well as smaller tributaries and oxbows. Past research in Brazos River indicates that it is common in oxbow lakes that frequently reconnect to the mainstem river (Balon 1981). It is founds in the main channel of rivers with moderate to swift current velocities and moderate to deep depths. It is often found in turbid water over silt, sand, and gravel substrate. The species is tolerant of high turbidities. The spawning season occurs from May through mid August at least and possibly mid-fall.(Bonner 2009). Spawning occurs in the main channels of rivers. Breeding aggregations have been observed over hard sand to fine gravel substrates in water 1-2 m deep in strong current (Bonner 2009). The species is likely a broadcast spawner. This species may migrate into tributaries for spawning, especially during high flows. The reported maximum lifespan of approximately 2 years. No other specific data on instream flow requirements for Texas populations or elsewhere were encountered.

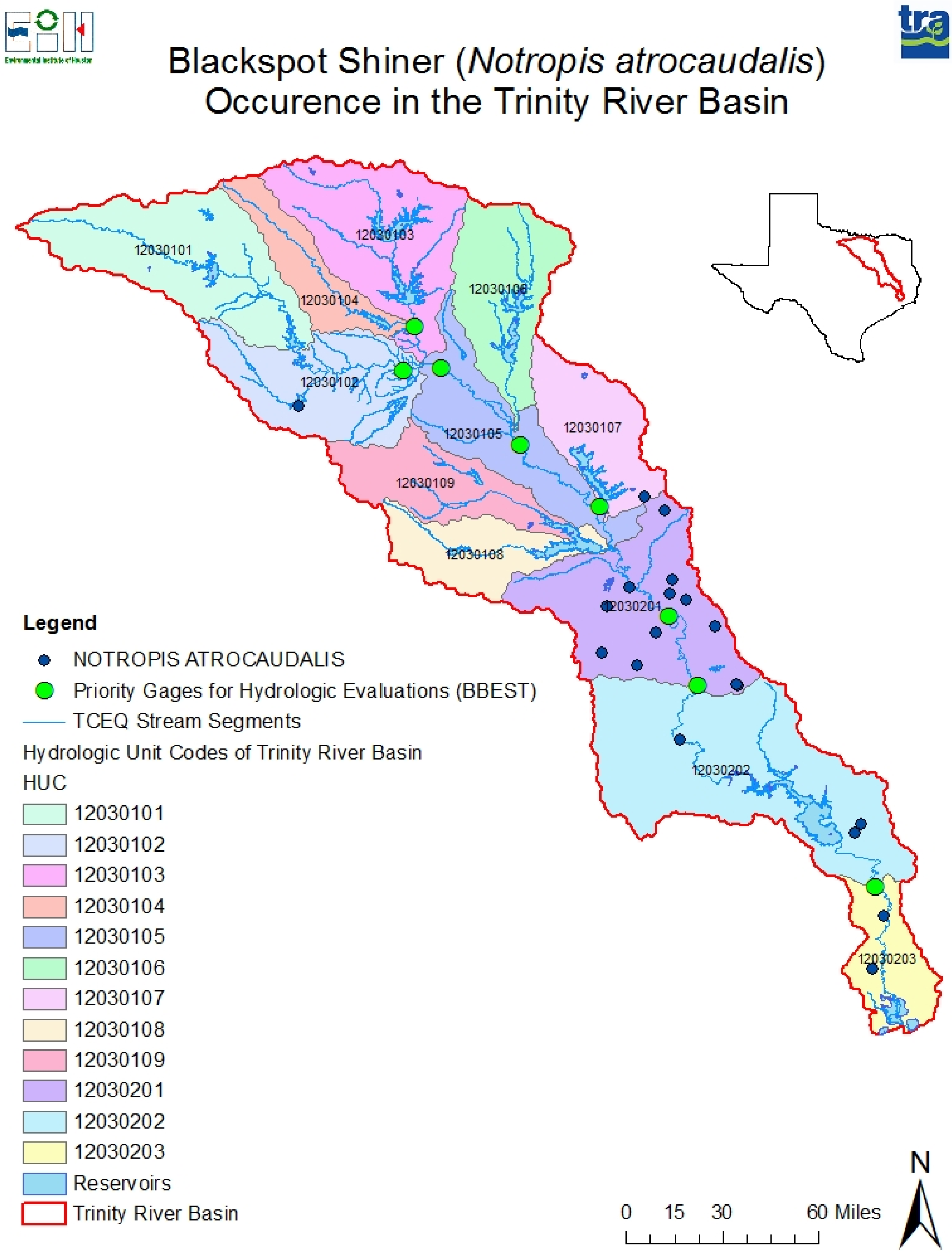


Figure 165. Spatial distribution of blackspot shiner in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

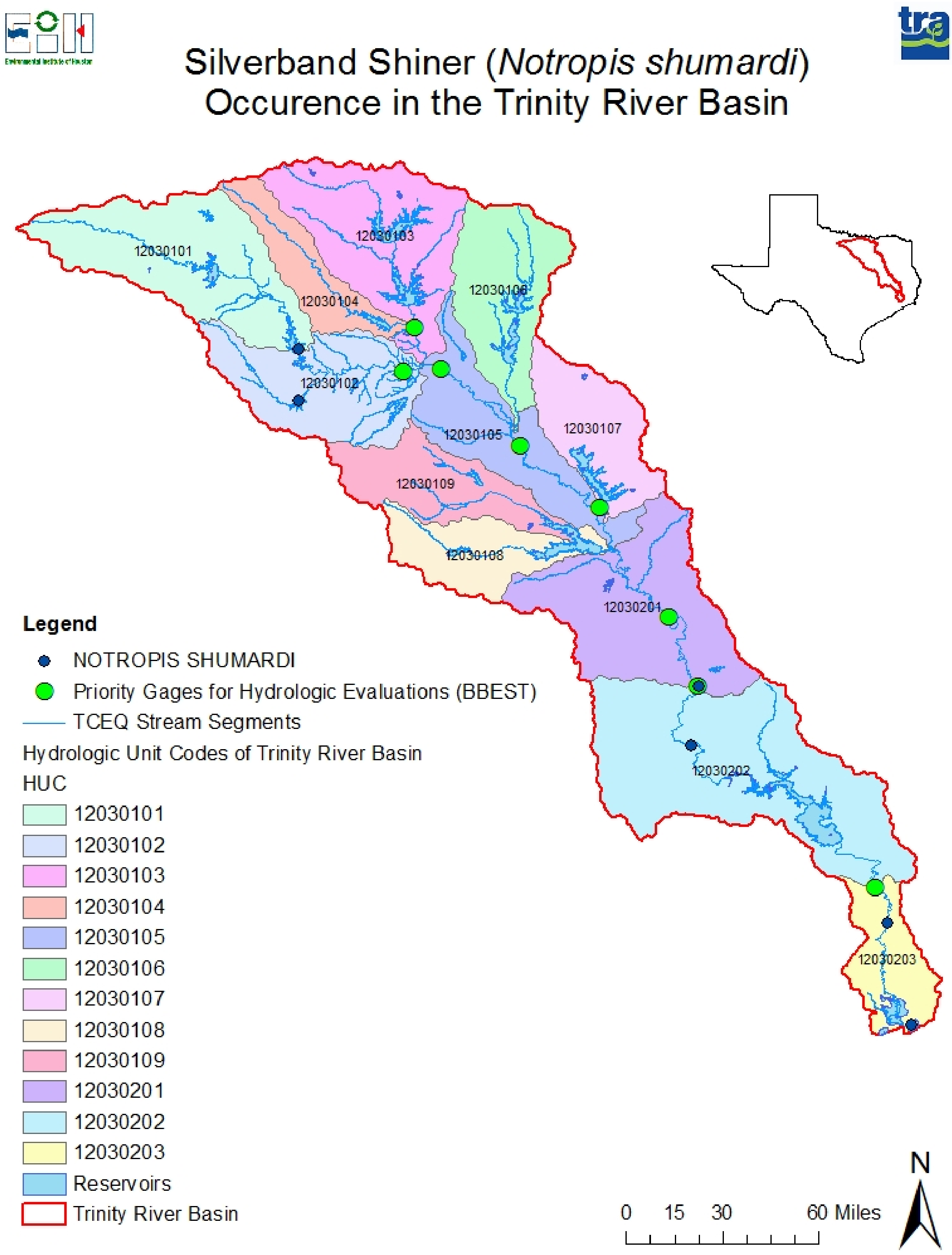


Figure 166. Spatial distribution of silverband shiner in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

