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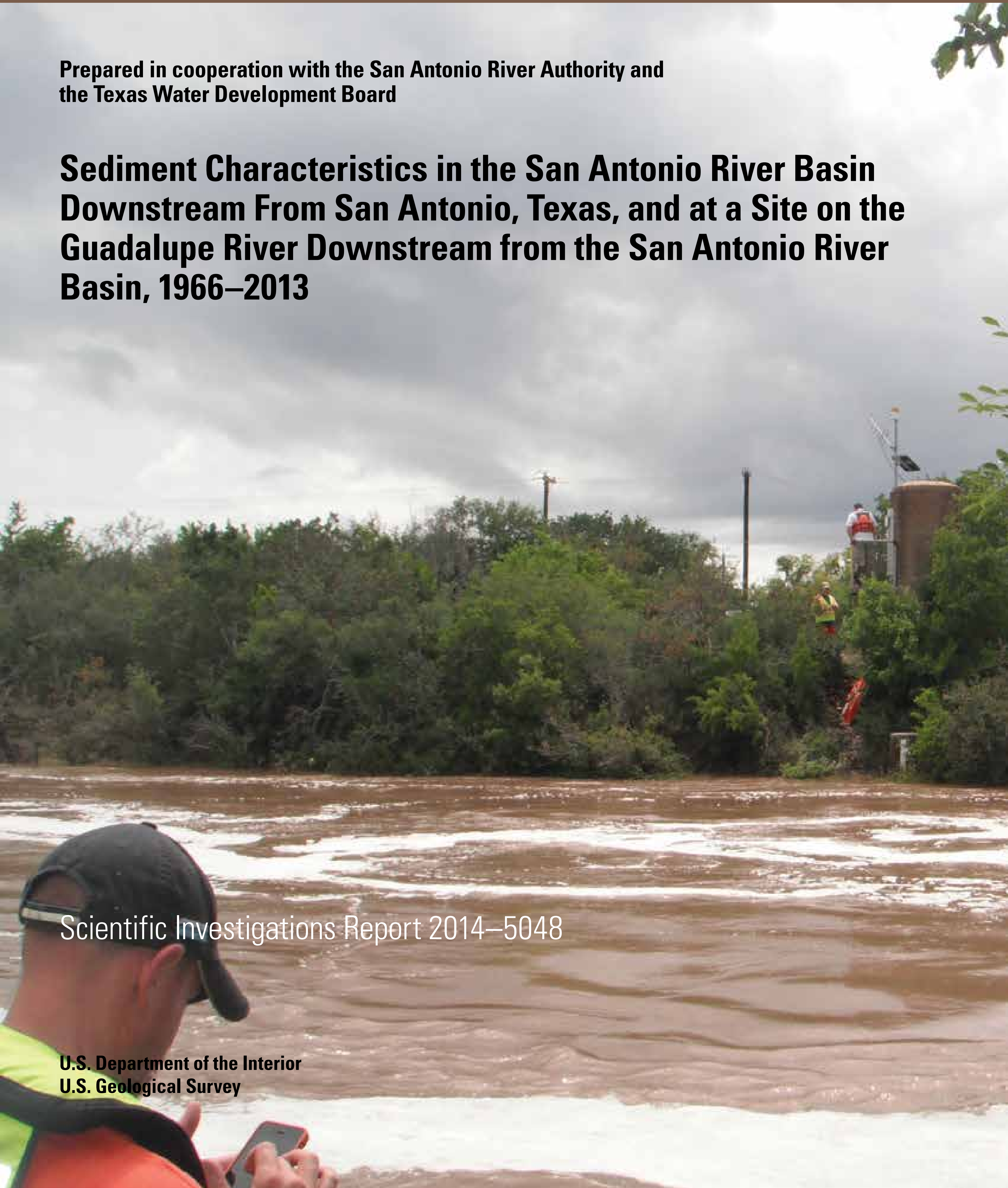
Sediment Characteristics in the San Antonio River Basin Downstream From San Antonio, Texas, and at a Site on the Guadalupe River Downstream from the San Antonio River Basin, 1966–2013



Scientific Investigations Report 2014–5048

U.S. Department of the Interior
U.S. Geological Survey

Front cover: Collection of a suspended-sediment sample by hydrologic technicians at U.S. Geological Survey station 08185000 Cibolo Creek at Selma, Texas, on May 25, 2013. The technician in the foreground is using a smart phone to check peak discharge at the site during the flood by accessing http://m.waterdata.usgs.gov (http://waterdata.usgs.gov/nwis on the Web). Photograph by Chiquita Lopez, U.S. Geological Survey.

