UNITED STATES DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
19241 David Memorial Drive., Suite 180
The Woodlands, TX 77385

To: Caimee Schoenbaechler, Texas Water Development Board

From: Michael Lee, Ryan Banta, Zulimar Lucena, Cassi Crow, Darwin Okerman

U.S. Geological Survey, Texas Water Science Center

Subject: Progress Summary of Coastal Inflows Project

Dear Ms. Schoenbaechler,

The attached memo is a summary of the progress for the Coastal Inflows Project activities undertaken during agreement #1600011927. In general, the overall project goal was to provide new data to the scientific community and stakeholders for the study of freshwater inflows, sediment, and nutrient concentrations and loads entering Texas bays and estuaries across a range of hydrologic conditions for select rivers.

This project started as a data collection program on the Trinity River watershed in 2009 evaluating sediment and nutrient data for model development and evaluation. It has grown into a pilot program to evaluate if suspended-sediment concentrations could be estimated using measurements from an acoustic doppler velocity meter. The project has since expanded further into three additional basins: Colorado River, Guadalupe-San Antonio River, and Nueces River. Each of the basins are at a different level of maturity, ranging from the initial demonstration of capabilities to having established real time suspended-sediment concentration estimates that are published on the USGS website. Further, leveraging other USGS program activities could see this effort expand even further into the San Jacinto River and Buffalo Bayou feeding Galveston Bay.

The USGS thanks Texas Water Development Board for their continued collaboration on this important project. The data collected from this project is instrumental for the stewardship of Texas bays and estuaries. The status of each basin is further discussed below.

Progress Summary for TWDB Agreement # 1600011927

Background

The amount of freshwater, sediment, and nutrients delivered to an estuary affects the water quality, productivity, and characteristic of a coastal ecosystem. Excess suspended sediment and nutrients can alter the nutrient cycle balance and can be detrimental to the health of organisms living in and using coastal waters. High sediment loads delivered to an estuary can alter water quality. Concentrations of suspended sediment are affected by natural conditions (*e.g.,* soil erosion and streambed re-suspension) and can be affected by human activities (*e.g.,* construction, timber harvesting, certain agricultural practices, and hydraulic alteration). An increased sediment load delivered to an estuary can reduce water clarity and light penetration in the water column. Suspended sediment also plays a major role in the transport and fate of nutrients and other contaminants.

Nitrogen and phosphorus compounds occur naturally in coastal streams and rivers but also are commonly applied to land as commercial fertilizers and livestock waste. Nutrients that are not utilized by crops or stored in the soil can runoff to streams in overland flow or infiltrate with groundwater recharge. Poor water quality caused by an abundance of these nutrients in an estuary can stimulate the excessive growth of phytoplankton, reduce dissolved oxygen (DO) levels, and potentially lead to fish kills.

In Texas, periods of high flow in streams and rivers flowing into a coastal ecosystem are usually caused by local rainfall or releases from upstream reservoirs made in response to rainfall upstream in the basin. The increase in rain and resultant flooding can increase sediment erosion and nutrient runoff into coastal rivers and consequently increase sediment and nutrient input into estuaries and bays.

Previous studies between the United States Geological Survey (USGS) and the Texas Water Development Board (TWDB) evaluated the sediment and nutrient concentration input of the Trinity River into Galveston Bay (beginning in 2009), the Colorado River into Matagorda Bay (beginning in 2013), the Guadalupe River into the San Antonio Bay System (beginning in 2012), and the Nueces River into the Nueces Bay System (beginning in 2016). In these river studies, the concentration of suspended sediment, total nitrogen, and total phosphorus were compared to river discharge and turbidity measured at the time the discrete water-quality samples also were collected.

The previous work in these four river systems suggests that the response of sediment and nutrient concentration to hydrologic conditions vary among the river basins and according to the cause of increased flows (*e.g.*, reservoir releases versus local precipitation events). Variations in the response of nutrient and sediment loading to the bays can be event-specific and/or basin-specific, however, the data thus far supports the idea that large pulses of nutrients and sediments are transported to the bays during peak inflow periods. Therefore, the timing and supply of sediment and nutrients has the potential to significantly affect bay health and fisheries resources.

Results from these previous studies revealed a possible correlation between the concentrations of suspended sediment and nutrients measured with *in-situ* measurements during periods of high flow at all stations. Additionally, a correlation between measures of turbidity and the strength of the returned pulse signal (backscatter) from an acoustic Doppler velocity meter (ADVM) suggests that backscatter data may be used as a proxy for suspended sediment concentration and possibly further as a proxy to estimate certain nutrient concentrations. Results from these studies indicated that it may be possible to better understand the extent of sediment and nutrient loading to the bays using a combination of select discrete measurements of water-quality data with continuous measures of stream discharge and surrogate measures of sediment and nutrient concentrations**.**

The purpose of this project was to add data and information to further the understanding of the variability of sediment and nutrient concentrations and loads entering selected Texas bays and estuaries across a range of hydrologic conditions. In addition, methodologies were developed to advance our ability to monitor freshwater inflow, sediment and nutrients entering these systems through acoustic and/or optical instrumentation and surrogate model development.

Data and information from this project can be used by scientists and stakeholders of the environmental flows process to validate or refine freshwater inflow standards. Specifically, the information from this project contributes to the following priority work plan studies as outlined below:

- Contributes to several priority activities identified by the Trinity, San Jacinto Basin and Bay Area Stakeholder Committee in the Trinity, San Jacinto basin and bay area work plan (TSJ BBASC 2012) including to gather water quality data and sediment characterization data.

- Contributes to several priority activities identified by the Colorado, Lavaca Basin and Bay Area Stakeholder Committee in the Colorado, Lavaca basin and bay area work plan (Tasks 11, 12, and 16) to improve estimates of freshwater inflows and quantify sediment and nutrient loading to Matagorda Bay.

- Contributes to a Tier 1 recommendation to improve *streamflow gaging and water quality monitoring* as well as a Tier 3 recommendation to *evaluate sediment transport affecting the Guadalupe Estuary delta* as identified by the Guadalupe, San Antonio Basin and Bay Area Stakeholder Committee in the Guadalupe, San Antonio basin and bay area work plan (GSA BBASC 2012).

- Contributes to Tier 2b recommendation for assessment of transportation and loading of sediment to the Nueces Estuary (Nueces BBASC).

Project Methodology

Methodologies that are standard across all river systems are outlined within this section. Methods associated with a project task unique to a specific river system are described in more detail below in the relevant Task Section.

Streamflow Measurements

Streamflow is the volume of water passing an established reference point in a stream at a given time. Discharge measurements were made using an acoustic Doppler current profiler (ADCP) as described in Mueller and others (2009) prior to each sample.

Additionally, the application of the index-velocity method for computing continuous records of discharge is being evaluated and developed at each site. The index-velocity method has become increasingly common, especially since the introduction of low-cost acoustic Doppler velocity meters (ADVMs) in 1997. Presently, the index-velocity method is being used to compute discharge records for approximately 500 gaging stations operated and maintained by the U.S. Geological Survey.

Computing discharge using the index-velocity method differs from the traditional stage-discharge method by separating velocity and area into two ratings—the index-velocity rating and the stage-area rating. The outputs from each of these ratings, mean channel velocity (V) and cross-sectional area (A), are then multiplied together to compute a discharge. For the index-velocity method, V is a function of such parameters as stream velocity, stage, cross-stream velocity, and velocity head, and A is a function of stage and cross-section shape. The index-velocity method can be used at locations where stage-discharge methods are used, but it is especially appropriate when more than one specific discharge can be measured for a specific stage (Levesque and Oberg, 2012), such as tidally influences areas.

Although the primary purpose of this type of ADVM is to measure water velocity, it has been found that additional measures are useful to monitor suspended-sediment transport. As the instrument emits an acoustic pulse into the water and measures the Doppler-shifted frequency of the pulse as it bounces off acoustic reflectors (typically assumed to be primarily sediment particles), the strength of the returned pulse (backscatter) also is measured as it returns to the instrument along the beam path. Backscatter should increase when more particles are present in the water. As a result, the backscatter measurement may be related to suspended-sediment concentration. ADVM technology is low maintenance and sturdy over a range of hydrologic conditions, and measured variables can be modeled to estimate suspended-sediment concentration, load, and duration of elevated levels on a real-time basis (Levesque and Oberg, 2012).

ADVMs installed at each site collect data on water velocities and backscatter. The ADVMs can be used to estimate river discharge and provide a backscatter signal for estimating suspended sediment concentrations. Each gage house contains a battery, solar panel, Data Collection Platform, and regulator. The data are recorded in 15-minute intervals and then transmitted to the GOES satellite for display on the web and storage in the USGS NWIS database. The data are used to continue developing index-velocity ratings and optical turbidity and/or acoustic backscatter surrogate methodology for each major river.

Water-Quality Sample Collection

Water-quality samples were collected and processed following standard USGS sampling methods as described in the National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, variously dated). USGS field personnel used isokinetic samplers to manually collect water samples. Isokinetic samplers are designed to accumulate representative, continuous, and depth-integrated water samples within a designated range of stream velocities (Senus and others, 2004). Depth-integrated samples were collected, within each of five vertical sections to capture variability of constituent concentration within the river cross-section either by multiple verticals when stream velocities were less than about 1.5 feet per second or by utilizing the Equal Discharge Increment approach (EDI) (Edwards and Glysson, 1998) when stream velocities were greater than about 1.5 feet per second. Water-quality samples were composited in a polyethylene churn splitter, and sub-samples for whole-water analysis were drawn while churning at a standard rate. The churn splitter was used to allow for subsamples to be drawn while maintaining a uniform distribution of suspended material in the composite sample (Darrell and others, 1999). Water samples for filtered nutrients were passed through a 0.45-micrometer (µm) pore-size filter that was pre-rinsed with deionized water. Whole-water (unfiltered) nutrient samples were preserved using 1 milliliter (mL) of 4.5N sulfuric acid.

Physical water-quality properties (water temperature, specific conductance, pH, dissolved oxygen concentration, and turbidity) were measured at the sampling sites using a water-quality multi-probe instrument at the time of sampling. Discrete water-quality samples were also routinely collected and measured or analyzed for selected water-quality properties and dissolved constituents. These selected water-quality properties included suspended-sediment concentration, total phosphorus, and total nitrogen. Dissolved constituents included nutrients (filtered ammonia, filtered nitrate plus nitrite, filtered nitrite, and filtered orthophosphate). Calculated constituents include filtered nitrate and organic-nitrogen (U.S. Geological Survey, variously dated).

Sample Analysis

All nutrient samples were chilled and shipped overnight to the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colo. for analysis using published methods. Methods for nutrient analysis are documented in Fishman (1993), U.S. Environmental Protection Agency (1993; method 365.1), and Patton and Kryskalla (2003, 2011). Suspended-sediment samples were shipped to the USGS Kentucky Water Science Center Sediment Laboratory and/or the USGS New Mexico Water Science Center Sediment Laboratory and analyzed for suspended-sediment concentration and particle-size with methods described in Guy (1969).

Quality Control

Quality assurance and quality control (QA/QC) measures were followed, including the collection of blanks and replicates, to ensure the quality, precision, accuracy, and completeness of the data generated during the project. The quality-assurance objectives are to provide data that: (1) withstand scientific scrutiny, (2) are obtained by methods appropriate for their intended use, and (3) are representative and of known precision, accuracy, and comparability.

For this project, quality-control (QC) samples were collected to help identify potential sources of measurement bias that could be introduced by the collection and analytical processes which are needed in interpretation of the environmental data. QC samples included field blanks and replicates. Field blanks collected on each watershed are used to assess the potential contamination that can be related to equipment, sample collection methods, and sample processing procedures used during sample collection. Split replicate samples are collected during the sampling events to assess potential variability from the laboratory analysis processes. Split replicates were collected and prepared by dividing a single volume of water into multiple samples to provide a measure of the variability of sample processing and analysis. Replicate samples were compared by computing relative percent difference (RPD); the larger the RPD, the greater the variability in sample-replicate pairs.

Project Results

The results below are organized to correspond with the "Project Tasks" designated for each river basin within TWDB Agreement # 1600011927. Since each river basin is at a different level of project maturity, task numbers do not necessarily correspond to the same effort within each river basin.