Percina sciera (dusky darter)

Based on historical records dusky darter was collected primarily in the middle and lower portions of the watershed at various flows up to approximately 12 cfs. (Figures 150-155, 167). It was collected in numerous tributaries as well. It is considered and invertivore and considered intolerant of poor water quality (Table 3)(Linam and Kleinsasser 1998). Dusky darter inhabits main stem and tributaries in run and riffle areas and is considered flow sensitive by TPWD biologists. The primary literature on the ecology of dusky darter in Texas has been summarized by (Bonner 2009). The species is found in medium to large streams of moderate to low gradients which are not highly turbid. (Herbert and Gelwick 2003a) found this fluvial specialist to be associated with the free-flowing East Fork of the San Jacinto River, Texas. Prior to impoundment, this species was common in the West Fork of the San Jacinto River, Texas, but no specimens were collected during the study at West Fork sites where the species had been present before impoundment. This species is most common over gravel or gravel and sand raceways and often occupy midwater stratum in moving current within accumulations of branches and leaves (Bonner 2009). The young, in contrast to adults are often found along the shallow gravel edges of pools with moderate currents and at times may enter tributaries not visited by adults (Bonner 2009). Throughout its range this species is often forms species associations with other fishes including *Percina caprodes* and *Etheostoma* (including *E. spectabile, E. lepidum and E. fonticola*, *E. gracile*, and *E. histrio* (Bonner 2009). Many of species were categorized into the same guild based on our cluster analysis (Figure 144 and Table 11). Spawning most likely occurs in Texas from February - June (Bonner 2009). Dusky darters are considered lithophils spawning over rock and gravel substrate (Simon 1999a). Spawning has occurred over gravel riffles at depths of 30-90 cm. During the winter dusky darter may shallower upstream locations and smaller tributaries and move to deeper downstream habitats. Males typically live up to 4+ years while females tend to live to 3+ years (Bonner 2009). (Edwards 1997) described the mean and range of velocities at which dusky darter typically occur including habitat they were usually found in. He found that this species most often (68%) in riffles most often at 0.5 to 0.74 m/s. (Herbert and Gelwick 2003a) considered this species a fluvial specialist. (Bio-West Inc 2008) classified this species into riffle guild and proposed HSC criteria for the guild (Figure 168).

Polyodon spathula (paddlefish)

Based on our historical review paddlefish have only been collected in the mainstem Trinity River below Lake Livingston at low flows (Figures 155-160, 169). However, at least 130,503 juveniles were stocked in Lake Livingston during 4 years (1990-1993) (Henson and Webb 2004). Paddlefish is considered threatened in Texas (Table 3)(Hubbs et al. 2008). They are riverine dependent and inhabit medium to large rivers usually in pool and backwater areas (Schramm Jr. 2005; Wilson and McKinley 2004). The primary literature on the ecology of paddlefish in Texas has been summarized by (Bonner 2009). The are usually found in low-gradient areas of moderate to large-sized rivers, sluggish pools, backwaters, bayous, and oxbows with abundant zooplankton (Bonner 2009; Wilson and McKinley 2004). Large reservoirs provide good feeding areas, with paddlefish moving from reservoirs into flowing streams in the spring for spawning (Bonner 2009). In altered reaches of large rivers, fish occur in areas where they may find protection from strong currents, such as near dikes, or bridges (Bonner 2009). In the winter, paddlefish usually move into deep water, as in the Nueces River system, Texas, where spring to fall capture depths averaged 3.9-5.0 m, increasing to 7.6 m in the winter (Bonner 2009).

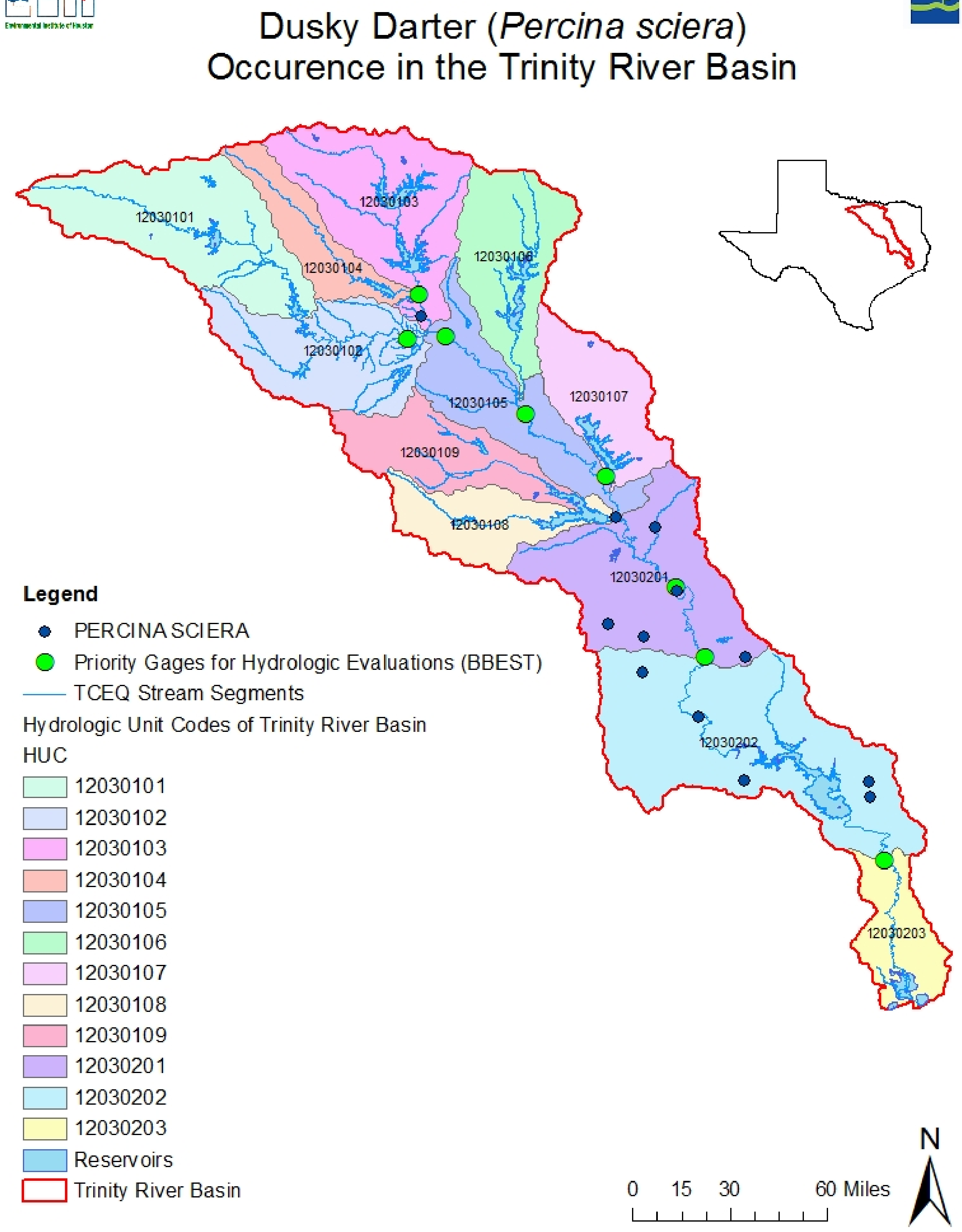


Figure 167. Spatial distribution of dusky darter in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