Back cover:

Top, Collection of a bedload sample at U.S. Geological Survey station 08186500 Ecleto Creek near Runge, Texas. Photograph by Chiquita Lopez, U.S. Geological Survey.

Bottom, Collection of a suspended-sediment sample from the bridge at U.S. Geological Survey station 08181800 San Antonio River near Elmendorf, Texas. Photograph by Michael Nyman, U.S. Geological Survey.

Sediment Characteristics in the San Antonio River Basin Downstream From San Antonio, Texas, and at a Site on the Guadalupe River Downstream from the San Antonio River Basin, 1966–2013

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SALLY JEWELL, Secretary

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
	Mass	
ton per day (ton/d)	0.9072	metric ton per day
ton per day (ton/d)	0.9072	megagram per day (Mg/d)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
	Volume	
liter (L)	1.0567	quart (qt.)
	Mass	
gram (g)	0.03527	ounce (oz.)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Concentrations of suspended sediment in water are reported in milligrams per liter (mg/L) .

Sediment Characteristics in the San Antonio River Basin Downstream From San Antonio, Texas, and at a Site on the Guadalupe River Downstream from the San Antonio River Basin, 1966–2013

By Cassi L. Crow, J. Ryan Banta, and Stephen P. Opsahl

Abstract

San Antonio and surrounding municipalities in Bexar County, Texas, are in a rapidly urbanizing region in the San Antonio River Basin. The U.S. Geological Survey, in cooperation with the San Antonio River Authority and the Texas Water Development Board, compiled historical sediment data collected between 1996 and 2004 and collected suspended-sediment and bedload samples over a range of hydrologic conditions in the San Antonio River Basin downstream from San Antonio, Tex., and at a site on the Guadalupe River downstream from the San Antonio River Basin during 2011–13. In the suspended-sediment samples collected during 2011–13, an average of about 94 percent of the particles was less than 0.0625 millimeter (silt and clay sized particles); the 50 samples for which a complete sediment-size analysis was performed indicated that an average of about 69 percent of the particles was less than 0.002 millimeter. In the bedload samples collected during 2011–13, an average of 51 percent of sediment particles was sand-sized particles in the 0.25–0.5 millimeter-size range. In general, the loads calculated from the samples indicated that bedload typically composed less than 1 percent of the total sediment load. A least-squares log-linear regression was developed between suspended-sediment concentration and instantaneous streamflow and was used to estimate daily mean suspended-sediment loads based on daily mean streamflow. The daily mean suspended-sediment loads computed for each of the sites indicated that during 2011–12, the majority of the suspended-sediment loads originated upstream from the streamflow-gaging station on the San Antonio River near Elmendorf, Tex. A linear regression relation was developed between turbidity and suspended-sediment concentration data collected at the San Antonio River near Elmendorf site because the high-resolution data can facilitate understanding of the complex suspended-sediment dynamics over time and throughout the river basin.

Introduction

Sediment characteristics including suspended sediment, bedload, particle-size distribution, and turbidity in a river system are important to characterize because data pertaining to sediment characteristics are needed to understand the magnitude and type of sediment transported in a river basin. The magnitude and type of sediment transported in a river basin can affect biological communities (Wood and Armitage, 1997), the concentration and movement of natural constituents and anthropogenic contaminants (Moran and others, 2012; Kemble and others, 2013; Kolpin and others, 2013), and the amount of sediment deposition in coastal environments (Milliman and Meade, 1983). The processes related to sediment transport are complex and dependent on many factors including (1) basin geology; (2) the frequency, magnitude, and duration of storm runoff events; (3) the presence of man-made impoundments or channel modifications; and (4) urban and rural land use in the basin (Leopold, 1997). Sediment transport in streams generally can be categorized as suspended-sediment transport (sediment transported within the water column) and bedload transport (sediment transported along the bottom of the streambed). The complex nature of sediment transport poses challenges in collecting quality sediment data (Edwards and Glysson, 1999). Sediment properties are specific to individual river basins, including the temporal and spatial variability of sediment concentrations and loads, and the particle-size distribution of suspended and bedload sediment. Historical patterns of sediment transport are important for understanding river channel geomorphology and interactions with the flood plain (Leopold, 1997).