Trinity River

Task 1: Analysis of streamflow and nutrient and sediment concentrations in the Lower Trinity River watershed

Previous research in the lower Trinity River showed that flow along the main channel of the Trinity River does not exceed approximately 20,000 cubic feet per second (ft^3/s) regardless of upstream conditions (Lucena and Lee, 2016). This task was designed to obtain data that can help improve our understanding of the route and destination of unaccounted flow between the upstream stations and the lower reaches of the Trinity River and the potential effects of this travel path on the nutrient and sediment concentrations of inflow to Galveston Bay. This task also includes the continuation of water-quality monitoring that was initiated in 2009 and the maintenance of a streamgage and sediment surrogate in the main channel of the lower Trinity River.

Task 1a: Operation and Maintenance of Index-velocity streamgage

The streamgage at USGS station 08067252 Trinity River at Wallisville, Texas (hereinafter referred to as the Wallisville streamgage) was installed in 2014 as part of a previous study. USGS continued the operation and maintenance of this index-velocity gage throughout the duration of this study through support from the U.S. Army Corps of Engineers. Operation and maintenance of this station included the relocation of the streamgage enclosure in June 2017 due to bank scouring (Figure 1).

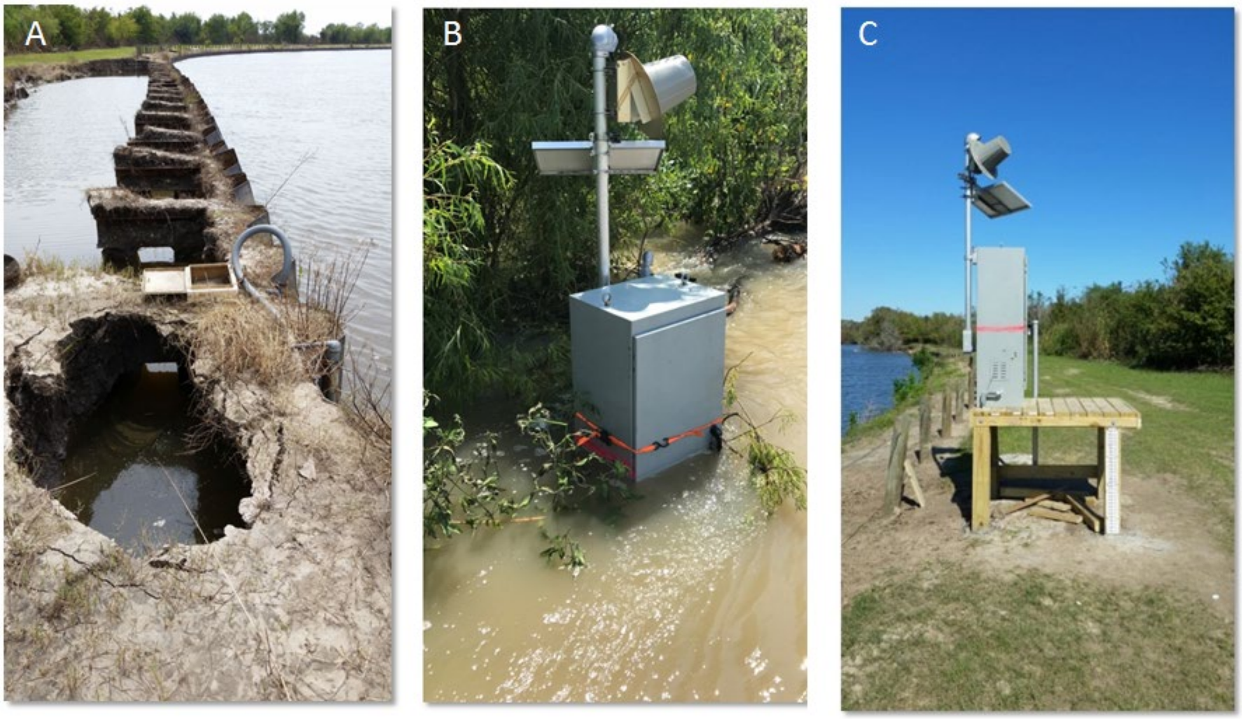

Figure 1. USGS streamgage at station 08067252 Trinity River at Wallisville, Texas, before (A and B) and after (C) relocation due to flooding and scouring.

During a previous study, a suspended sediment surrogate was developed from acoustic backscatter data collected by the ADVM at the Wallisville site (Lucena and Lee, 2016). The surrogate allows the computation of suspended sediment concentrations and loads every 15-minutes and provides a continuous record of suspended sediment data. Suspended sediment time-series from the Wallisville site are published on NWIS and updated hourly.

To validate the sediment surrogate and determine nutrient concentrations entering Galveston Bay, fifteen samples were collected at the Wallisville site over a range of hydrologic conditions between March 1st, 2016 and December 31st, 2018. Streamflow at USGS station 08067252 Trinity River at Wallisville, Texas, and corresponding water-quality samples collected are shown (Figure 2). Most of these samples were coincident with water-quality samples collected for Task 1b.

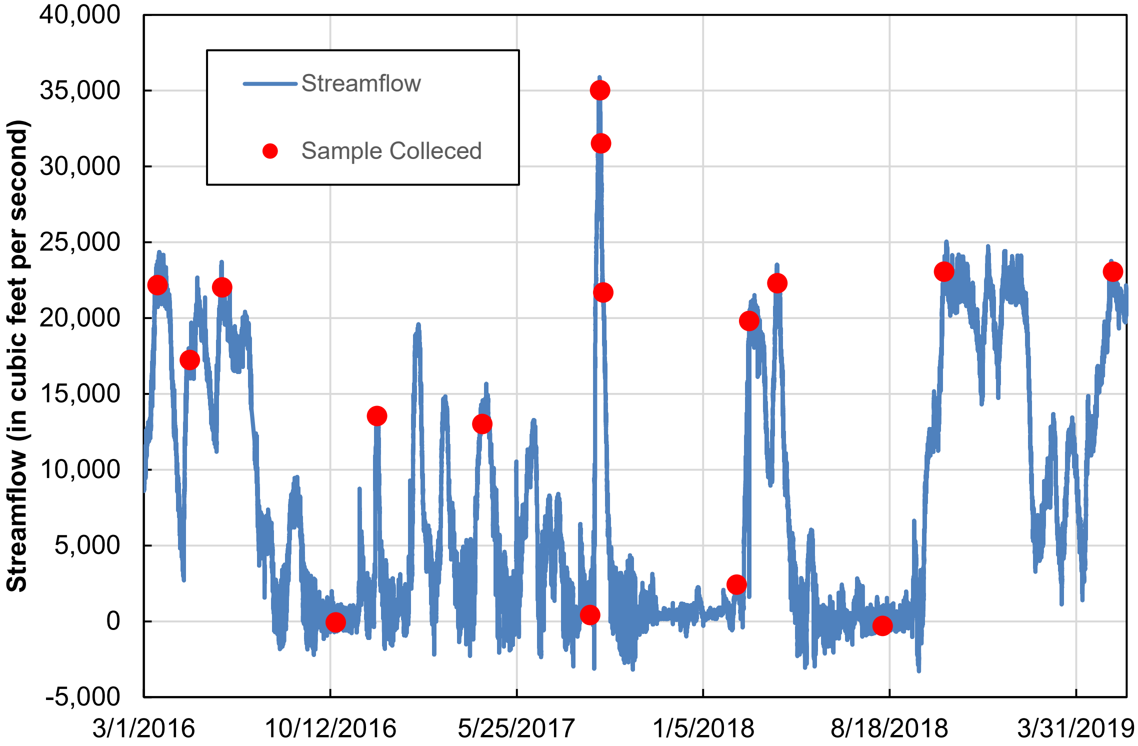

Figure 2. Instantaneous discharge and discrete water-quality and sediment sample dates at USGS station 08067252 Trinity River at Wallisville, Texas, March 2016-May 2019

Task 1b: Instantaneous streamflow measurements and water-quality sample collection

Streamflow was measured at multiple locations in the Trinity River delta during high flow events when the river discharge observed at upstream gaging stations exceeded the discharge observed at the Wallisville streamgage. Water-quality samples were also collected at selected sites. Measurement and sampling stations are listed on Table 1.

Table 1. USGS stations with streamflow measurements and/or water-quality and sediment samples in the lower Trinity River watershed.

Station number	Station Name	Short name	Streamflow measurement (Y/N)	Water-quality sample collected (Y/N)
08067252	Trinity River at Wallisville, Texas	Wallisville streamgage	Y	Y
08067230	Old River near Wallisville, Texas	Old River station	Y (if possible)	Y
294809094434600	7168030Trinity-San Jacinto ES Line 680 Site 30	Old River Cutoff	Y	N
294759094432700	7168020Trinity-San Jacinto ES Line 680 Site 20	Trinity River Downstream	Y	N
294815094444200	7168040Trinity-San Jacinto ES Line 680 Site 40	Trinity-Old River Mixing Point	N	Y

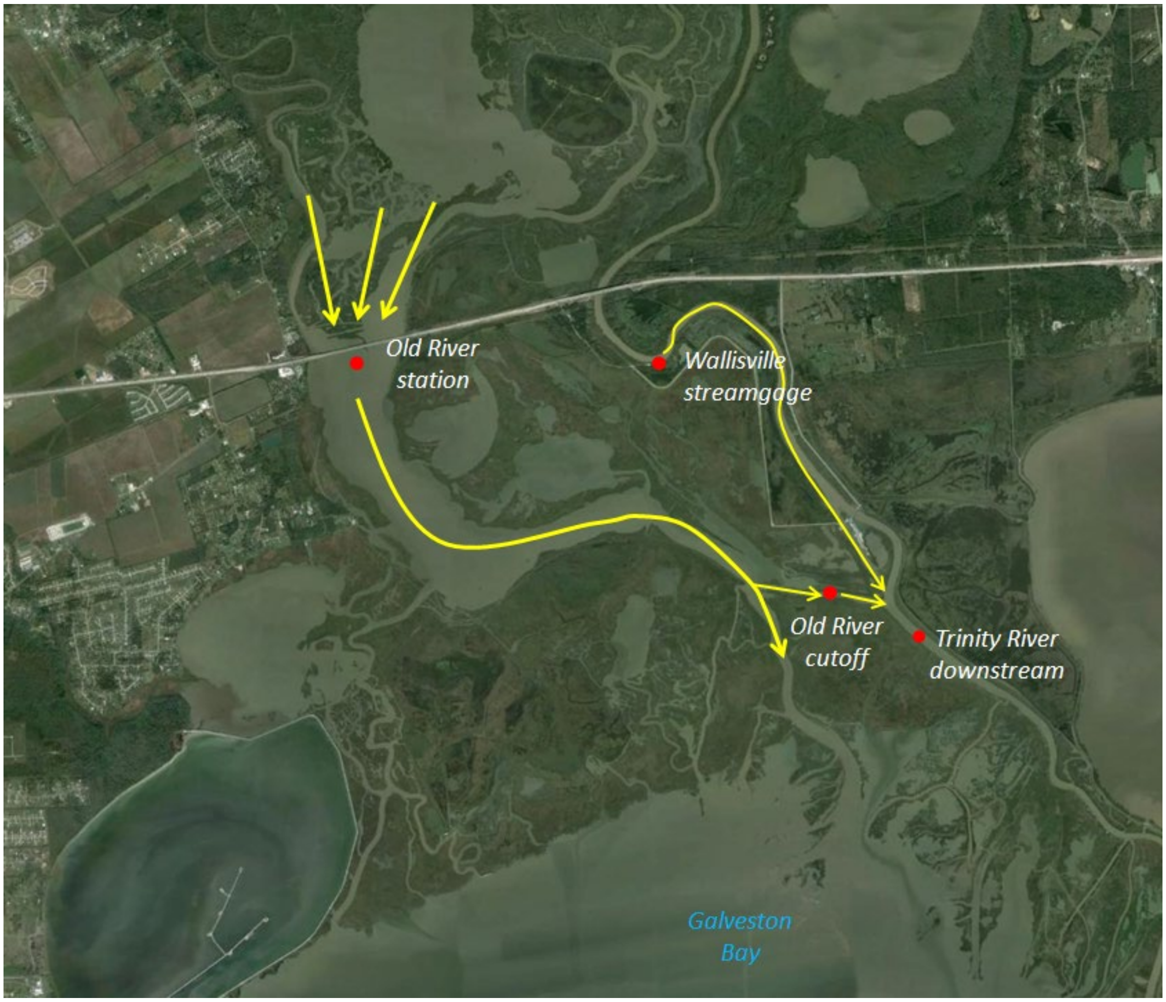

Figure 3. Initial water-quality sampling and discharge measurement locations (red circles) and expected flow patterns (yellow arrows) in the lower Trinity River.