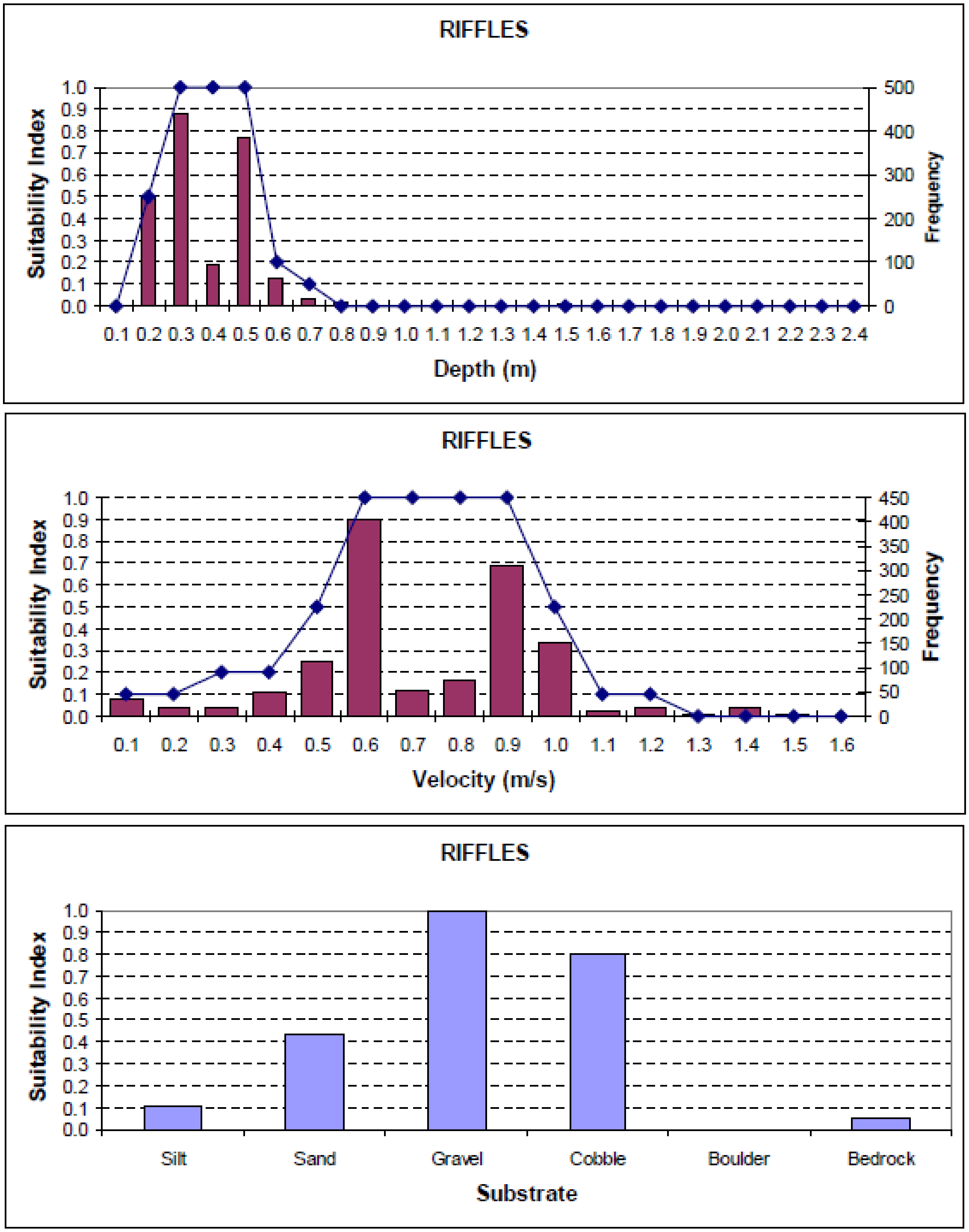


Figure 168. Frequency distribution and HSC values for riffles habitat guild for depth, velocity and substrate in the lower Colorado River. Note: Dusky Darter part of this guild. Source: (Bio-West Inc 2008)

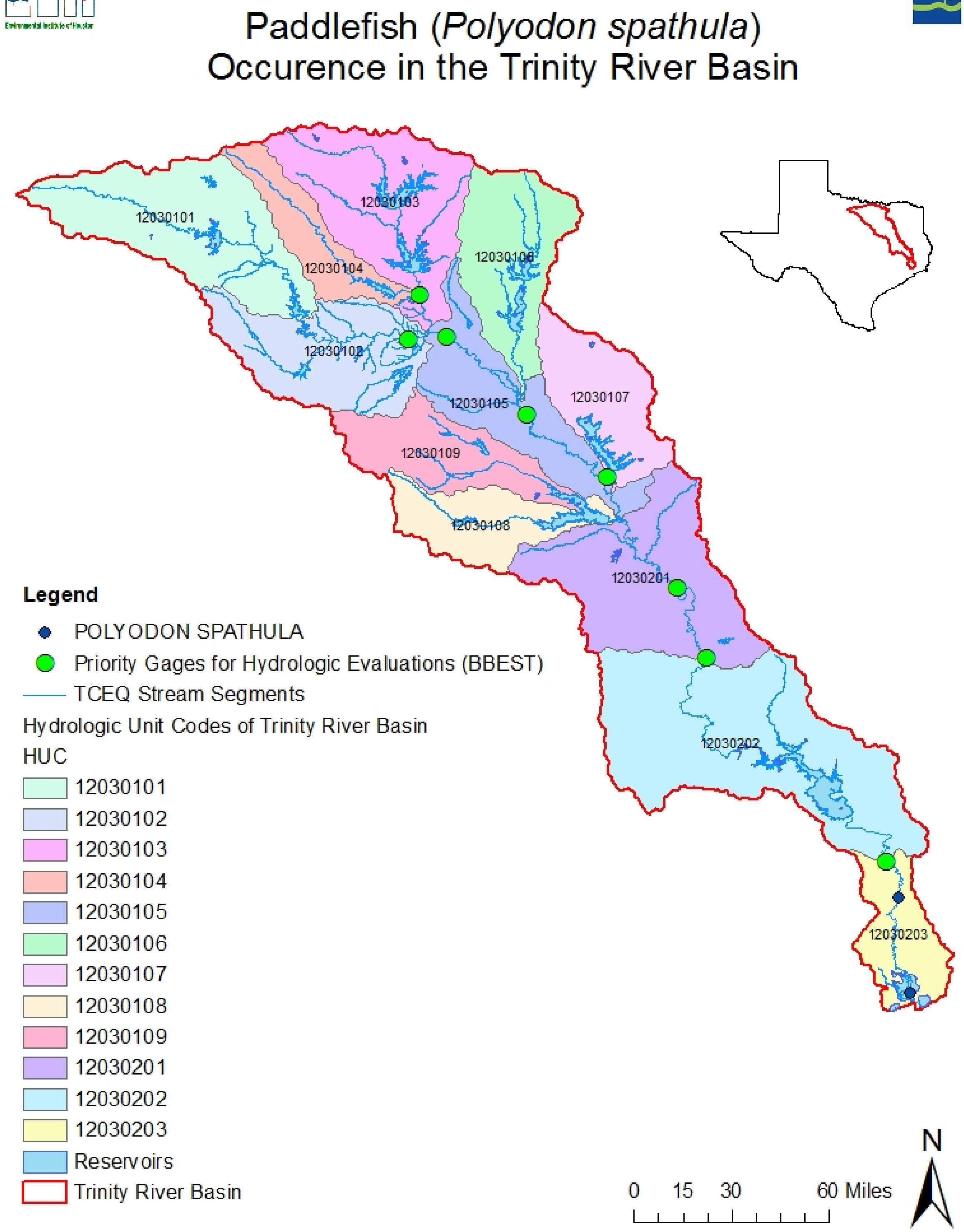


Figure 169. Spatial distribution of paddlefish in relation to priority gage sites within the Trinity River Basin. Period of record 1953-2007.

Large river populations make extensive spawning migrations in the spring associated with pools during high water, and with tailwater (where dams exist) and turbulent main-channel border habitats. Optimum temperatures for this species have been shown to range from about 12-24 C (Bonner 2009). Paddlefish spawning occurs between late February and late June when water temperatures are 10-17°C(Bonner 2009). Even at optimum temperatures, only increased and prolonged river flow will attract fish onto the gravel beds. Flow must be able to maintain a 3-5 m rise in the river for about 10-14 days (Bonner 2009; Wilson and McKinley 2004). Paddlefish typically spawn over gravel beds in swift water. Paddlefish are non-guarding open substratum spawners or lithopelagophils with pelagic embryos (Simon 1999a). Velocity, depth, or substrate may be used as cover, either singly or in combination (Bonner 2009). In the Cumberland River, Tennessee, paddlefish were observed spawning over gravel-rubble substrate in waters 2-12 m deep (Pasch et al. 1980).