The sediment characteristics of the San Antonio River Basin downstream from San Antonio, Tex., are not well understood because relatively little sediment data have been collected. Some historical data were collected prior to 2004. Changes in land use in the study area such as urban development in the greater San Antonio area and development activities downstream from San Antonio might increase runoff into streams during storm events. Increases in runoff during storm events can potentially increase the amount and timing of sediment transported into the drainage network, affecting water quality and sediment loads throughout the San Antonio River Basin downstream from San Antonio (Ockerman and McNamara, 2003).

To better understand sediment characteristics in the San Antonio River Basin downstream from San Antonio, the U.S. Geological Survey (USGS), in cooperation with the San Antonio River Authority (SARA) and the Texas Water Development Board (TWDB), collected and analyzed suspended-sediment, bedload, particle-size distribution, and turbidity data over a wide range of hydrologic conditions at sampling sites in the San Antonio River Basin downstream from San Antonio, Tex., and at one site on the Guadalupe River downstream from the San Antonio River Basin from January 2011 through May 2013 and combined that data with the available historical sediment data collected at the same sampling sites. During 2011–13, most sediment samples were collected at USGS streamflow-gaging stations. At two locations, sampling sites were established downstream from streamflow-gaging stations because the bridge where the gaging station was located was deemed unsuitable for sediment sampling (fig. 1).

Turbidity data were collected to develop a basinwide understanding of sediment characteristics and to provide insight into sediment sources and transport dynamics. Because turbidity data are simpler to collect than sediment data, the establishment of the relation between suspended-sediment concentration (SSC) and turbidity in the study area could prove useful for additional investigations.

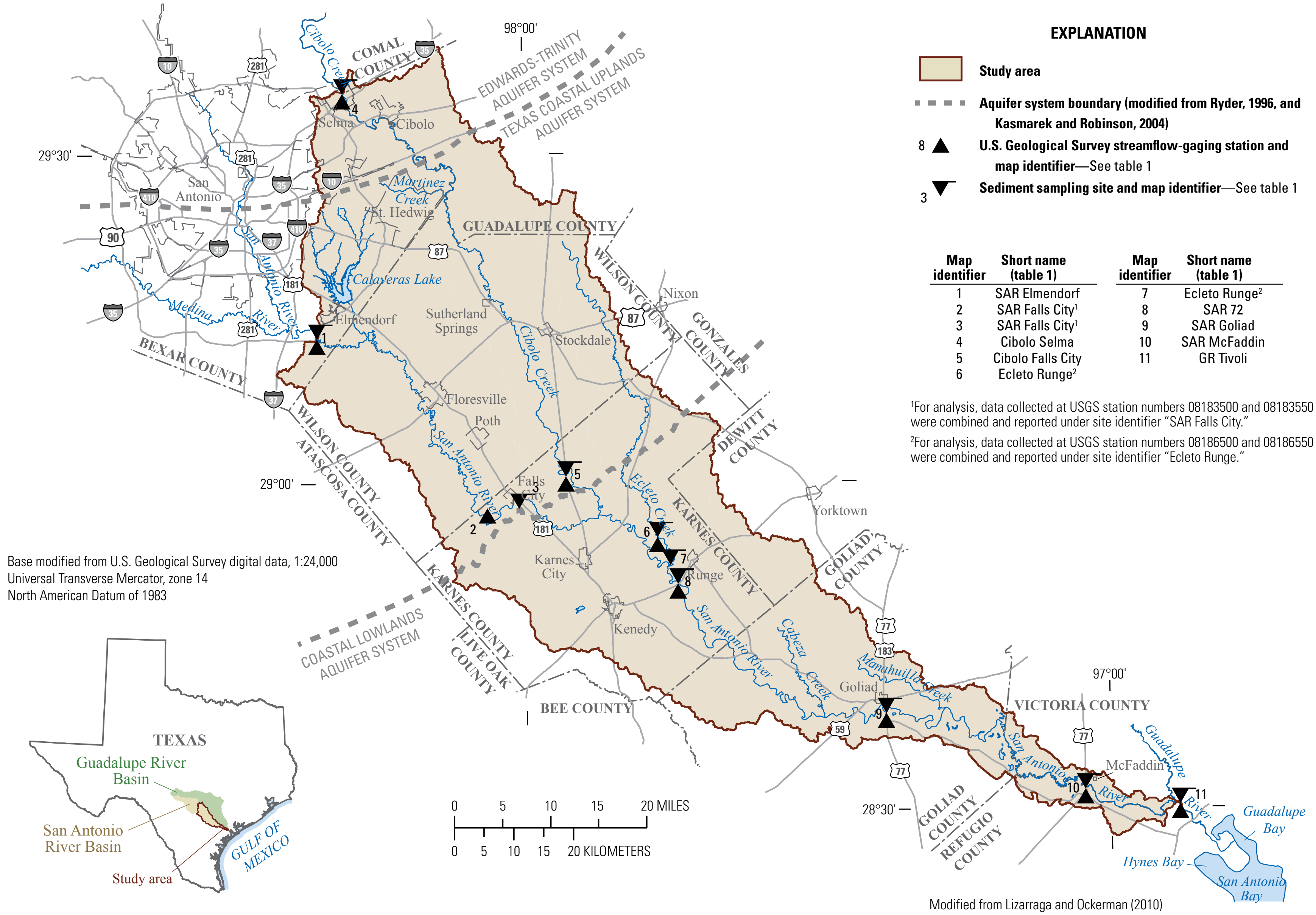
The presence of dissolved and suspended material (clays, silt, fine organic matter, and other material) in stream water typically results in more turbid (less clear) water (ASTM International, 2007). Turbidity, a measure of water clarity, is often correlated to discrete measurements of SSC and the resulting relation is used as a surrogate for SSC (Rasmussen and others, 2009). Previous studies have demonstrated that during stormflow events, sediment loads often peak prior to the streamflow hydrograph peak (Wood, 1977; VanSickle and Beschta, 1983; Glysson, 1987; Clark and others, 2013). As a result, the suspended-sediment loads (SSL) associated with a certain streamflow value observed during the rising limb of a hydrograph might be different than the loads associated with the same streamflow value observed during the receding limb of the hydrograph. For this reason, turbidity has been theorized to be a better surrogate for predicting SSC than streamflow (Lewis, 1996). Once a strong relation between SSC and turbidity is established for a given river basin, real-time turbidity data can be used to estimate SSC, and high-resolution data from selected sites can be collected to facilitate understanding of the complex suspended-sediment dynamics over time and throughout the river basin.