Figure 3 shows the original measurement locations and expected flow patterns. The first set of measurements indicated that flow did not follow the expected pattern. Instead, most of the water volume from the Trinity River channel flows back into Old River through the Old River cutoff (Figure 4), resulting in a mixing point at the confluence of the Old River cutoff and Old River. After this finding, the Trinity River downstream station was no longer measured as part of this study, but a water-quality sample was collected at the Trinity-Old River Mixing Point.

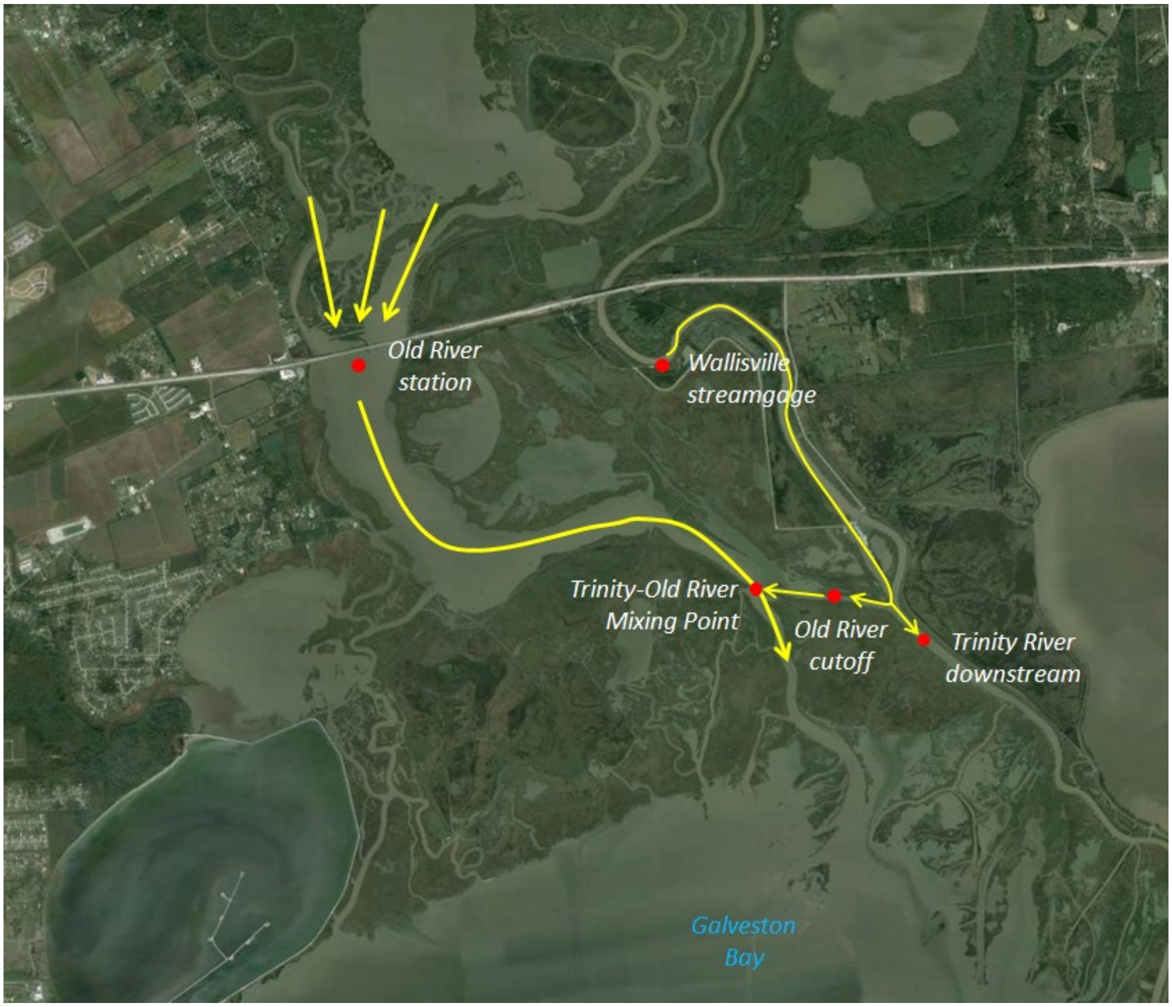

Figure 4. Modified water-quality sampling and discharge measurement locations (red circles) and measured flow patterns (yellow arrows) in the lower Trinity River.

Eleven sets of streamflow measurements were obtained in the lower Trinity River delta during periods of high flow. At the time these measurements were collected, streamflow at upstream station 0806700 Trinity River at Liberty, Texas ranged from 16,000 to 125,000 ft^3/s. Of the eleven events, nine resulted in measurable overflow into Old River. The difference between the streamflow at upstream stations and the combination of the Old River station and Wallisville streamgage streamflow ranged from 0.4% to 23% at the time of these measurements. Streamflow data for all discrete measurement sets are shown (Table 2).

Table 2. Streamflow results (in cubic feet per second) at the Wallisville streamgage and Old River station between 2016 and 2019. The differences in streamflow between upstream station 08067000 Trinity River at Liberty, Texas and the sum of the discharge measured downstream at the Wallisville streamgage and the Old River station are shown.

[--, unable to measure/not available]

Date	Trinity River at Liberty, Texas	Trinity River at Wallisville, Texas	Old River Lake near Wallisville, Texas	Wallisville streamflow plus Old River streamflow	Difference in streamflow	Percent difference
3/17/2016	52,000	22,700	34,800	57,500	5,500	10.6
4/25/2016	32,000	17,200	7,360	24,560	-7,440	-23.3
6/3/2016	81,000	22,300	62,700	85,000	4,000	4.9
12/7/2016	16,000	12,600	Tidal	--	--	--
4/13/2017	17,000	13,200	Tidal	--	--	--
9/2/2017	125,000	38,500	96,200	134,700	9,700	7.8
9/6/2017	47,000	20,200	26,600	46,800	-200	-0.4
3/1/2018	34,000	18,400	13,300	31,700	-2,300	-6.8
4/4/2018	65,000	21,400	37,800	59,200	-5,800	-8.9
10/22/2018	60,000	21,900	35,900	57,800	-2,200	-3.7
5/14/2019	67,000	21,300	41,700	63,000	-4,000	-6.0

Water-quality samples were collected concurrently with streamflow measurements at the selected stations listed on Table 2. Five baseflow samples were also collected at the Wallisville site and Old River. Data from these samples can be accessed on the Texas Coastal Watershed Dashboard and NWIS. Summary statistics for selected water-quality constituents are included in Appendix 1 (Table 1-1). Three replicates and one field blank were collected for quality control. Quality control data are also included in Appendix 1 (Tables 1-2, 1-3).

Task 1c: Lower Trinity River watershed streamflow

The USGS currently operates streamflow and discrete water-quality stations in the Trinity River below Lake Livingston (Table 3). These stations provide data useful for an assessment of flow patterns in the watershed as water travels from Lake Livingston to Galveston Bay. Data from four stations in the lower Trinity River watershed from March 2016 to December 2018 are presented by calendar year (Figures 5-7).

Table 3. Description of USGS streamgaging station in the lower Trinity River watershed.

Station name	Station number	Latitude (degrees , minutes, seconds)	Longitude (degrees, minutes, seconds)	Drainage Area (square miles)	Elevation above NGVD29 (feet)
Trinity River near Goodrich, Texas	08066250	30°34'19"	94°56'55"	16,844	40.00
Trinity River at Romayor, Texas	08066500	30°25'30"	94°51'02"	17,186	25.92
Trinity River at Liberty, Texas	08067000	30°03'27"	94°49'05"	17,468	-2.22
Trinity River at Wallisville, Texas	08067252	29°48'44"	94°43'52"	17,796	0

The Goodrich site, Romayor site, and Liberty site hydrographs followed a similar hydrographic trend in flow throughout the duration of the study. Except for Hurricane Harvey, discharge at the Wallisville site did not exceed 25,000 ft^3/s even when flow at upstream stations was higher (>35,000 ft^3/s) (Figures 5-7). For example, during an event in April 2018 the peak discharge at the Goodrich site was approximately 80,000 ft^3/s, whereas the peak discharge at the Wallisville site was 22,300 ft^3/s. During Hurricane Harvey (August 2017) the peak discharge at the Goodrich site was approximately 125,000 ft^3/s, whereas the peak discharge downstream at the Wallisville site was 35,900 ft^3/s (Figure 6). The majority water volume not accounted for by the streamgage at the Wallisville site was measured at the Old River site during these events as described in Task 1b above.

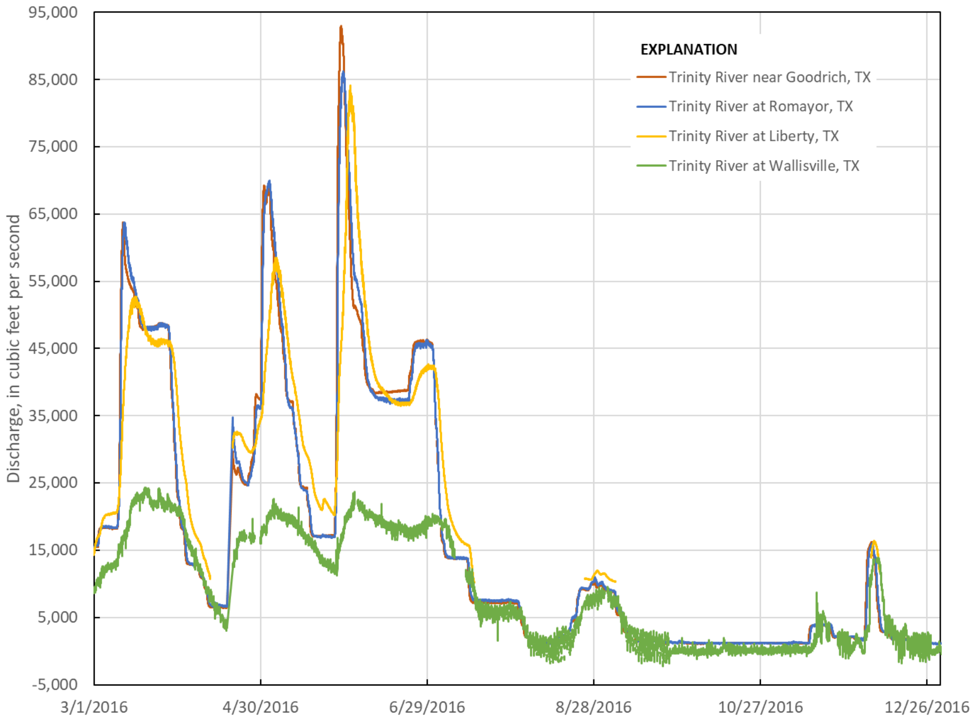

Figure 5. Instantaneous discharge at USGS streamgaging stations in the lower Trinity River watershed, March 2016-December 2016