Two habitat suitability index models have been developed for paddlefish, one for spawning habitat and one for adult summer and winter habitat (Hubert et al. 1984)(Figure 170). According to the authors, the models are applicable throughout the natural range of paddlefish in North America in riverine and associated reservoir habitat. Various levels of habitat variable that support reproduction and adult habitat were defined. The authors defined appropriate levels of spawning temperature, access to riverine habitat, spawning substrate, spring water level rise, spring current velocity and dissolved oxygen that would support reproduction in paddlefish. The authors also defined appropriate levels of ratios of area of summer/winter habitat, stream/reservoir width, percent backwaters and instream eddy that would provide sufficient adult habitat. Specific variables that are directly related to flow include spawning water temperature, spring water rise and spring current velocity (Hubert et al. 1984). To support reproduction it is recommended that a 21 day period of rising water temperatures between 10 and 17 C should occur annually (Hubert et al. 1984). Furthermore the authors recommended that average magnitude of spring water rise in the river over average midwinter flow for a period exceeding 10 days while temperatures are 10 to 17 C should be at a minimum 3 meters. The also recommended that the average current velocity measured at a point 0.3 meters above the substrate over potential spawning substrates during the spring water rise should be equal to or greater than 0.4 m/sec. These metrics, along with the other less flow dependent variables, are used in the construction of a total HSI that can used in the Habitat Evaluation Procedure (HEP) and/or the Instream Flow Incremental Approach (IFIM) physical habitat simulation model (PHABSIM), or similar approaches, to define and describe how overall habitat and quality vary with flow. A copy of this document with associated suitability index curves is provided with this report. (Winemiller et al. 2005) constructed a life history table relative to median flow values in the Big Cypress Bayou system where it has been extirpated. (Figure 171). He noted that because so little is known about the spawning and ecology of paddlefish, it may prove difficult to make a recommendation regarding instream flows to restore a self sustaining population under existing constraints.

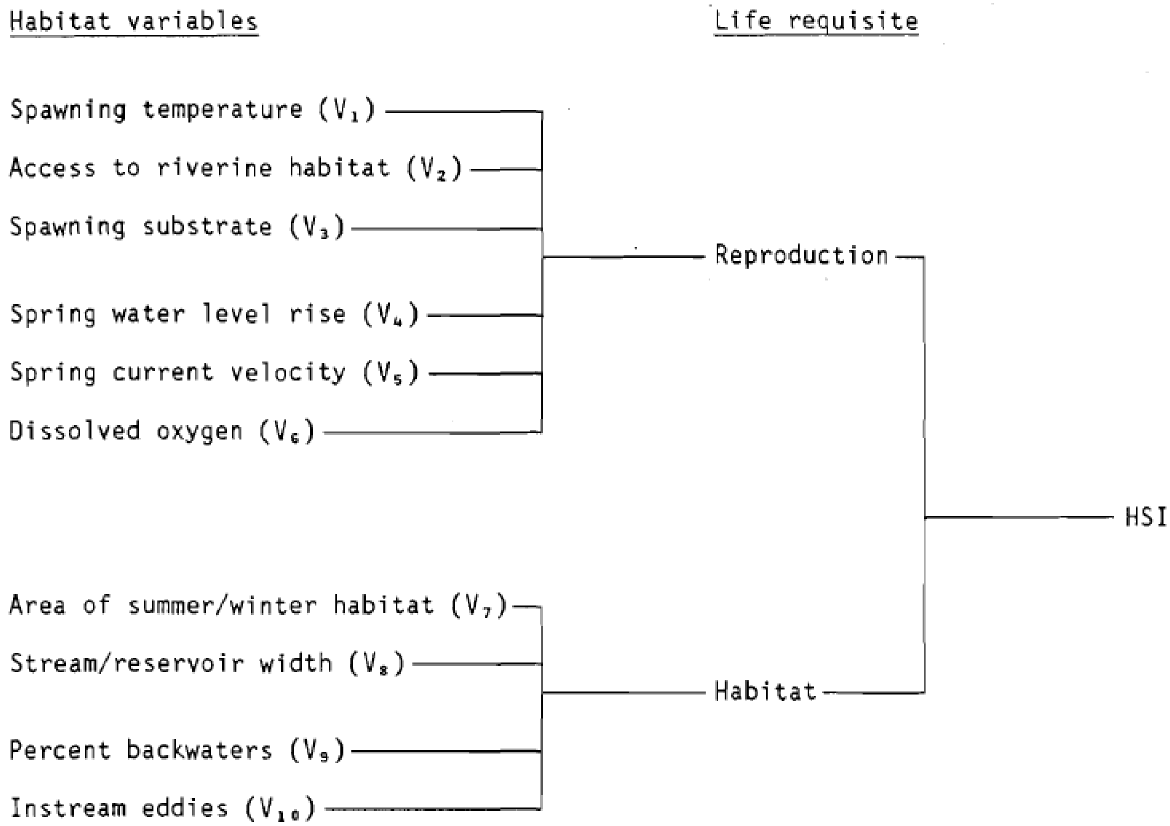


Figure 170. Conceptual structure for riverine model for paddlefish.

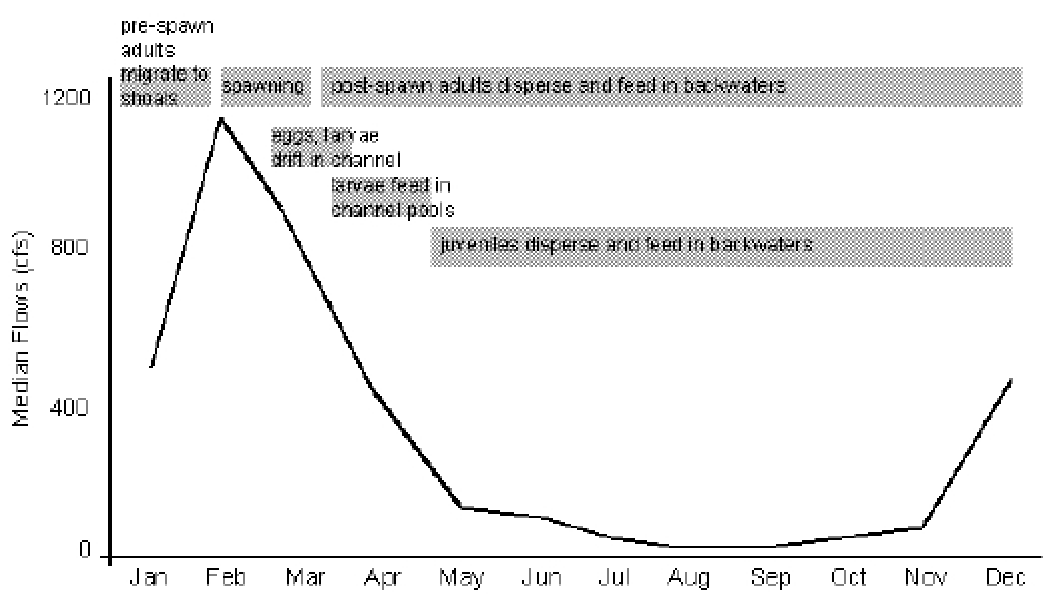


Figure 171. Paddlefish (flow dependent riverine species) life cycle in relations to seasonal flow (relative to per-1957 median flows in Big Cypress Bayou). Source: (Winemiller et al. 2005)

Guidance on Development of Recommended Hydrological Regime

Based on our literature survey targeted instream flow studies which document biological responses to flow and associated variables are lacking in the Trinity River. However, based on literature summarized in this report, most notably published habitat suitability models, and current studies in Texas, fish distribution data within the Trinity River, online literature syntheses and additional published literature we can provide generic and in some cases specific recommendations and guidance on development of instream flow requirements for focal species and by extension similar species within the trophic-reproductive guilds identified by cluster analysis. Based on our review of the ecology of the focal species several patterns emerge. Spawning of many of these fish species occurs in the spring and early summer (Table 12). This corresponds with the period of increasing overall median flows and increased daily fluctuation in flows (e.g. Figures 11,13,15,17,19,21). Invertebrates however had in many cases extended spawning periods. Many of the focal mussel species are also dependent on focal species and other species within the fish guild as hosts for their larvae. Therefore maintenance of flow sufficient to support these species, maintain sufficient dissolved oxygen and prevent dewatering should support most mussel populations. Several species of mussel were however noted in their ability to tolerate poor water quality and/or drought conditions. Several species including largemouth bass, white bass and paddlefish had more specific habitat requirements delineated in accompanying habitat suitability index documents. However, the majority of species did not. Some discussion of paddlefish habitat needs is warranted. Based on our literature review and lists compiled by Drs. Bonner and Hendrickson it is unclear how extensive the historical distribution of paddlefish may have been in the Trinity River. Currently, all recent historical records of paddlefish have been constrained to areas below Lake Livingston dam although they were stocked in Lake Livingston during the early 1990s (Henson and Webb 2004). Paddlefish occur in every major river drainage from the Trinity Basin eastward, but its numbers and range had been substantially reduced by the 1950's (Hubbs et al. 2008). Therefore it may not be appropriate to develop instream flow recommendations for this species above Lake Livingston.