Purpose and Scope

Sediment properties in the San Antonio River Basin downstream from San Antonio were characterized by using historical sediment data collected during 1966–2004 and recent sediment data collected during 2011–13. Suspended-sediment and bedload were characterized at 10 sites in the San Antonio River Basin and at 1 site on the Guadalupe River downstream from the San Antonio River Basin. Sixty-seven suspended-sediment samples and 22 bedload samples were collected from January 2011 through May 2013 (hereinafter referred to as 2011–13 samples), and data from these samples were compared with historical suspended-sediment data collected before 2011 (hereinafter referred to as historical samples) at 5 sites sampled during 2011–13. Daily SSLs were estimated during 2011–12; the SSLs were estimated based on regression equations developed between streamflow and SSCs at five sites by using the historical and 2011–13 data. In addition, regression equations between turbidity measurements and suspended-sediment samples were developed at three sites in the San Antonio River Basin.

Description of the Study Area

The study area consists of 2,150 square miles (mi^2) of the San Antonio River Basin downstream from San Antonio, Tex., and about 2 mi^2 of the Guadalupe River Basin downstream from the San Antonio River Basin (fig. 1). The upstream boundary of the study area includes the San Antonio River near Elmendorf, Tex., site (SAR Elmendorf) and the Cibolo Creek at Selma, Tex., site (Cibolo Selma) (map identifiers 1 and 4, respectively, fig. 1 and table 1). The downstream boundary of the study is the Guadalupe River near Rivoli, Tex., site (GR Tivoli) on the Guadalupe River about 1 mile (mi) downstream from the confluence of the San Antonio and Guadalupe Rivers. Cibolo Creek and Ecleto Creek are part of the study area, which encompasses parts of Bexar, Guadalupe, Wilson, Karnes, DeWitt, Goliad, Victoria, and Refugio Counties (fig. 1). The San Antonio River extends about 190 river mi from Elmendorf, Tex., to the confluence of the San Antonio and Guadalupe Rivers. From the upstream boundary of the study area near Selma, Tex., Cibolo Creek extends about 75 river mi downstream to the confluence of Cibolo Creek and the San Antonio River in Karnes County. Ecleto Creek extends about 55 river mi from northern Wilson County to the confluence of Ecleto Creek and the San Antonio River in Karnes County.