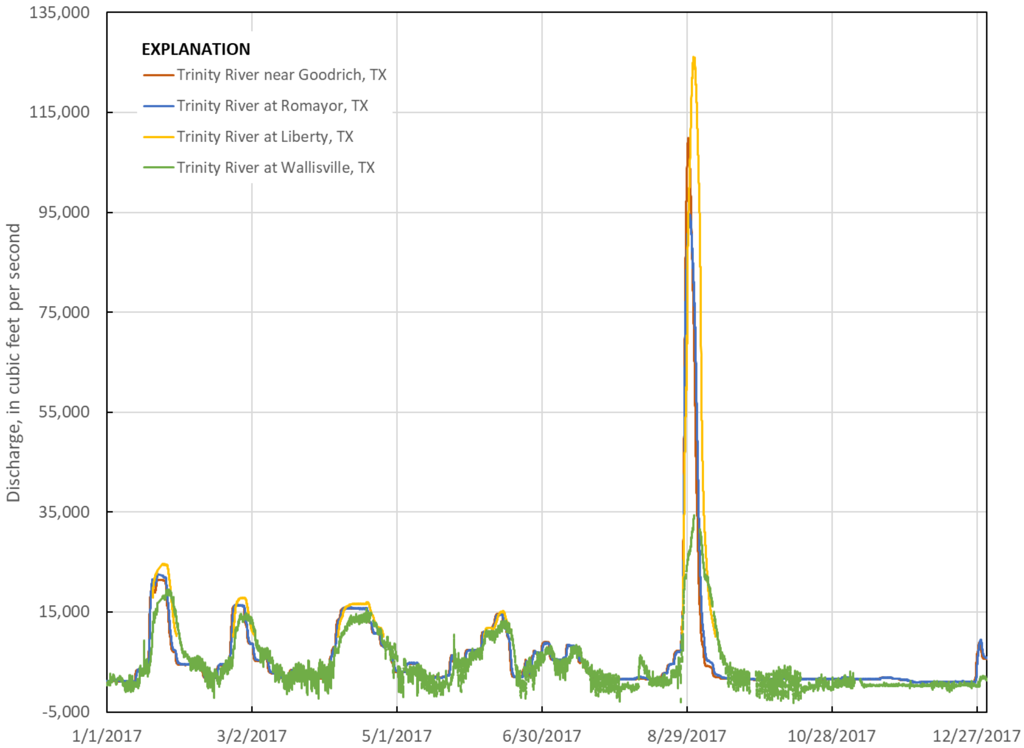

Figure 6. Instantaneous discharge at USGS streamgaging stations in the lower Trinity River watershed, January-December 2017. Peak in discharge in August 2017 occurred during Hurricane Harvey.

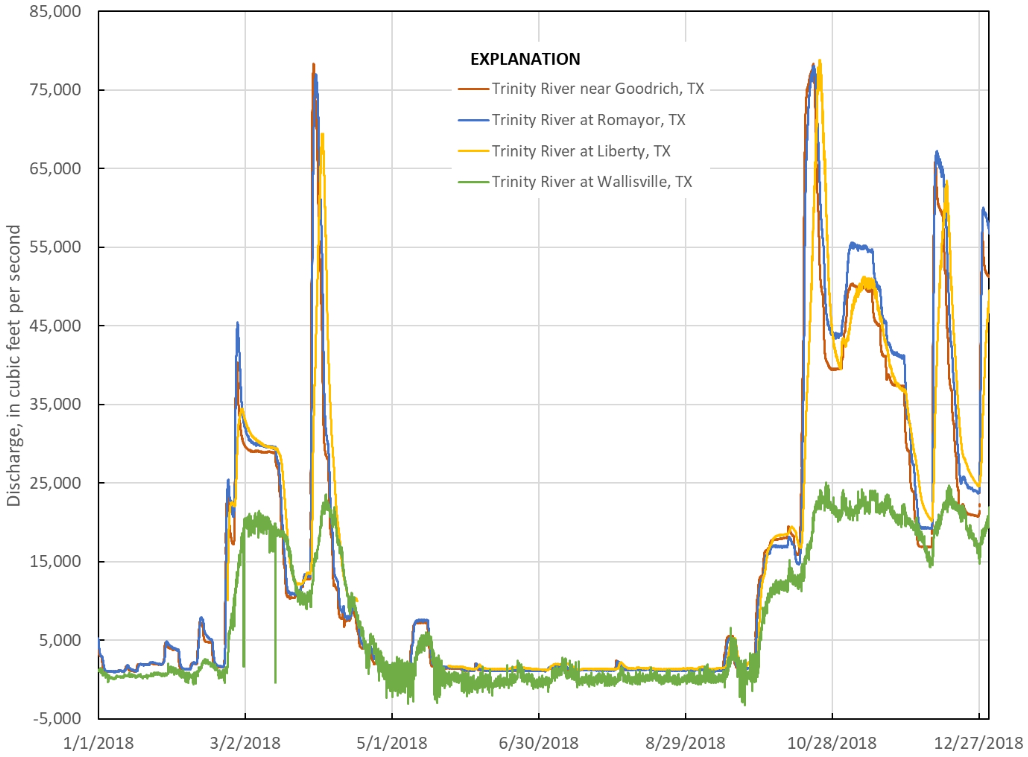

Figure 7. Instantaneous discharge at USGS streamgaging stations in the lower Trinity River watershed, January-December 2018

To examine the effects of streamflow patterns in the lower Trinity River watershed on water-quality traveling to Galveston Bay, samples were collected at USGS station 08067000 Trinity River at Liberty, Texas in coordination with samples collected at the Wallisville site. Samples at the Liberty site are routinely collected by the USGS as part of a project in cooperation with the City of Houston and include the measurement of similar water-quality constituents as those measured at the Wallisville site. A total of seven sample pairs were collected from March 2016 to December 2018. The dates and streamflow associated with these samples are shown in Figure 8 Water-quality data for these seven samples are also shown (Appendix 1, Table 1-3). For all parameters measured, no statistically significant differences were observed between concentrations measured at the Liberty site and concentrations measured at the Wallisville site ($p > 0.05$).

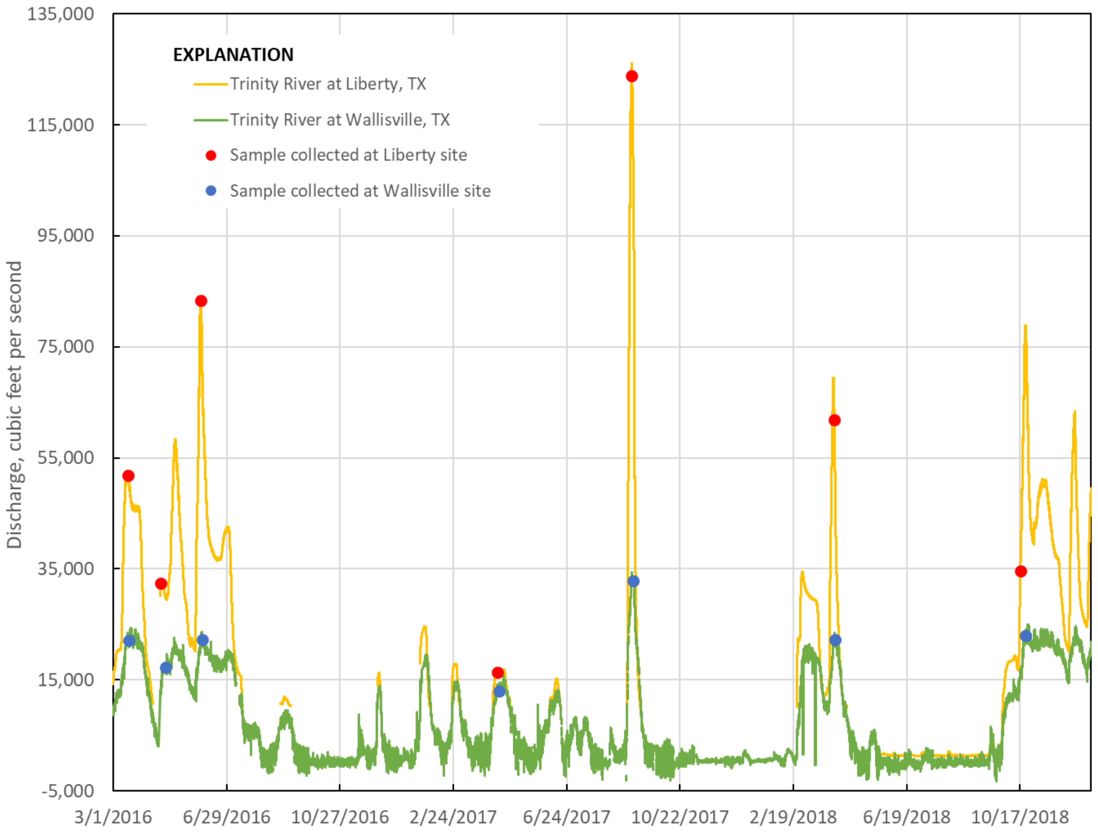

Figure 8. Instantaneous discharge at USGS streamgaging stations 08067000 Trinity River at Liberty, Texas and 08067252 Trinity River at Wallisville Texas, March 2016-October 2018, and corresponding water-quality samples collected at each station.

Task 2: Evaluation of the variability of sediment and nutrient loading into Matagorda Bay

The objective of this task was to provide instrumentation for a continuous measurement of river discharge in the lower Colorado River from which a quantitative relationship between flow and sediment and nutrient loading could be developed and validated in future studies. The continuation of sediment and nutrient samples are included in this task on the Colorado River.

Task 2a: Installation, operation, and maintenance of index-velocity streamgage

A 1.5-megahertz SonTek SL 3G was installed at the USGS streamgaging station 08162501 Colorado River near Wadsworth, Texas. (Figures 9 and 10) in accordance with USGS standards and practices and with additional assistance and in-kind services from the Texas Water Development Board. Streamflow and stage data from this station begin on September 27, 2016 and can be accessed on NWIS.

Figure 9. Location of USGS streamgaging station 08162501 Colorado River near Wadsworth, Texas.

Figure 10. Streamgage at USGS station 08162501 Colorado River near Wadsworth, Texas.

Task 2b: Water-quality sample collection

Water-quality samples were collected at USGS station 08162501 Colorado River near Wadsworth, Texas after installation of the streamgage. Due to predominant baseflow conditions at this station during the period of this study, only eight samples were collected. Five of the eight water-quality samples were collected during events resulting in flows higher than 7,000 ft^3/s. Streamflow at USGS station 08162501 Colorado River near Wadsworth, Texas during the period of this study and corresponding water-quality samples collected are shown (Figure 11). Nutrient and suspended sediment data can be accessed on the Texas Coastal Watershed Dashboard and NWIS. Summary statistics for selected water-quality constituents are shown in Appendix 1 (Table 1-1).

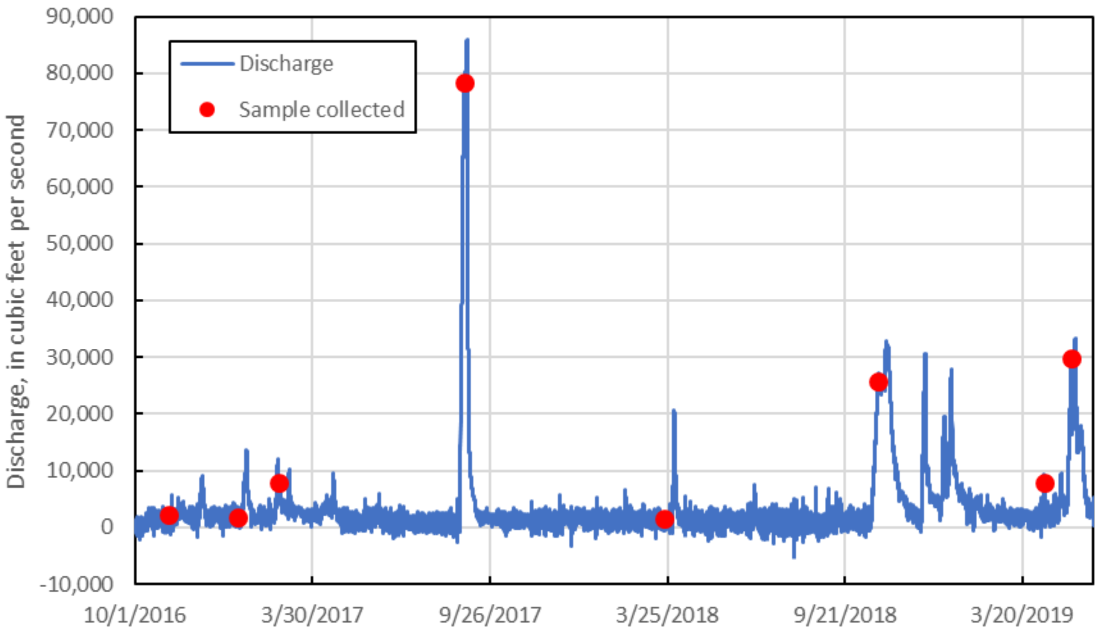

Figure 11. Instantaneous discharge at USGS station 08160501 Colorado River near Wadsworth, Texas, March 2016 to May 2019, and corresponding discrete water-quality samples.