The only instream recommendations that can be made are either going to be generic or specific depending on the availability of existing habitat suitability criteria that can be linked to easily measurable hydrological features (e.g. flow, gage height etc), availability of HEP and previous IFIM/PHABSIM studies in the basin or similar rivers. Examples of generic recommendations include maintaining flows and associated velocities and depths (e.g. maintain connectivity of backwater and oxbows to promote survival and growth of alligator gar and other species utilizing these areas). Another example is managing flows to reduce flooding events during the nesting period for longear sunfish and largemouth bass (Table 12). Examples of specific criteria include paddlefish. For example a recommendation may be to maintain the average magnitude of spring water rise in the river over average midwinter flow at a minimum of 3 meters, for a period exceeding 10 days while temperatures range from 10 to 17 C. Another example is promoting management that would reduce the probability of water levels increases during the months of April and May to maximize the spawning potential of white bass. A final example is managing flows to maintain minimum water temperatures between 17 and 22 C to promote largemouth spawning during the months of March through May. These recommendations are described in detail in the HEP documents provided.

Table 12. Summary of life history requirements for focal species of fish and invertebrates.

Species	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Key Instream Flow Needs	HS Index?
	Spawning Season													
Freshwater Drum					■	■							It is usually found associated with benthic habitats of large, shallow bodies of water up to 40-60 feet deep. In large rivers, fish may move distances of at least 161 km. Individuals have been observed to become distressed when water temperatures exceed 25.6°C, and when dissolved oxygen concentrations remain low over an extended period. Spawning season for freshwater drum occurs in May and June, usually when water temperatures range between 18-26°C	
Alligator Gar				■	■	■							It has been collected from deep, frequently connected oxbow lakes; and has significantly higher abundance in oxbow habitats during wet years. Typically specimens collected from oxbows are juveniles (409- 810 mm), while only adults (1474-1850 mm) are captured in the river channel. However, this may be due in part to large individuals escaping capture in oxbow sampling. Adults may move into oxbows during flooding to exploit abundant prey, returning to the river channel later. Factors including enhanced foraging, growth and survival may influence juveniles to remain in oxbows for extended periods	
Blue Catfish				■	■	■							Blue catfish spawn between April and June at water temperatures of 21-25 degrees C	
Longear Sunfish					■	■	■	■					They are abundant in clear, small upland streams with rocky or sandy bottoms and permanent or semi-permanent flows with pools. In previous studies in Mississippi, longear sunfish habitat averaged 61 cm deep and had slow current flow (5.2 cm/s) and possessed a silt, mud or sand substratum Found in channels and slow pools in Texas between 0.08 and 0.29 m/s. Spawning has been reported in shallow water with gravel bottom, shallow water and little current. Flood events and potentially associated lowered water temperatures can delay initiation of spawning and result in high nest abandonment and decreased brood survival	
Largemouth Bass			■	■									Cover needs (percent pool and backwater), (percent cover, water level fluctuation), water quality (d.o., temp, turbidity), reproduction (percent pool&backwater, temp, water level fluctuation, current velocity), other (current velocity)	Yes
White Bass			■	■	■								Reproduction (Water level change, temperature), Other (percent low velocity, day-degrees).	Yes
Blackspot shiner				■	■	■							The species classified as a fluvial specialist. It is found in runs and pools over all types of substrates, generally avoiding areas of backwater and swiftest currents. Found at mean depths ranging from 0.19 to 0.29 m, and mean current velocities ranging from 0.13 to 0.30 m/s	
Silverband shiner					■	■	■	■	░	░			Past research in Brazos River indicates that it is common in oxbow lakes that frequently reconnect to the mainstem river. It is founds in the main channel of rivers with moderate to swift current velocities and moderate to deep depths. It is often found in turbid water over silt, sand, and gravel substrate. The species is tolerant of high turbidities. The spawning season occurs from May through mid August at least and possibly mid-fall. Spawning occurs in the main channels of rivers. Breeding aggregations have been observed over hard sand to fine gravel substrates in water 1-2 m deep in strong current. The species is likely a broadcast spawner. This species may migrate into tributaries for spawning, especially during high flows.	
Dusky darter		■	■	■	■	■							Spawning has occurred over gravel riffles at depths of 30-90 cm. (20-60 cm) in Colorado River. Fluvial specialist, intolerant to poor water quality and dam construction, requires flowing water; mean current velocities: 0.5 to 0.74-1.00 m/s. Prefers gravel and cobble.	
Paddlefish		■	■	■	■	■							Spawning season: Spawning occurs between late February and late June when water temperatures are 10-17°C. Even at optimum temperatures, only increased and prolonged river flow will attract fish onto the gravel beds; flow must be able to maintain a 3-5 m rise in the river for about 10-14 days. HS Index =:reproduction(spawn temp, access to riverine habitat, spawn ubstrate, spring water level rise, spring current velocity, d.o.) habitat(instream eddies, percent backwaters, stream/reservoir widt, area of summer/winter habitat)	Yes
Invertebrates	■	■	■	■	■	■	■	■	■	■	■	■	Maintain flows to prevent dessication and provide suitable habitat for host fishes	

Another option is to substitute or supplement some of the proposed priority focal species (e.g. paddlefish) with another species within the guild for which we may have habitat suitability criteria that can be coupled with flow regimes. Also, using habitat suitability criteria developed in adjacent watersheds for fish species or specific guilds may be another option. For example, in our classification scheme guild 3 includes the paddlefish. In addition, the channel catfish is found in this group. The channel catfish does in fact have a HSI Model (McMahon and Terrell 1982) Channel catfish habitat variables are illustrated in Figure 171 and a copy of the document is provided. Another example is the bigmouth buffalo, *Ictiobus cyprinellus*, which is found in guild 1 along with freshwater drum and alligator gar, which lack published criteria (Edwards 1983)(Figure 172). Another example is smallmouth buffalo *Ictiobus bulbalus*, which has HSI criteria, is found in guild 3 along with paddlefish(Edwards and Twomey 1982b)(Figure 173). Smallmouth buffalo is currently a candidate species being used to develop instream flow criteria on Big Cypress Bayou (Winemiller et al. 2005).

Other candidate species which possess HSI models that can be used to substitute or supplement other species in their guilds include bluegill sunfish, redear sunfish, slough darter, common carp, black bullhead, flathead catfish, smallmouth buffalo (Edwards et al. 1982; Edwards and Twomey 1982a; Edwards and Twomey 1982b; Lee and Terrell 1987; Stuber 1982; Stuber and Gebhart 1982; Twomey et al. 1984). Guidance is also available on the application of individual riverine and lacustrine HSI models with Habitat Evaluation Procedures (Terrell et al. 1982) (Figure 173). It should be noted however that many of the HSI models presented here are for habitat generalists, that is species that are not extremely sensitive to changes in streamflow (Herbert and Gelwick 2003b). The only fluvial specialist species present in our focal species list was Blackspot Shiner and Dusky darter. These habitat generalists however in some cases have preferred and required needs during their development (Schramm Jr. 2005)

Another potential approach would be to attempt to adopt criteria developed for other Texas Rivers. For example Bio-West, Inc. working for the LCRA has proposed several guilds and has been developing habitat suitability criteria (HSC) for selected guilds of fishes (Bio-West Inc 2008). Examples of their guilds and associated HSC are provided in Table 13 and Figures 168. Three of the Trinity Rivers focal species, dusky darter *Percina sciera*, largemouth bass *Micropterus salmoides* and longear sunfish *Lepomis megalotis* are found within two guilds 1) riffles and 2) shallow pools/edge/backwaters (Figure 168). Therefore to the extent the guilds identified in the Colorado River and those proposed for the Trinity can be consolidated into a meaningful group that can be validated at a later date it may be possible to construct some HSC using the combination of the site specific criteria developed for the Colorado River and published literature values (HSI model). Published HSI models and/or HSC developed in other watersheds may be necessary because several focal species identified in the Trinity River are not found or were not selected for the Colorado River analysis.