EXPLANATION

Study area

Aquifer system boundary (modified from Ryder, 1996, and Kasmarek and Robinson, 2004)

8 **U.S. Geological Survey streamflow-gaging station and map identifier**—See table 1

3 **Sediment sampling site and map identifier**—See table 1

Map identifier	Short name (table 1)	Map identifier	Short name (table 1)
1	SAR Elmendorf	7	Ecleto Runge[2]
2	SAR Falls City[1]	8	SAR 72
3	SAR Falls City[1]	9	SAR Goliad
4	Cibolo Selma	10	SAR McFaddin
5	Cibolo Falls City	11	GR Tivoli
6	Ecleto Runge[2]		

[1]For analysis, data collected at USGS station numbers 08183500 and 08183550 were combined and reported under site identifier "SAR Falls City."

[2]For analysis, data collected at USGS station numbers 08186500 and 08186550 were combined and reported under site identifier "Ecleto Runge."

Figure 1. Data collection sites in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, January 2011 through May 2013.

Table 1. The number of historical and 2011–13 sediment samples collected at sites in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin.

[SSC, suspended-sediment concentration; SSF, suspended-sediment sand-fine break; SSP, suspended-sediment particle-size distribution; BLM, bedload mass; BLP, bedload particle-size distribution; na, not available; USGS, U.S. Geological Survey]

Map identifier (fig. 1)	U.S. Geological Survey station number	U.S. Geological Survey station name	Short name for sampling site	Period of record (historical samples)	Period of record (2011–13 samples)	Data type and number of samples (samples collected prior to 2011/ samples collected during 2011–13)				
						SSC	SSF	SSP	BLM	BLP
1	08181800	San Antonio River near Elmendorf, Tex.	SAR Elmendorf	1996–2004	2011–12	95/10	1/3	0/7	0/6	0/1
2	08183500	San Antonio River near Falls City, Tex.	SAR Falls City[1]	1966–75	na	48/0	2/0	7/0	0/0	0/0
3	08183550	San Antonio River at Highway 181 near Falls City, Tex.	SAR Falls City[1]	na	2011–12	0/9	0/2	0/7	0/0	0/0
4	08185000	Cibolo Creek at Selma, Tex.	Cibolo Selma	na	2012–13	0/3	0/1	0/2	0/0	0/0
5	08186000	Cibolo Creek near Falls City, Tex.	Cibolo Falls City	1967–75	2011–12	36/7	1/2	6/5	0/1	0/1
6	08186500	Ecleto Creek near Runge, Tex.	Ecleto Runge[2]	1966–75	2011–12	31/3	0/0	10/3	0/1	0/1
7	08186550	Ecleto Creek at County Road 326 near Runge, Tex.	Ecleto Runge[2]	na	2012	0/2	0/0	0/2	0/2	0/2
8	08188060	San Antonio River at State Highway 72 near Runge, Tex.	SAR 72	na	2011–12	0/5	0/0	0/5	0/0	0/0
9	08188500	San Antonio River at Goliad, Tex.	SAR Goliad	1974–94	2011–12	162/8	163/2	0/6	0/3	0/1
10	08188570	San Antonio River near McFaddin, Tex.	SAR McFaddin	na	2011–12	0/6	0/3	0/3	0/0	0/0
11	08188800	Guadalupe River near Tivoli, Tex.	GR Tivoli	na	2011–12	0/14	0/4	0/10	0/9	0/4

[1]For analysis, data collected at USGS station numbers 08183500 and 08183550 were combined and reported under short name “SAR Falls City.”

[2]For analysis, data collected at USGS station numbers 08186500 and 08186550 were combined and reported under short name “Ecleto Runge.”