Task 2c: Development of sediment surrogate

The USGS continued collecting data for developing a sediment surrogate for USGS station 08162501 Colorado River near Wadsworth, Texas. The data from samples collected during this project will be used to develop a relation between measures of acoustic backscatter and suspended-sediment concentrations once a representative number of samples are collected. The adequacy of the calibration dataset depends primarily on how well it represents the range of hydrologic and sedimentologic conditions. The dataset should describe how seasonal, hydrology, and particle size may affect the surrogate relation. These factors, more than the count of measurements, determine calibration dataset adequacy. Due to predominant low flow conditions throughout the duration of this project, additional samples during periods of elevated flow are needed to describe suspended-sediment concentrations over the range of hydrologic conditions and develop an adequate calibration dataset for the surrogate model.

Task 3: Evaluation of the variability of sediment and nutrient loading into San Antonio Bay

This task continues ongoing efforts to analyze river discharge and sediment and nutrient concentrations entering San Antonio Bay from the San Antonio and Guadalupe River system and will support analysis of historic flow data from stations in the Guadalupe River and San Antonio River below Victoria, Texas to determine the magnitude of unaccounted flow that might be entering the estuary through canals and wetlands instead of the main channel.

Task 3a: Operation and Maintenance of Index-velocity streamgage and collection of water-quality samples

The streamgage at USGS station 08188810 Guadalupe River at SH 35 near Tivoli, Texas was installed in 2013 as part of the USGS stream-gaging network. A 1.5-megahertz SonTek Argonaut-Side-Looker ADVM is installed at the site. USGS continued the operation and maintenance of this index-velocity gage throughout the duration of this study through support from the Guadalupe-Blanco River Authority. Operation and maintenance of this station included repair of the ADVM and streamgage in August 2017 after damage resulting from storm surge from Hurricane Harvey (Figure 12). Forty periodic suspended-sediment and nutrient samples have been collected at the site between April 2013 and August 2018 (Figure 13). Data from these samples can be accessed on the Texas Coastal Watershed Dashboard and NWIS**.**

Figure 12. Damage resulting from Hurricane Harvey at USGS station 08188810 Guadalupe River at SH 35 near Tivoli, Tex.

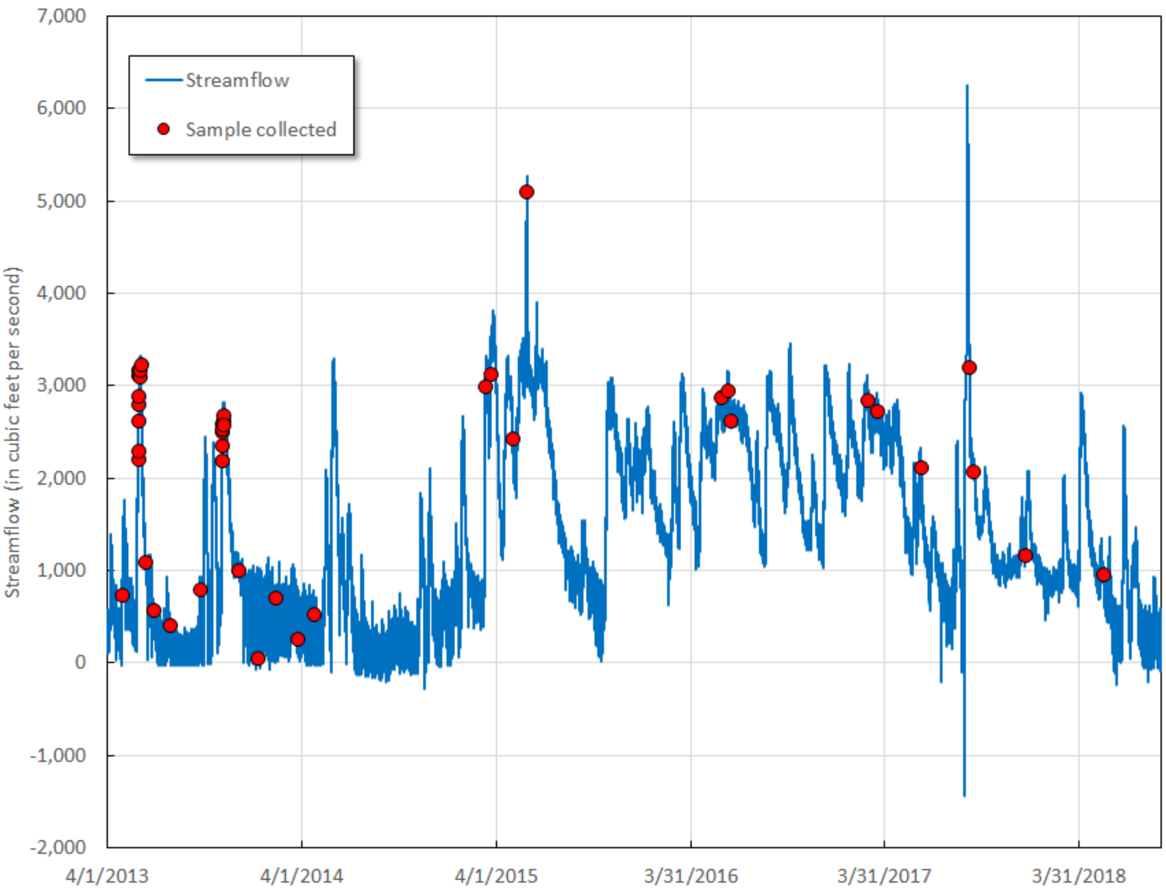

Figure 13. Streamflow and samples collected at USGS Streamflow Station 08188810 Guadalupe River at State Highway 35 near Tivoli, Texas, 2013-18.

Task 3b/3c: Development of Sediment Surrogate Model

Periodic suspended-sediment samples collected between April 2013 and June 2017 were used to develop a surrogate model using acoustic backscatter data from the ADVM. All samples were collected using USGS protocols described in Edwards and Glysson (1999), Landers and others (2016), and the USGS National Field Manual. All data are stored in the NWIS database.

Suspended-sediment samples were collected bimonthly during the first year of model development. During high-flow events, samples were collected at a higher frequency depending on the duration of the event. After the first year, samples were collected during targeted hydrologic events to fill in data gaps.

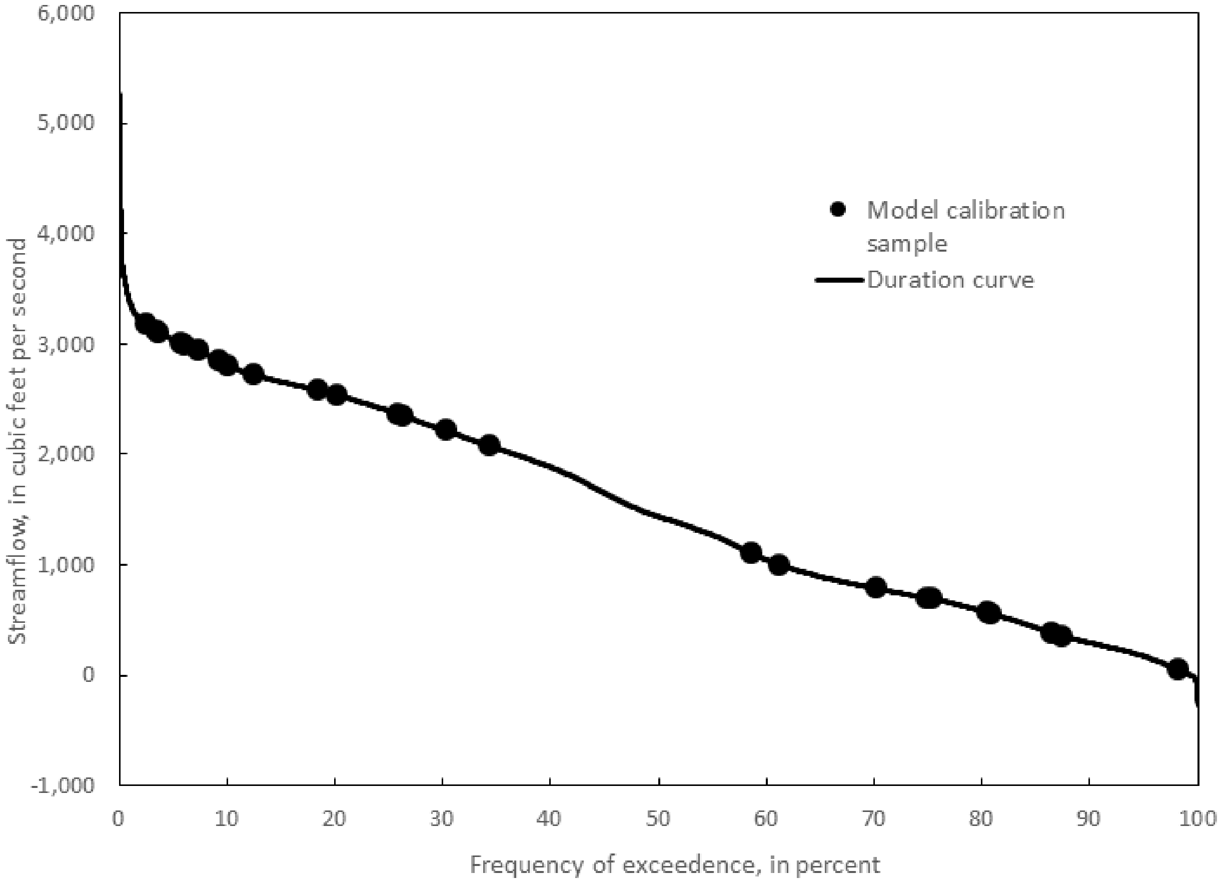

Figure 14. Streamflow duration curve with model calibration samples for U.S. Geological Survey streamflow-gaging station 08188810 Guadalupe River at State Highway 35 near Tivoli, Texas, April 2013–June 2017.

The dataset used to develop the regression model consisted of 36 measurements of suspended-sediment concentration and ADVM data collected from April 29, 2013 to June 6, 2017. From the 36 samples, 25 were used in the model calibration dataset. Ten samples collected at higher frequency during high flow events were not used in the calibration because they could introduce autocorrelation and could not be considered independent; and one sample was missing acoustic backscatter data. The 25 samples were collected over the range of continuously observed conditions shown in the duration curves in Figures 14 and 15. The duration curves were developed for streamflow and sediment corrected backscatter (SCB) data collected from April 2013–June 2017.