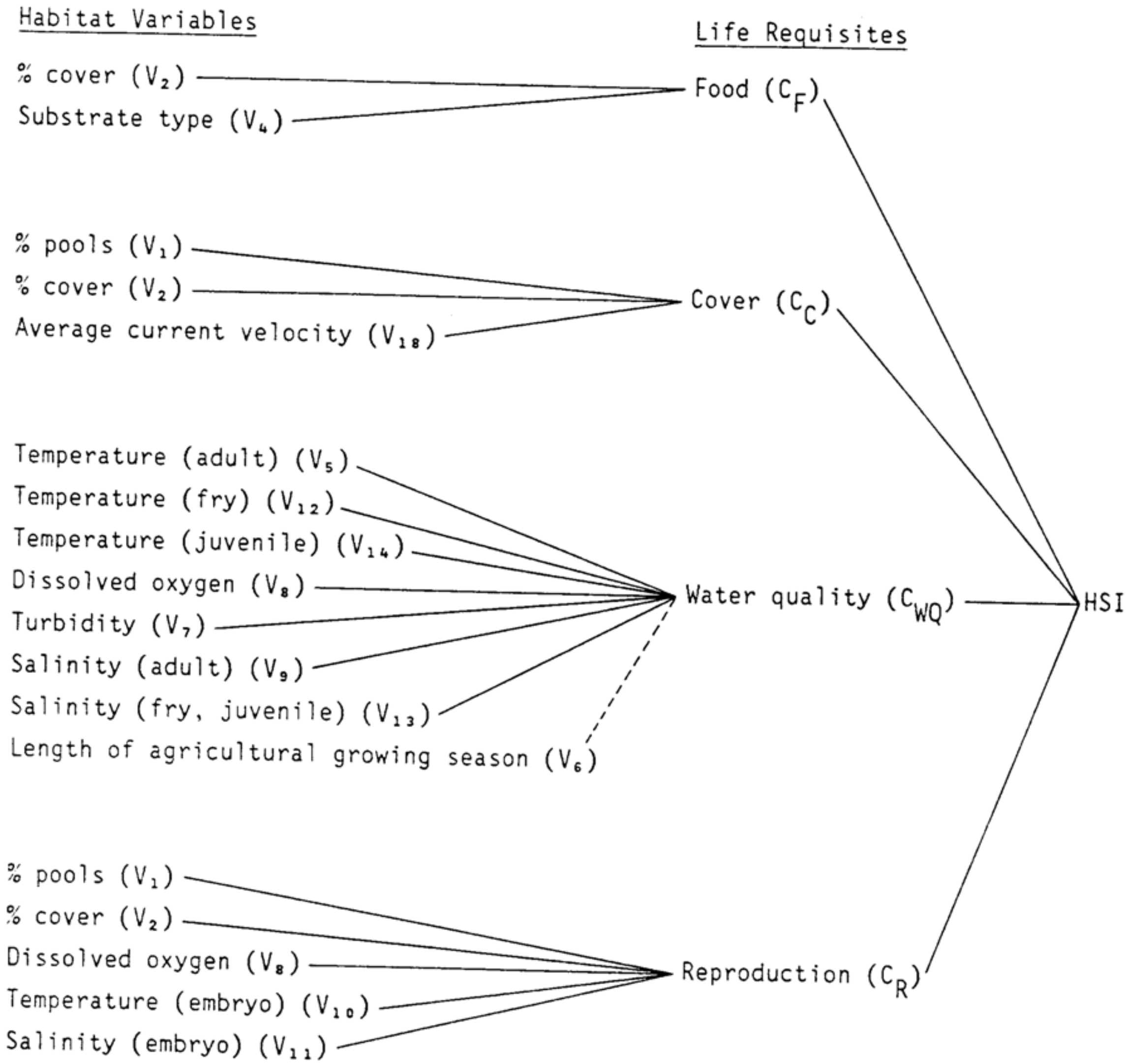


Figure 171. Conceptual structure for riverine model for channel catfish.

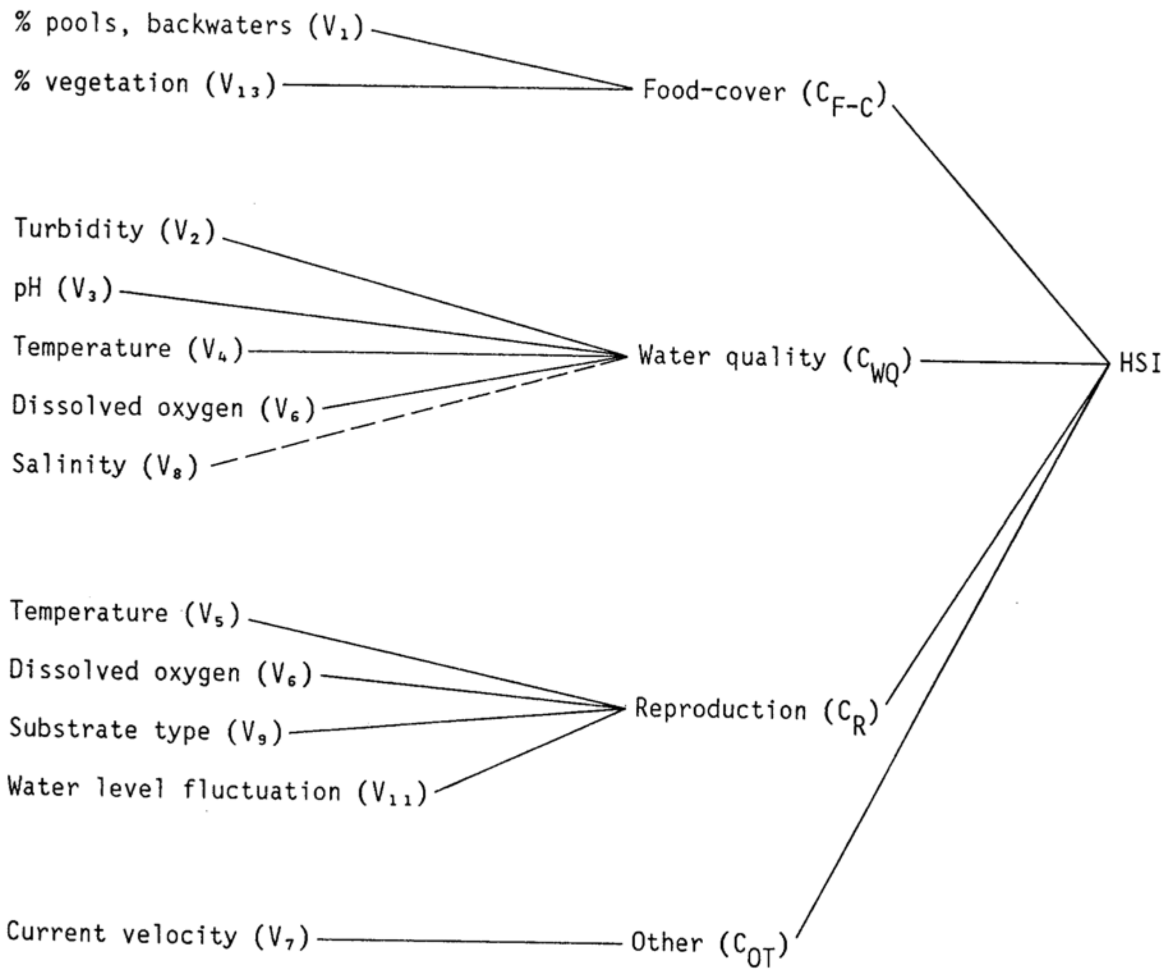


Figure 172. Conceptual structure for riverine model for bigmouth buffalo.