The northern part of the study area overlies the Edwards-Trinity aquifer system. The remainder of the study area overlies the Texas Coastal Uplands and Coastal Lowlands aquifer systems (Ryder, 1996) (fig. 1). The Cretaceous-age rocks of the Edwards-Trinity aquifer system primarily consist of limestone and sandstone (Ashworth and Hopkins, 1995). The Texas Coastal Uplands aquifer system is composed of formations of Paleocene and Oligocene age, with the sediments (in order of dominance) consisting mostly of sand, silt, and clay, distributed as relatively uniform sequences of predominantly fine- or coarse-grained material (Ryder, 1996). The Texas Coastal Lowlands aquifer system is composed of younger formations from Oligocene through Holocene age that dip and thicken towards the Gulf of Mexico, with sediments that exist in complex, overlapping mixtures of sand, silt, and clay as a result of numerous oscillations of ancient shorelines (Kasmarek and Robinson, 2004; Lizárraga and Ockerman, 2010).

Topography, land cover, precipitation, and population can affect sediment characteristics in the study area. The study area is composed of gently sloping, rolling terrain; the coastal uplands are somewhat more dissected and rolling compared to the coastal lowlands (Ryder, 1996). The land cover consists mostly of brush and grassland (Multi-Resolution Land Characteristics Consortium, 2013), and average annual precipitation ranges from about 30 inches in the northern sections of the basin to about 40 inches in the southern sections of the basin near the coast (National Oceanic and Atmospheric Administration, 2013). San Antonio, the seventh most populous city in the Nation (U.S. Census Bureau, 2012), was founded on the headwaters of the San Antonio River. The population of San Antonio grew by 35 percent from 1990 to 2010 (U.S. Census Bureau, 2012).

Methods

Historical suspended-sediment data collected between 1966 and 2004 were compiled for use with the 2011–13 suspended-sediment and bedload data. Historical data were collected for various periods at each site ranging from about 10 to 21 years. The historical and 2011–13 data were collected by the USGS at sites in the study area (fig. 1; table 1). In this report, each site is referred to by its map identifier and short name. All sampling sites were located at USGS stream-gaging stations with the exception of two sites sampled during 2011–13—USGS stations 08183550 and 08186550. For analysis, data collected at USGS stations 08183500 and 08183550 were combined and reported under the short name “SAR Falls City.” Similarly, data collected at USGS stations 08186500 and 08186550 were combined and reported under the short name “Ecleto Runge” (table 1).

Sample Collection and Analysis

During 2011–13, samples of suspended sediment were collected at 10 sites (map identifiers 1 and 3–11; fig. 1; table 1) for the analysis of SSC and particle-size distribution. In addition, samples of bedload material were collected at six sites (map identifiers 1, 5, 6, 7, 9, and 11; fig. 1; table 1) for the analysis of bedload mass and particle-size distribution. Suspended-sediment samples were collected over a range of streamflows ranging from a minimum instantaneous streamflow of 1.9 cubic feet per second (ft^3/s) at the Cibolo Selma site (map identifier 4, fig. 1; table 1) on September 17, 2012, to a maximum instantaneous streamflow of 10,600 ft^3/s at the same site on May 25, 2013 (fig. 2). Note that the streamflow plotted in figure 2 is the daily mean streamflow for each site in cubic feet per second, but the streamflow associated with each sample is the instantaneous streamflow recorded at the time the sample was collected.

Suspended-Sediment Sample Collection and Laboratory Analysis

Suspended-sediment samples were collected during 2011–13 following standard USGS methods described in Edwards and Glysson (1999). At each sampling site, samples were collected at a minimum of 10 equal-width increments across the stream by using samplers designed to allow water to enter the sampler with no change in velocity or direction as it entered the sampler from the stream, a method referred to as isokinetic sampling. When stream depths were shallow enough to be waded, samples were collected using a US DH–81 1-liter bottle sampler (Davis, 2005) attached to a wading rod (fig. 3). When the stream was too deep to be waded, samples were collected from a bridge using a US DH–2 1-liter collapsible bag sampler (Davis, 2005) attached to a reel and crane system (fig. 3). Samples collected using the US DH–81 sampler at streamflow velocities less than 1.5 feet per second (ft/s) and samples collected using the US DH–2 sampler at velocities less than 2.0 ft/s were labeled as grab samples because the samplers are unable to collect isokinetic samples at or less than those velocities. Samples were composited into a 14-liter polyethylene churn splitter, and representative suspended-sediment samples were dispensed from the churn splitter into 3-liter polypropylene bottles. The churn splitter method can potentially bias results when sand-sized (greater than or equal to 0.0625 millimeter [mm]) particles are present in suspended-sediment samples because the heavier sand-sized particles might not remain uniformly suspended in the churn (Capel and Larson, 1995; Horowitz and others, 1997). This potential bias was not expected to substantially influence samples because historical data from sites in the study area indicate the system is dominated by suspended particle sizes much less than 0.0625 mm, even during stormflow events.