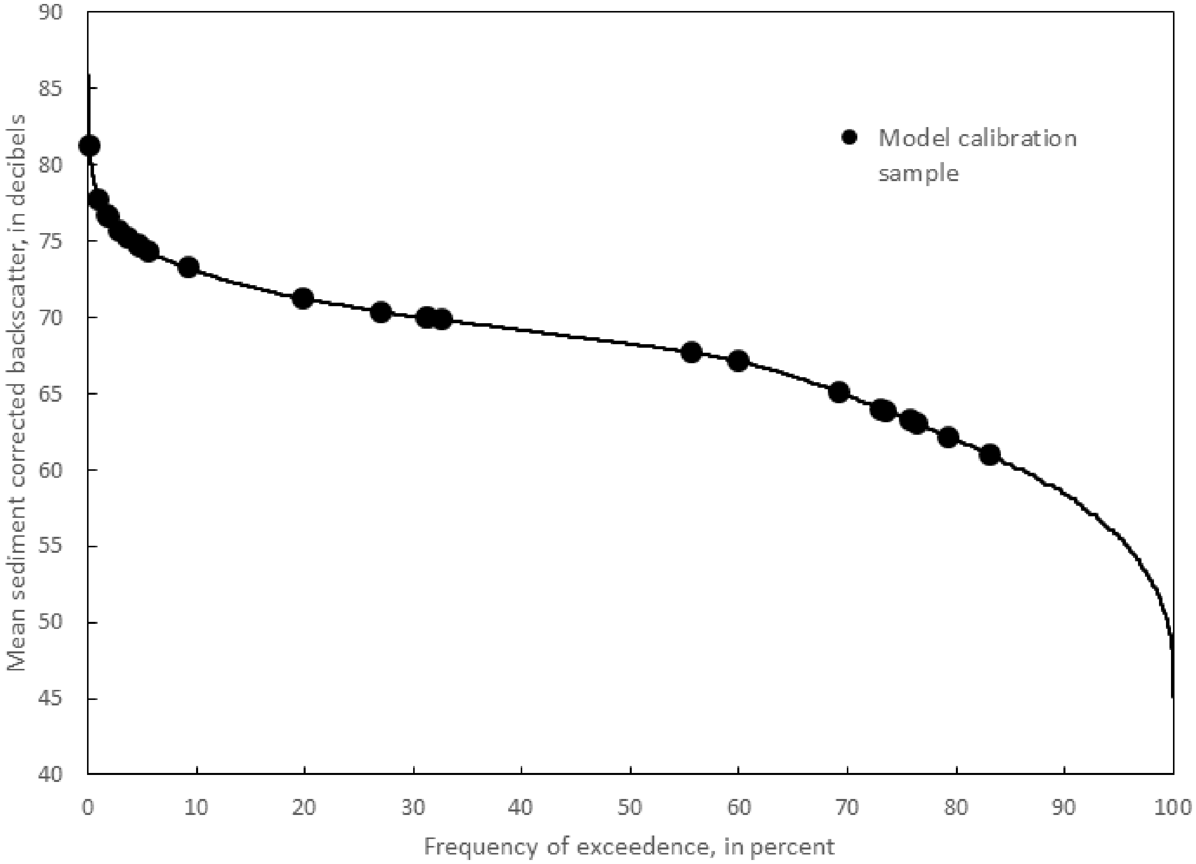

Figure 15. Sediment corrected backscatter duration curve with model calibration samples for U.S. Geological Survey streamflow-gaging station 08188810 Guadalupe River at State Highway 35 near Tivoli, Texas, April 2013–June 2017.

While the methodology and tools used to develop the surrogate model follow standard USGS protocols, the specific predictive variables and model selection for this sight are unique. The model for station 08188810 Guadalupe River at State Highway 35 near Tivoli, Texas was developed by the evaluation of mean sediment-corrected backscatter (SCB), sediment attenuation coefficient (SAC), and streamflow as explanatory variables for suspended-sediment concentration. By using the Surrogate Analysis and Index Developer (SAID) tool (version 1.1), SCB was calculated from measured backscatter following the methods described in Landers and others (2016). The SAID tool also was used to develop an ordinary least squares linear regression analysis, which examined streamflow, SAC, and SCB as explanatory variables for estimating suspended-sediment concentration. Combinations of these three variables were evaluated to determine the best explanatory variables for suspended-sediment concentration. A linear regression model with SCB as the explanatory variable was determined to be the best model based on adjusted coefficient of determination (R^2_a), significance tests, model root mean square error, residual plots, and correlation of explanatory variables.

The model of suspended-sediment concentration for USGS streamflow-gaging station 08188810 Guadalupe River at State Highway 35 near Tivoli, Texas., has an adjusted coefficient of determination of 0.91 and is its equation in linear form is:

$$\log_{10}SSC = -3.12 + 0.0747 \text{ x SCB}$$

Where

SSC is the suspended-sediment concentration, in milligrams per liter; and
SCB is th mean sediment corrected backscatter, in decibels.

The SSC was transformed before regression analysis, and the predicted mean of the variable may be biased. To account for this bias, a nonparametric smearing bias correction factor (BCF) of 1.08 was applied to the predicted variable.

The model-produced estimate of SSC and suspended-sediment loads (SSL) at USGS streamflow-gaging station 08188810 Guadalupe River at State Highway 35 near Tivoli, Texas, are available on the station page at https://waterdata.usgs.gov/tx/nwis/uv/?site_no=08188810 along with the 90 percent confidence intervals for both SSC and SSL.

Evaluation of the nutrient data from the 40 periodic samples collected at the USGS stream-gaging station 08188810 Guadalupe River at State Highway 35 near Tivoli, Texas, between 2013 and 2018, showed no statistically significant correlation between nutrient concentrations and streamflow or suspended-sediment concentration. Consequently, real-time monitoring of nutrients would require a dedicated monitor. Nitrate monitors have been successfully used at locations across the US, the sondes would need to be tested at this site.

Task 3d: Historical flows for Guadalupe and San Antonio Rivers

Freshwater streamflow at Guadalupe River at State Highway 35 near Tivoli, Texas is largely from the San Antonio River and the Guadalupe River (Figure 16). The nearest upstream USGS streamflow gaging stations are at San Antonio River near McFadden, Coleto Creek near Victoria, and Guadalupe River at Victoria (Figure 16). The gage at Guadalupe River at SH35 was installed in 2013, and hence, the following summary statistics focus on the 2013–17 time period.

There are also potential surface water contributions from the ungaged areas downstream of these sites. The ungaged area is about 249 mi^2 and includes: Coleto Creek watershed between the USGS 08177500 station and the confluence with the Guadalupe River (46 mi^2); San Antonio River watershed between the USGS 08188570 gaging station and the confluence with the Guadalupe River (26 mi^2); Guadalupe River watershed between the USGS 08176500 gaging station and the 08188810 gaging station (162 mi^2); and the Kuy Creek watershed (15 mi^2).

Streamflow from the ungauged areas was estimated using the streamflow measurements at Copano Creek (an 88 mi^2 coastal watershed adjacent to the Lower San Antonio River watershed in Refugio County) and multiplying by the ratio of the drainage areas (that is, 249 divided by 88).

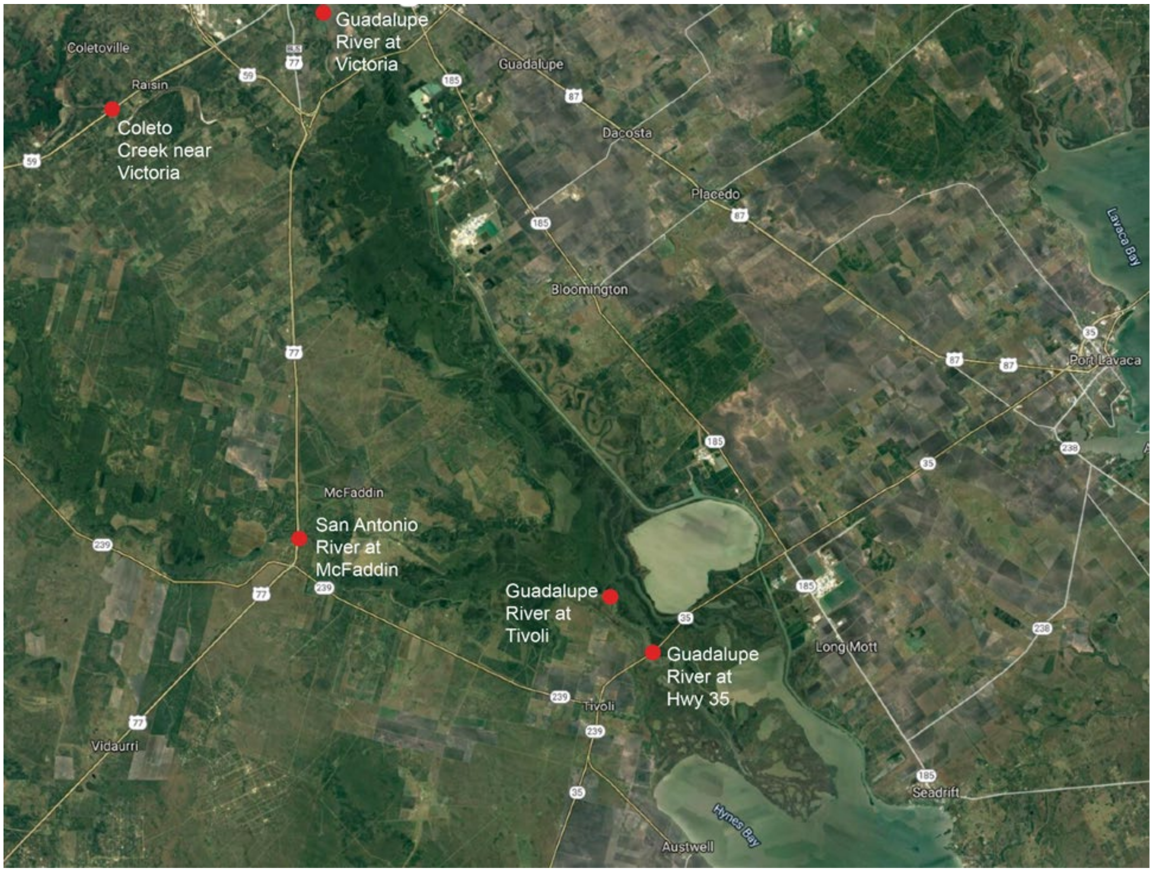

Figure 16. Map of the Lower San Antonio-Guadalupe River Basin and Selected U.S. Geological Survey Streamflow Gaging Stations.

The following streamflow statistics are based on a continuous measurement record.The average streamflow measured at the Guadalupe River at Highway 35 during 2013–17 was 1,490 ft^3/s. The average sum of upstream streamflows was 2,890 ft^3/s. This difference in streamflow represents a loss of about 48 percent of the upstream flows. Graphical comparison shows that during baseflow conditions, the sum of upstream contributing flows from the San Antonio River and the Guadalupe River are in general agreement with the streamflow measured downstream at the Guadalupe River at State Highway 35 (Figure 17). However, especially during higher flows, the sum of upstream flows is greater than the flow measured at Highway 35, indicating that some streamflow bypasses the main channel in the San Antonio-Guadalupe River delta, downstream of the Guadalupe River at Victoria and the San Antonio River near McFadden.

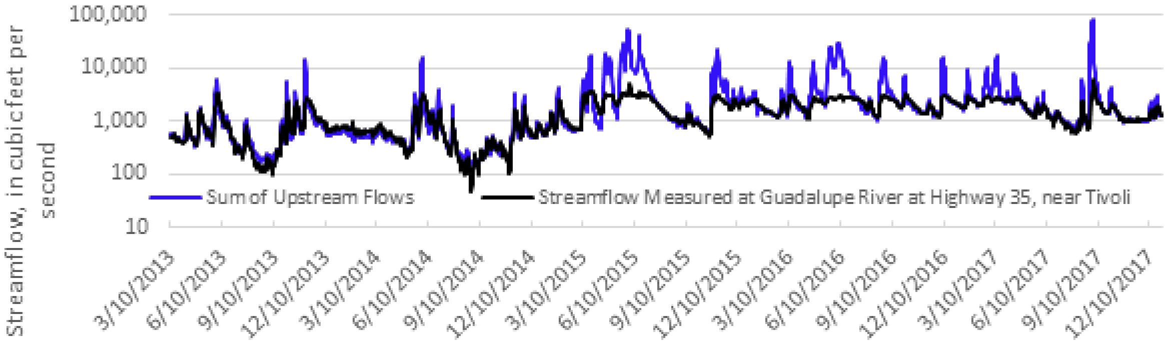

Figure 17. Comparison of measured streamflow at Guadalupe River at Highway 35, near Tivoli, Texas and the sum of upstream measured and ungauged streamflow.

The amount of flow bypassing the Guadalupe River gaging station at Highway 35 and entering San Antonio Bay is not known. Some of the flow may enter Green Lake or other ineffective flow areas and could be lost to evaporation or ground water infiltration. Figure 18 shows general areas where high flow may leave the main channels of the San Antonio and Guadalupe Rivers upstream of the Highway 35 gaging station. For example, during high flow events, substantial flow has been observed in bayous that flow under (and infrequently over) a five-mile stretch of Highway 35, between the gaging station and the Victoria Barge Canal, such as Schwings Bayou, Hog Bayou, and Goff Bayou (Figure 19).