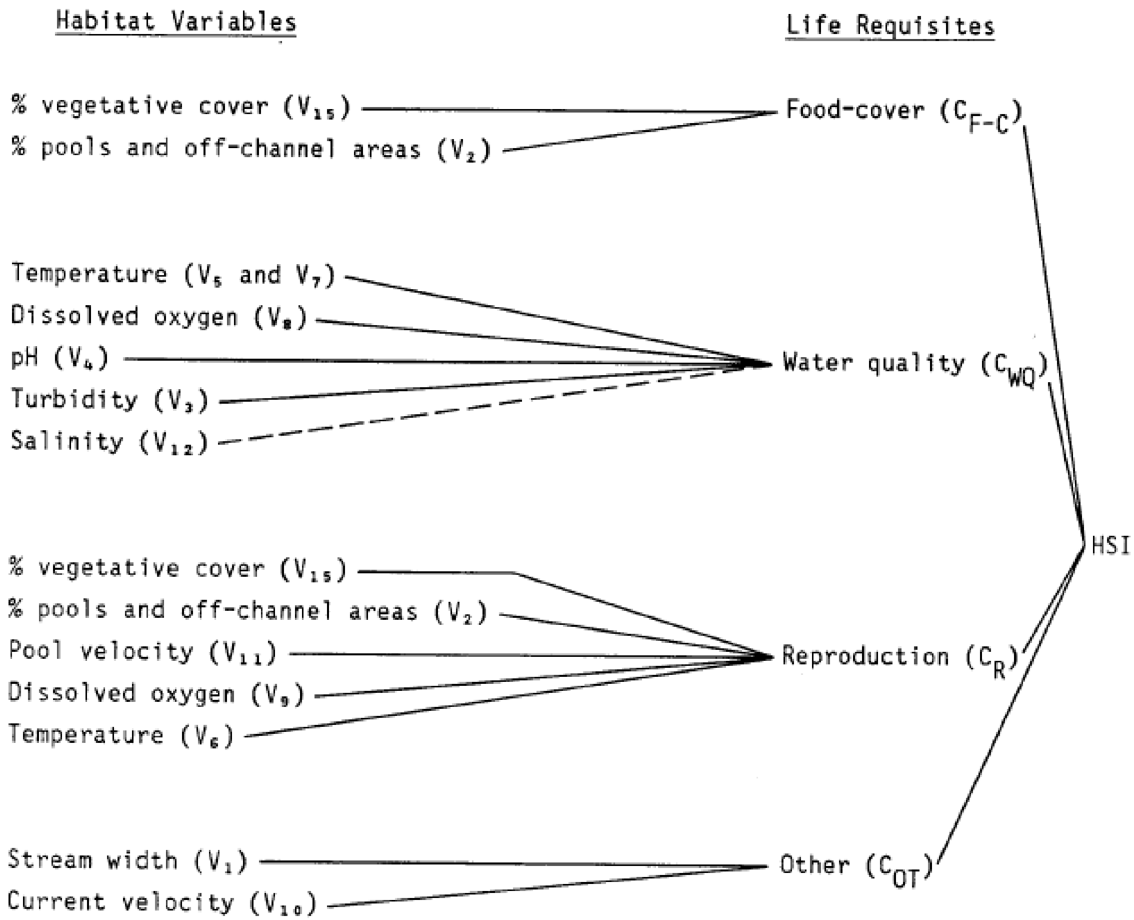


Figure 173. Conceptual structure for riverine model for smallmouth buffalo.

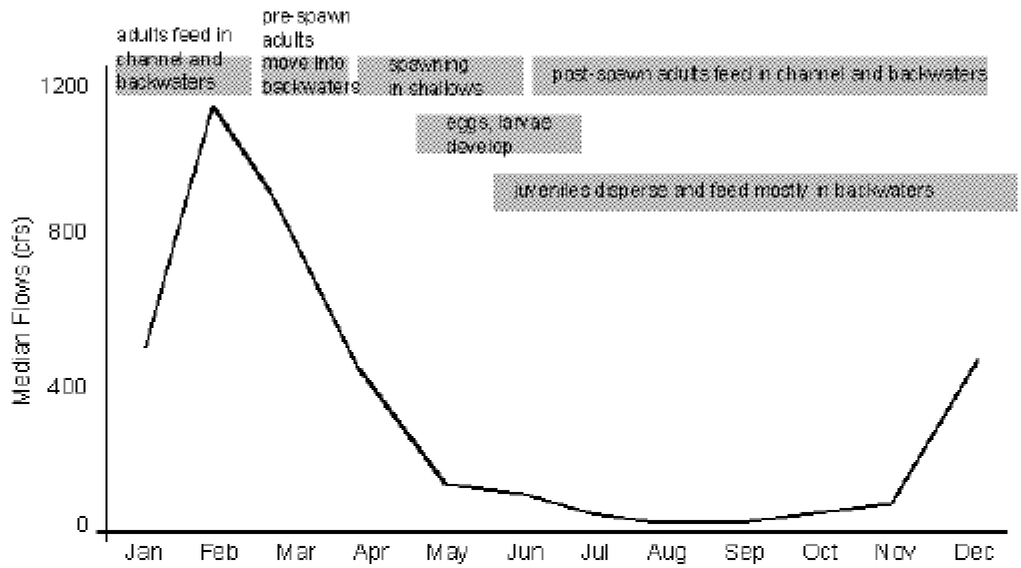


Figure 174. Smallmouth buffalo (flow-responsive species) life cycle in relation to seasonal flow (relative to pre-1957 median flows in Big Cypress Bayou. Source: (Winemiller et al. 2005)

Species[c]	Riverine: Habitat: Riffles, runs	Riverine: Habitat: Pools, eddies	Riverine: Habitat: Backwaters, bayous, oxbow lakes	Riverine: Stream size: Small (< 5 m); order: 1-3	Riverine: Stream size: Medium (5-30 m); order: 2-6	Riverine: Stream size: Large (> 30 m); order: 5+	Lacustrine: Habitat: Near-shore: Shallow (≤ 5 m)	Lacustrine: Habitat: Near-shore: Deep (> 5 m)	Lacustrine: Habitat: Open-water: Surface (< 5 m)	Lacustrine: Habitat: Open-water: Mid-water (5-15 m)	Lacustrine: Habitat: Open-water: Deep (> 15 m)	Cover: Rocky substrate	Cover: Aquatic vegetation	Cover: Cut-banks	Cover: Logs, brush, debris piles	Cover: No special cover needs	Temperature[a]: Cold (< 20°C)	Temperature[a]: Cool (20-28°C)	Temperature[a]: Warm (> 28°C)	Spawning[b]: Free-drifting eggs, no substrate req.	Spawning[b]: Eggs deposited in or on rocky substrates; current required	Spawning[b]: Eggs deposited in or on rocky substrates; no current required	Spawning[b]: Eggs deposited on plants	Spawning[b]: Eggs deposited in holes, cavities	Spawning[b]: Eggs deposited in nests of mud, sand, or plant debris	Spawning[b]: Eggs deposited over a variety of substrates	Turbidity tolerance: Low (< 25 JTU)	Turbidity tolerance: Moderate (25-100 JTU)	Turbidity tolerance: High (> 100 JTU)
Largemouth bass			x		x	x	x						x		x				x						x			x	
Spotted bass		x			x	x		x		x		x			x				x						x			x	
Black crappie		x	x		x	x	x		x				x		x				x						x			x	
White crappie		x	x		x	x	x		x				x		x				x						x				x
Bluegill		x	x		x	x	x			x			x						x						x			x	
Warmouth			x		x	x	x	x					x		x				x						x				x
Slough darter			x		x	x							x						x				x					x	
Common carp		x	x			x	x	x			x		x						x				x						x
Smallmouth buffalo	x	x	x		x	x		x		x	x		x		x				x				x					x	
Channel catfish	x	x	x		x	x		x			x	x		x	x				x					x					x
White sucker		x	x	x	x			x			x	x	x	x				x			x							x	
Northern hogsucker	x	x		x	x							x						x			x						x		
Striped bass	x					x			x	x	x					x		x		x								x	x
Rainbow trout	x	x		x	x		x		x	x		x	x	x	x		x				x						x		

[a]Categories from Hokanson (1977)

[b]Categories from Balon (1975)

[c]Common names from Robbins et al. (1980)

Figure 175. Example of guilding criteria for use in freshwater fishes HSI models: Source (Terrell et al. 1982)

Table 13. Example of habitat Guilds and Blue Sucker life stage categories derived from depth, velocity and substrate use and supplemental radio telemetry for the Colorado River. Source: (Bio-West Inc 2008)

Habitat Guild	Species/Life Stage	Species/Life Stage Abbreviation	Number of Locations Where Observed	Total Number Observed
Riffles	*Percina sciera*	*Psci*	33	121
	Percina carbonaria	*Pcar*	30	95
	Ictalurus punctatus (juvenile, <180 mm)	*IpunJ*	44	640
	Phenacobius mirabilis	*Pmir*	8	65
	Etheostoma spectabile	*Espe*	13	27
	Campostoma anomalum	*Cano*	13	30
	Macrhybopsis spp.	*Maes*	21	280
Shallow Runs	*Cyprinella lutrensis*	*Clut*	66	1989
	Cyprinella venusta	*Cven*	71	1305
	Pimephales vigilax	*Pvig*	32	698
	Notropis volucellus	*Nvol*	40	516
	Micropterus treculii (juvenile, <170 mm)	*MtreJ*	31	91
Deep Runs	*Pylodictis olivaris*	*Poli*	40	107
	Ictalurus punctatus (adult, >180 mm)	*IpunA*	28	71
	Moxostoma congestum	*Mcon*	36	131
	Micropterus treculii (adult, >170 mm)	*MtreA*	13	23
	Carpiodes carpio	*Ccar*	35	215
	Dorosoma cepedianum	*Dcep*	29	451
Shallow Pools / Edge / Backwaters	*Micropterus salmoides*	*Msal*	9	19
	Lepomis megalotis	*Lmeg*	23	490
	Lepomis macrochirus	*Lmac*	21	115
	Lepomis cyanellus	*Lcya*	5	29
	Cichlasoma cyanoguttatum	*Ccya*	11	45
	Gambusia affinis	*Gaff*	14	92
	Poecilia latipinna	*Plat*	6	33
	Fundulus notatus	*Fnot*	6	15
Deep Pools	*Ictiobus bubalus*	*Ibub*	9	16
	Cyprinus carpio	*Carp*	9	18
Blue Sucker Life Stage				
Adult blue suckers / Rapids	*Cycleptus elongatus*	*Celo*	93*	102*
Spawning blue suckers	*Cycleptus elongatus*	*N/A*	10	**