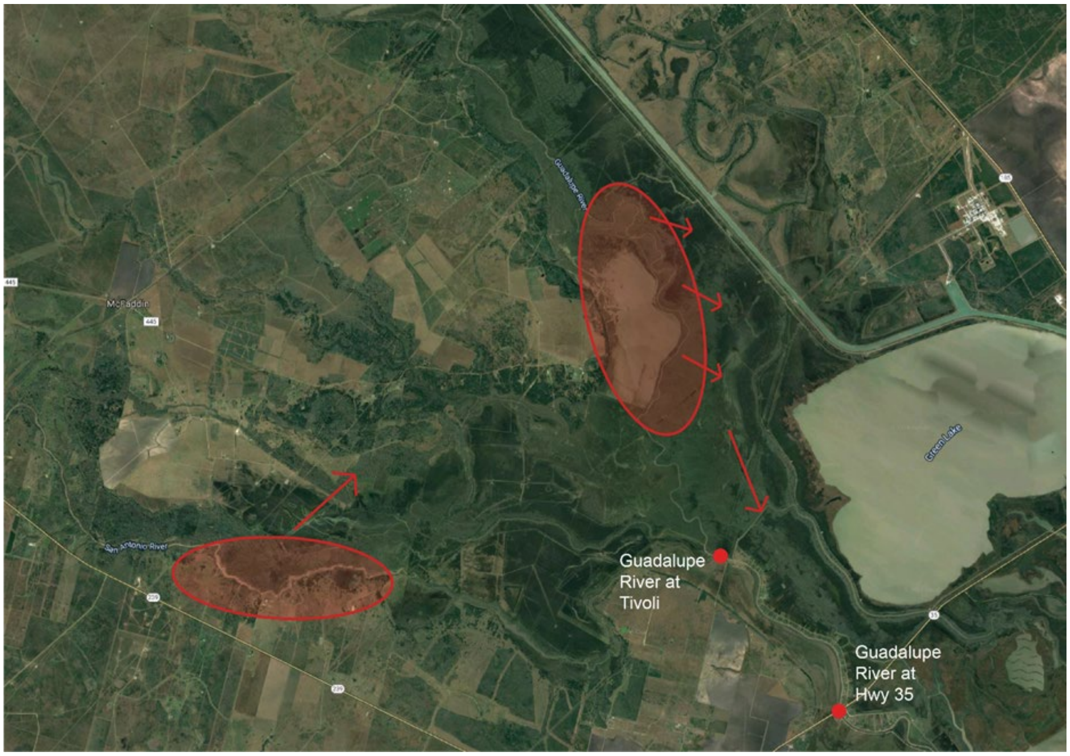

Figure 18. Lower San Antonio River-Guadalupe River basin and general areas where streamflow leaves the main San Antonio and Guadalupe River channels during periods of high flow.

Figure 19. Selected locations of Guadalupe River bypass flow during high flow periods.

During periods of high flow, streamflow measurements could be made at these bayou channels along Highway 35 to gain a better understanding of the amount of flow that bypasses the gaging station and enters San Antonio Bay. One method to estimate long-term flow through these bayou channels would be to install a new gaging station on one of the bayous channels (for example, Hog Bayou at Highway 35). This station would provide a continuous measurement of the flow in Hog Bayou. In addition, periodic streamflow measurements would be made at all the other bayou channels. The measured total flow of all the bayous would be related to the flow measured at the index station, as well as the flow measured at the Guadalupe River at Highway 35 station, over a range of flow conditions, to develop a rating to estimate total flow through the bayou overflow channels. Continued evaluation of overbank conditions will be part of the next phase as more streamflow data are collected (during both baseflow and stormflow conditions).

Task 4: Evaluation of the variability of sediment and nutrient loading into Nueces Bay

This task initiates the evaluation of stream discharge and sediment and nutrient concentrations across a range of hydrologic conditions in the lower reaches of the Nueces River in an effort to improve our understanding of how peak inflows, relative to base or low inflows, contribute to nutrient and sediment loading within estuaries and to develop surrogate models for generating real-time estimates of sediment and nutrient loadings to Nueces Bay and Corpus Christi Bay.

Task 4a: Collection of streamflow and water-quality samples

Periodic streamflow, suspended-sediment, and nutrient samples have been collected at two sites below the salt-water barrier on the Nueces River Basin between September 2013 and September 2018 to determine the feasibility of creating surrogate models leading to the real-time monitoring of suspended-sediment nutrient loads into the Nueces Bay. Five measurements and samples were collected at USGS sampling site 08211502 Nueces River at IH37 near Odem, Texas (Figure 20), and six measurements and samples were collected at USGS sampling site 0821150305 Rincon Bayou Channel near Odem, Texas (Figure 21).

Figure 20. USGS sampling site 08211502 Nueces River at IH37 near Odem, Texas, showing temporary ADVM mount.

Figure 21. USGS sampling site 0821150305 Rincon Bayou Channel near Odem, Texas, showing semi-permanent ADVM mount.

One synoptic measurement was collected on April 11, 2018 at these two sites and two additional sites in the watershed (08211200 Nueces River at Bluntzer, Texas, and 08211500 Nueces River at Calallen, Texas) to determine if any sediment gains or losses might be detected in the system. Data from these samples can be accessed on the Texas Coastal Watershed Dashboard and NWIS**.**

Task 4b: Recommendation of permanent monitoring stations

Two monitoring sites are recommended to better account for the sediment and nutrient concentrations entering Nueces Bay from the Nueces River system (Figure 22). The first site is the Nueces River at the Highway 37 bridge (USGS sampling site 08211502 Nueces River at IH37 near Odem, Texas). Although the flow at this site is typically regulated during times of low flow by the salt-water barrier dam upstream, it will capture all flow entering the Nueces Bay during high flow events because all flow from the Nueces River system is funneled under the IH37 bridge. A permanent real-time streamgaging and water quality monitoring station is set to be installed at this location in 2019 in cooperation with the Coastal Bend Bays and Estuary Program and the City of Corpus Christi. The second site is located on the Rincon Bayou Channel downstream from the bypass pipeline outflow (USGS sampling site 0821150305 Rincon Bayou

Channel near Odem, Texas). This site will capture all flow entering the Nueces Bay during periods of low flow when water is being pumped through the bypass pipeline.

Figure 22. Recommended permanent stations (Site 08211502 and 0821150305) for monitoring sediment and nutrient loading into Nueces Bay

Future Considerations

Future projects should advance the tasks outlined above through a continuation of efforts conducted on these four major rivers (Trinity, Colorado, Guadalupe, Nueces). The objectives should provide more data to identify changes in nutrient and sediment concentrations during flood periods, as compared to base or low flow periods and should follow procedures for discharge measurement, nutrient (total and fractions of nitrogen and phosphorus), and sediment (total suspended and size fractionation) collection as previously established for this series of studies. Consideration should be given to add environmental isotopes, such as δ15N and δ18O of nitrate, to the water-quality constituents collected. These data may help identify potential sources of nitrogen contributions to the inflows. For example, specific isotopes of nitrogen (δ15N) that are from atmospheric sources are often isotopically distinct from solutes derived from geologic or biologic sources. Additionally, future efforts should continue developing the optical turbidity and/or acoustic backscatter surrogate methodology for each major river, although achievement of an applicable (validated) surrogate model for generating real-time estimates of sediment and nutrient concentrations and loadings will vary based on progress previously accomplished for a given river location. Specific tasks for each major river basin should be made in conjunction with TWDB.

Literature Cited

Edwards, T.K., and Glysson, G.D., 1999, Field methods for measurement of fluvial sediment: U.S Geological Survey Techniques of Water-Resource Investigations, book 3, chap. C2 (rev.), 89 p.

Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory— Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey OpenFile Report 93–125, 217 p. [Available online at http://pubs. usgs.gov/of/1993/0125/report.pdf.]

Guy, H.P., 1969, Laboratory theory and methods for sediment analysis: U.S. Geological Survey Techniques of WaterResources Investigations, chap. Cl, book 5, 58 p.

Landers, M.N., Straub, T.D., Wood, M.S., and Domanski, M.M., 2016, Sediment acoustic index method for computing continuous suspended-sediment concentrations: U.S. Geological Survey Techniques and Methods, book 3, chap. C5, 63 p., http://dx.doi.org/10.3133/tm3C5.

Levesque, V.A., and Oberg, K.A., 2012, Computing discharge using the index velocity method: U.S. Geological Survey Techniques and Methods 3–A23, 148 p.

Lucena, Z., and Lee, M.T., 2017, Characterization of streamflow, suspended sediment, and nutrients entering Galveston Bay from the Trinity River, Texas, May 2014–December 2015: U.S. Geological Survey Scientific Investigations Report 2016–5177, 38 p., accessed August 19, 2019 at https://doi.org/10.3133/sir20165177.

Mueller, D.S., Wagner, C.R., Rehmel, M.S., Oberg, K.A., and Rainville, Francois, 2013, Measuring discharge with acoustic Doppler current profilers from a moving boat (ver. 2.0, December 2013): U.S. Geological Survey Techniques and Methods, book 3, chap. A22, 95 p., accessed August 19, 2019, at https://dx.doi.org/10.3133/tm3A22.

Patton, C.J., and Kryskalla, J.R., 2003, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Evaluation of alkaline persulfate digestion as an alternative to Kjeldahl digestion for determination of total and dissolved nitrogen and phosphorus in water: U.S. Geological Survey Water-Resources Investigations Report 03–4174, 33 p.

Patton, C.J., and Kryskalla, J.R., 2011, Colorimetric determination of nitrate plus nitrite in water by enzymatic reduction, automated discrete analyzer methods: U.S. Geological Survey Techniques and Methods, book 5, chap. B8, 34 p. [Also available at https://pubs.usgs.gov/tm/05b08/.]

U.S. Environmental Protection Agency, 1993, Method 365.1 determination of phosphorus by semi-automated colorimetry, revision 2.0, in O'Dell, J.W., ed., Methods for the determination of inorganic substances in environmental samples: U.S. Environmental Protection Agency EPA/600/R–93/100.

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A10. [Also available at http://pubs.water.usgs.gov/twri9A].

Appendix 1

Water Quality Data Tables

Table 1-1. Summary statistics for selected water-quality constituents measured at USGS stations in the Trinity River, Colorado River, Guadalupe River, and Nueces River.

Basin	Station name		Ammonia (NH3 + NH4+), water, filtered, milligrams per liter as nitrogen	Nitrate plus nitrite, water, filtered, milligrams per liter as nitrogen	Nitrite, water, filtered, milligrams per liter as nitrogen	Total nitrogen [nitrate + nitrite + ammonia + organic-N], water, unfiltered, analytically determined, milligrams per liter	Total nitrogen [nitrate + nitrite + ammonia + organic-N], water, filtered, analytically determined, milligrams per liter	Phosphorus, water, unfiltered, milligrams per liter as phosphorus	Orthophosphate, water, filtered, milligrams per liter as phosphorus	Organic carbon, water, unfiltered, milligrams per liter	Organic carbon, water, filtered, milligrams per liter	Absorbance, 254 nm, water, filtered, absorbance units per centimeter	Suspended sediment concentration, milligrams per liter	Suspended sediment, sieve diameter, percent smaller than 0.0625 millimeters
Trinity River	Trinity River at Wallisville, TX	Min	<0.01	<0.040	<0.001	0.43	0.36	0.049	0.012	5.3	2.49	0.120	6	32
		Median	0.02	0.295	0.004	0.98	0.74	0.155	0.037	8.4	6.02	0.204	140	69
		Max	0.05	0.658	0.014	1.29	1.11	0.204	0.080	9.9	7.86	0.308	520	100
	Old River Lake near Wallisville, TX	Min	<0.01	<0.040	<0.001	0.62	0.38	0.113	0.016	5.6	5.06	0.147	19	58
		Median	0.02	0.303	0.003	0.87	0.69	0.142	0.039	8.8	6.08	0.199	66	97
		Max	0.05	0.663	0.006	1.19	1.20	0.179	0.066	9.8	7.68	0.297	176	100
	7168040Trinity-San Jacinto ES Line 680 Site 40	Min	<0.01	<0.040	0.001	0.71	0.50	0.107	0.022	6.9	4.25	0.120	76	71
	(Mixing point)	Median	0.02	0.267	0.004	1.05	0.70	0.154	0.036	8.5	6.25	0.221	141	87
		Max	0.06	0.673	0.014	1.29	1.10	0.200	0.061	9.8	7.56	0.325	262	98
Colorado River	Colorado River near Wadsworth, TX	Min	<0.01	0.169	0.004	1.00	0.57	0.240	0.054	3.6	2.70	0.068	17	85
		Median	0.04	1.094	0.033	2.84	2.32	0.657	0.116	11.2	4.84	0.159	339	96
		Max	0.20	4.145	0.168	4.76	4.50	0.823	0.442	18.8	10.50	0.409	1590	97
Guadalupe River	Guadalupe River at SH 35 near Tivoli, TX	Min	<0.01	<0.040	<0.001	1.21	0.84	0.269	0.129	2.7	2.11	0.060	16	88
		Median	0.02	1.610	0.025	2.18	2.25	0.522	0.268	8.6	6.06	0.200	243	98
		Max	0.07	4.92	0.097	5.81	3.75	1.25	0.461	13.3	12.0	0.519	1,520	100
Nueces River	Nueces River at IH 37 near Odem, TX	Min	<0.01	<0.040	<0.001	0.85	0.61	0.179	0.112	9.5	7.66	0.161	13	94
		Median	0.12	0.04	0.001	1.04	0.77	0.262	0.159	10.3	7.77	0.189	18	96
		Max	0.67	0.12	0.006	1.49	1.23	0.408	0.302	11.6	8.97	0.293	50	99
	Rincon Bayou Channel near Odem, TX	Min	0.02	<0.040	<0.001	0.82	0.58	0.116	0.039	8.0	6.95	0.148	35	94
		Median	0.025	0.102	0.003	0.93	0.71	0.253	0.188	9	7.16	0.193	52	99
		Max	0.05	0.198	0.005	1.06	0.84	0.394	0.29	10.5	9.02	0.233	72	99

Table 1-2. Results from replicate samples collected in the Trinity River, Colorado River, Guadalupe River, and Nueces River.
[--, sample not collected; RPD, relative percent difference]

Station name	Sample Date and time	Ammonia (NH3 + NH4+), water, filtered, milligrams per liter as nitrogen	Nitrate plus nitrite, water, filtered, milligrams per liter as nitrogen	Nitrite, water, filtered, milligrams per liter as nitrogen	Total nitrogen [nitrate + nitrite + ammonia + organic-N], water, unfiltered, analytically determined, milligrams per liter	Total nitrogen [nitrate + nitrite + ammonia + organic-N], water, filtered, analytically determined, milligrams per liter	Phosphorus, water, unfiltered, milligrams per liter as phosphorus	Orthophosphate, water, filtered, milligrams per liter as phosphorus	Organic carbon, water, unfiltered, milligrams per liter	Organic carbon, water, filtered, milligrams per liter	Absorbance, 254 nm, water, filtered, absorbance units per centimeter	Suspended sediment concentration, milligrams per liter	Suspended sediment, sieve diameter, percent smaller than 0.0625 millimeters
Trinity River at Wallisville, TX	2/25/2016 12:00	<0.01	0.607	<0.001	1.18	0.96	0.124	0.039	--	--	--	71	94
	2/25/2016 12:01	<0.01	0.612	<0.001	1.21	0.98	0.125	0.042	--	--	--	71	94
	RPD	0.00%	0.81%	0.00%	2.43%	1.85%	0.64%	5.94%	--	--	--	0.00%	0.00%
Trinity River at Wallisville, TX	2/14/2018 12:35	0.03	0.291	0.004	1.1	0.74	0.175	0.034	9.1	7.27	0.305	126	97
	2/14/2018 12:36	0.03	0.299	0.004	1.14	0.78	0.172	0.034	9.2	7.28	0.308	130	98
	RPD	2.58%	2.92%	8.53%	3.31%	4.08%	1.73%	1.24%	0.54%	0.03%	1.11%	3.13%	1.03%
Old River Lake near Wallisville, TX	10/18/2016 10:31	0.05	<0.040	<0.001	0.62	0.47	0.126	0.05	9.8	5.34	0.147	19	95
	10/18/2016 10:32	0.05	<0.040	<0.001	0.67	0.38	0.121	0.053	8.2	5.15	0.15	20	95
	RPD	5.70%	0.00%	0.00%	7.28%	21.54%	4.06%	6.38%	17.66%	3.66%	1.66%	5.13%	0.00%
Colorado River near Wadsworth, TX	3/21/2018 11:30	0.03	1.352	0.032	2.23	1.59	0.24	0.104	4.6	4.04	0.09	18	95
	3/21/2018 11:35	0.03	1.443	0.034	2.3	1.73	0.243	0.108	4.8	3.98	0.091	17	97
	RPD	1.92%	6.46%	5.05%	3.27%	8.20%	1.20%	4.02%	3.03%	1.72%	1.08%	5.71%	2.08%
Colorado River near Wadsworth, TX	4/11/2019 12:45	0.12	3.069	0.168	4.76	3.91	0.632	0.128	11.9	5.2	0.166	Pending	Pending
	4/11/2019 12:50	0.12	2.996	0.162	4.64	3.67	0.653	0.128	8.4	5.11	0.166	Pending	Pending
	RPD	3.03%	2.42%	3.89%	2.57%	6.33%	3.19%	0.02%	33.61%	1.63%	0.08%	Pending	Pending
Guadalupe River at SH35 near Tivoli, TX	5/31/2013 12:00	0.01	1.08	0.097	1.84	--	0.695	0.268	--	--	--	340	98
	5/31/2013 12:05	0.01	1.09	0.099	1.91	--	0.700	0.269	--	--	--	316	99
	RPD	0.00%	0.92%	2.04%	3.73%	--	0.72%	0.37%	--	--	--	7.32%	1.02%
Guadalupe River at SH35 near Tivoli, TX	6/3/2013 9:15	<0.01	0.515	0.022	1.26	--	0.527	0.27	--	--	--	274	96
	6/3/2013 9:16	<0.01	0.546	0.022	1.22	--	0.620	0.272	--	--	--	291	96
	RPD	0.00%	5.84%	0.00%	3.23%	--	16.22%	0.74%	--	--	--	6.02%	0.00%
Guadalupe River at SH35 near Tivoli, TX	9/24/2013 10:30	0.027	4.92	0.027	5.41	--	0.573	0.452	--	--	--	66	99
	9/24/2013 10:31	0.029	4.94	0.028	5.66	--	0.572	0.435	--	--	--	66	99
	RPD	7.14%	0.41%	3.64%	4.52%	--	0.17%	3.83%	--	--	--	0.00%	0.00%
Guadalupe River at SH35 near Tivoli, TX	11/5/2013 12:00	0.03	4.09	0.024	5.48	--	0.737	0.34	--	--	--	484	99
	11/5/2013 12:50	0.03	4.10	0.024	5.14	--	0.720	0.331	--	--	--	475	99
	RPD	0.00%	0.24%	0.00%	6.40%	--	2.33%	2.68%	--	--	--	1.88%	0.00%
Rincon Bayou Channel near Odem, TX	4/11/2018 16:30	0.03	0.198	0.004	0.90	0.71	0.345	0.281	8.0	6.95	0.204	35	99
	4/11/2018 17:00	0.03	0.192	0.004	0.87	0.75	0.343	0.281	8.8	6.73	0.21	--	--
	RPD	0.00%	3.08%	0.00%	3.39%	5.48%	0.58%	0.00%	9.52%	3.22%	2.90%	--	--

Table 1-3. Results for blank samples collected in the Trinity River, Guadalupe River, and Nueces River.

[*, below the laboratory reporting level and above the long-term method detection level; **, laboratory result verification pending; --, parameter not measured]

Station name	Sample Date	Blank type	Ammonia (NH3 + NH4+), water, filtered, milligrams per liter as nitrogen	Nitrate plus nitrite, water, filtered, milligrams per liter as nitrogen	Nitrite, water, filtered, milligrams per liter as nitrogen	Total nitrogen [nitrate + nitrite + ammonia + organic-N], water, unfiltered, analytically determined, milligrams per liter	Total nitrogen [nitrate + nitrite + ammonia + organic-N], water, filtered, analytically determined, milligrams per liter	Phosphorus, water, unfiltered, milligrams per liter as phosphorus	Orthophosphate, water, filtered, milligrams per liter as phosphorus	Organic carbon, water, unfiltered, milligrams per liter	Organic carbon, water, filtered, milligrams per liter	Absorbance, 254 nm, water, filtered, absorbance units per centimeter
Trinity River at Wallisville, TX	2/25/2016	Field	0.01*	<0.040	<0.001	<0.05	0.252**	<0.008	<0.004	--	--	--
USGS Gulf Coast Program Office Laboratory	6/4/2018	Equipment	<0.01	<0.040	<0.001	<0.05	0.060*	<0.004	<0.004	<0.7	<0.23	<0.005
Guadalupe River at SH35 near Tivoli, TX	5/29/2013	Field	<0.01	<0.040	<0.001	<0.05	--	0.007*	<0.004	--	--	--
Nueces River at IH37 near Odem, TX	4/11/2018	Field	<0.01	<0.040	<0.001	<0.05	<0.05	<0.004	<0.004	<0.7	<0.23	<0.005

Table 1-4. Results from water-quality and sediment sample pairs collected at USGS stations 08067000 Trinity River at Liberty, Texas and 08067252 Trinity River at Wallisville,Texas

Station Name	Sample date	Discharge, instantaneous, cubic feet per second	Ammonia (NH3 + NH4+), water, filtered, milligrams per liter as nitrogen	Nitrite, water, filtered, milligrams per liter as nitrogen	Nitrate plus nitrite, water, filtered, milligrams per liter as nitrogen	Phosphorus, water, unfiltered, milligrams per liter as phosphorus	Orthophosphate, water, filtered, milligrams per liter as phosphorus	Organic carbon, water, unfiltered, milligrams per liter	Organic carbon, water, filtered, milligrams per liter	Suspended sediment concentration, milligrams per liter	Suspended sediment, sieve diameter, percent smaller than 0.0625 millimeters
Trinity River at Liberty, TX	3/16/2016	51,400	< 0.01	0.008	0.796	0.113	0.046	6.8	--	200	43
Trinity River at Wallisville, TX	3/17/2016	22,700	0.02	0.003	0.650	0.129	0.037	6.8	--	145	43
Trinity River at Liberty, TX	4/20/2016	32,100	0.01	0.001	0.405	0.179	0.040	11.8	--	438	61
Trinity River at Wallisville, TX	4/25/2016	17,200	0.01	0.002	0.437	0.145	0.045	9.0	--	158	52
Trinity River at Liberty, TX	6/1/2016	82,200	0.02	0.001	0.367	0.115	0.042	8.0	--	350	31
Trinity River at Wallisville, TX	6/3/2016	22,200	0.02	0.002	0.230	0.131	0.041	7.6	--	134	41
Trinity River at Liberty, TX	4/11/2017	16,600	< 0.01	0.001	0.664	0.089	0.030	8.0	5.13	86	75
Trinity River at Wallisville, TX	4/13/2017	13,200	0.02	0.004	0.658	0.117	0.034	7.0	4.68	102	88
Trinity River at Liberty, TX	8/31/2017	124,000	< 0.01	< 0.001	0.122	0.133	0.041	9.1	6.60	204	66
Trinity River at Wallisville, TX	9/2/2017	38,400	0.01	0.001	0.112	0.148	0.038	8.7	6.18	283	32
Trinity River at Liberty, TX	4/3/2018	53,500	0.01	0.002	0.592	0.138	0.044	7.0	5.67	550	26
Trinity River at Wallisville, TX	4/4/2018	29,400	0.02	0.003	0.514	0.165	0.035	7.3	5.80	261	42
Trinity River at Liberty, TX	10/17/2018	34,200	0.04	0.056	0.288	0.319	0.051	4.6	4.47	--	--
Trinity River at Wallisville, TX	10/22/2018	21,900	0.02	0.014	0.274	0.174	0.047	6.7	5.45	--	--