These literature derived recommendations and associated information on the distribution of biological resources coupled with IHA/HEFR hydrological analyses can be used to validate and/or further refine instream flow recommendations. For example, if the hydrological analysis describes a flow regime that generally supports the general life history requirements and/or maximizes habitat suitability criteria values, then this would further reinforce the validity of the recommended flow regime derived from solely from hydrological analysis. In addition, if there are management options available (e.g. control of water releases, removal of migration barriers etc) that may optimize conditions necessary to promote or enhance critical hydrological and water quality parameters necessary to support a critical species function (e.g. migration, reproduction) then this should be explored as a potential future management options. At this stage of development of instream flow regimes it is recommended that an evaluation of the described and proposed hydrological regime be compared to these draft generic and specific biological criteria. A full discussion of these potential criteria and how they can be used to inform and/or further refine the hydrological analysis for development of instream flow recommendations should be conducted by the instream subcommittee of the Trinity-San Jacinto BBEST and eventually the BBEST committee.

Major Findings and Recommendations

1. Water Quality and Relation to Flow Regime

A brief review of water quality variables that may be effected by flow regime and in turn influence aquatic life was provided. Historically anoxia and hypoxia in the upper Trinity River below Fort Worth and Dallas has caused major declines in fish and aquatic organisms. Water quality has steadily improved since the mid-1980s and the incidence of hypoxia is low. However, violation of dissolved oxygen criteria is the most common reason for not supporting aquatic life uses in the Trinity River based on the most recent TCEQ assessment. The relationship of stream flow and dissolved oxygen is variable. During the period before the mid 1980s when wastewater treatment was insufficient and the "black rise" occurred, anoxic water was often associated with rising water levels. However, based on our analysis of historical data it appears that low dissolved oxygen is usually geographically oriented around developed portions of the watershed (near Dallas Fort Worth) and/or occurs more frequently at lower flows. A recommendation would be to maintain flows above 7Q2 or other empirically derived methods to maintain aeration and reduce the probability of hypoxic events. Nu instream flows are not the only factor affecting dissolved oxygen levels since point and non-point source loading (e.g. wastewater facilities, stormwater, agriculture) of organic pollutants also exert a strong influence on dissolved oxygen dynamics and must ultimately be controlled through best management practices and permitting. The fact that the two most common violations of water quality standards are dissolved oxygen and indicator bacteria suggests that some ongoing problems associated with organic loading remain.

2. Geomorphology and Estuarine Loading

Based on past research, current analyses of long-term USGS and TCEQ water quality and discharge data and recent geomorphological studies conducted below Lake Livingston, it appears that sediment and nutrient loading and an analysis of long term data it appears that sediment and nutrient loads in from reservoir have declined as a result of the construction of the dam in 1969. The ultimate impact of reduced nutrient loads on Galveston Bay ecosystem is difficult to assess because local watershed anthropogenic sources of nutrients may have offset the reduced riverine loading. (Jensen et al. 2003) noted that for many years chlorophyll-a levels have been declining in upper Galveston Bay. (Ward and Armstrong 1992) had record a 50% reduction in decadal concentrations of chlorophyll-a in Galveston Bay. Since very little data exist before 1969 it is hard to determine the potential contribution of reduced nutrient loading from the Trinity River. However, the trends were highly correlated with decreasing point source loading in the local watershed in the 1970s and 1980s so this may have been the primary causal factor (Ward and Armstrong 1992). Based on recent data the downward trends has stopped and annual average chlorophyll-a levels are fluctuating around 10 ug/l over the last 5-10 years (Houston Advanced Research Center. 2008. Galveston Bay Status and Trends Website: Water and Sediment Quality Data Portal 2009).

One of the major factors effecting native fish communities within the Trinity River basin is the highly fragmented nature of the watershed due to the high number of dams. Although there is limited pre-reservoir data on fish communities this appears to be one of the major factors leading to declines in certain fluvial specialists that are not adapted to lake conditions found in reservoirs. Studies conducted during the 1950s and 1980s show a major shift from fluvial species (Percidae, Cyprinidae and Ictaluridae) to more invasive and lentic species including shad Clupeidae, and mosquitofish *Gambusia affinis*, and silversides Atherinidae. One of the major factors associated with the decline of the original species composition is the construction of dams and fragmentation of riverine habitat. Highly migratory and diadromous species such as blue catfish, paddlefish, American eel and *Macrobrachium* shrimp now lack the minimum distances needed for spawning and/or can no longer reach spawning areas. Also, physical damage associate with passage through spillways and altered water quality below dam discharges can impact sensitive populations. (Herbert and Gelwick 2003a) found that the presence of dams and downstream reservoirs limited the ability for fluvial stream fish to recolonize adjacent streams and areas after droughts. Other hydrological and geomorphological impacts associated with dams include altered thermal regime, altered flows, reduced dissolved oxygen and reduction in sediment transport and scour of downstream areas (Yeager 1993). It is hard to estimate from a cumulative impacts of all the dams in the river, but since the Trinity River is the most fragmented watershed in the state it is likely large (Chin et al. 2008). Electronic copies of USGS rating curves for key gage sites are included for future analysis.

3. Candidate Biological Metrics for Development of Instream Flow Recommendations.

Targeted instream flow studies which document biological responses to changes in streamflow and associated variables are lacking in the Trinity River. However, based on literature summarized in this report, most notably published habitat suitability models, and current ongoing instream studies in Texas, fish distribution data within the Trinity River, online literature syntheses, and additional published literature we can provide generic and in some cases specific recommendations and guidance on development of instream flow requirements for focal species and by extension similar species within the trophic-reproductive guilds identified by our study and other investigators. Based on our review of the ecology of the focal species several patterns emerge. Open water broadcast spawners typically release their eggs during the mid to late spring and early summer. This corresponds to seasonal period of increasing overall median flows and increased daily fluctuation in flows. Invertebrates however had in many cases extended spawning periods. Many of the focal mussel species are also dependent on focal species and other species within the fish guild as hosts for their larvae. Therefore maintenance of flow sufficient to support these species, maintain sufficient dissolved oxygen and prevent dewatering should support most mussel populations. Several species including largemouth bass, white bass and paddlefish had more specific habitat requirements delineated in accompanying habitat suitability index documents. In some cases such as longear sunfish, largemouth bass and alligator gar it is extremely important to maintain seasonal connectivity with floodplain lakes and oxbows in order to provide necessary velocity refuge areas for spawning, nesting and rearing.

Based on our study it is unclear how extensive the historical distribution of paddlefish may have been in the Trinity River. Currently, all recent historical records of paddlefish have been constrained to areas below Lake Livingston dam although they were stocked in Lake Livingston during the early 1990s. Therefore it may not be appropriate to develop instream flow recommendations for this species above Lake Livingston.

The only instream recommendations that can be made are either going to be generic or specific depending on the availability of existing habitat suitability criteria that can be linked to easily measurable hydrological features (e.g. flow, gage height etc), availability of HEP and previous IFIM/PHABSIM studies in the basin or similar rivers. This can include substituting or supplementing some of the proposed priority focal species (e.g. paddlefish) with another species within the guild for which we may have habitat suitability criteria. Using habitat suitability criteria developed in adjacent watersheds for the same fish species or specific guilds may be another option. Again, even if ecologically relevant habitat suitability criteria or indices are available, and applicable to the local population, there must be a mechanism to validate these "modeled" predictions of habitat preference and use during varying flow regimes. This will not be a trivial exercise in a river as big and complex as the Trinity River. In addition, similar to other Gulf coast and southeastern rivers the inherent turbidity and depths often limit direction observation of habit use and availability when and if an instream flow study is conducted. For the time being biologists using the data compiled in this report and by others should be able to provide meaningful input to further fine tune and/or validate hydrologically derived recommendations (e.g. IHA, HEFR).

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