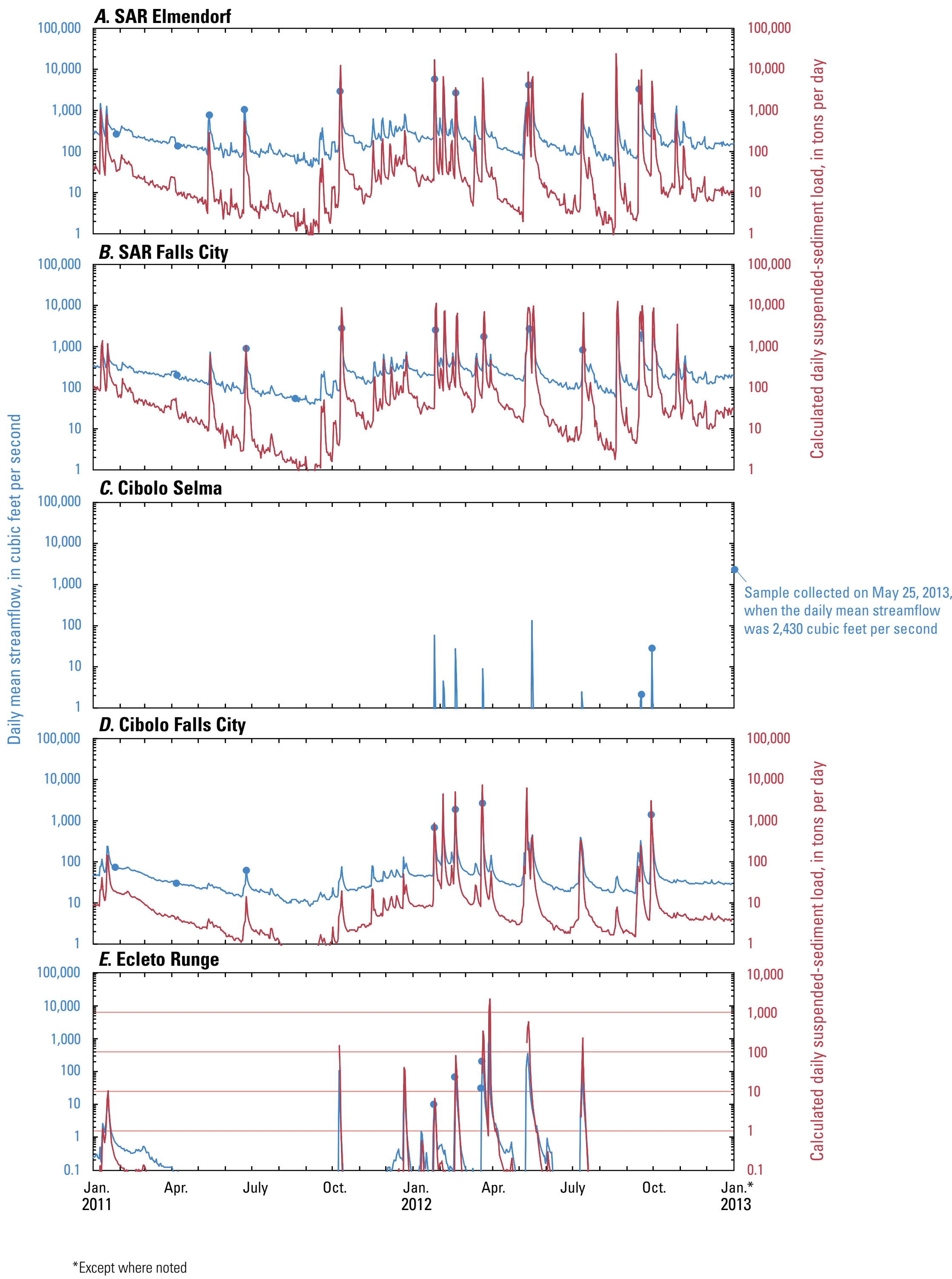
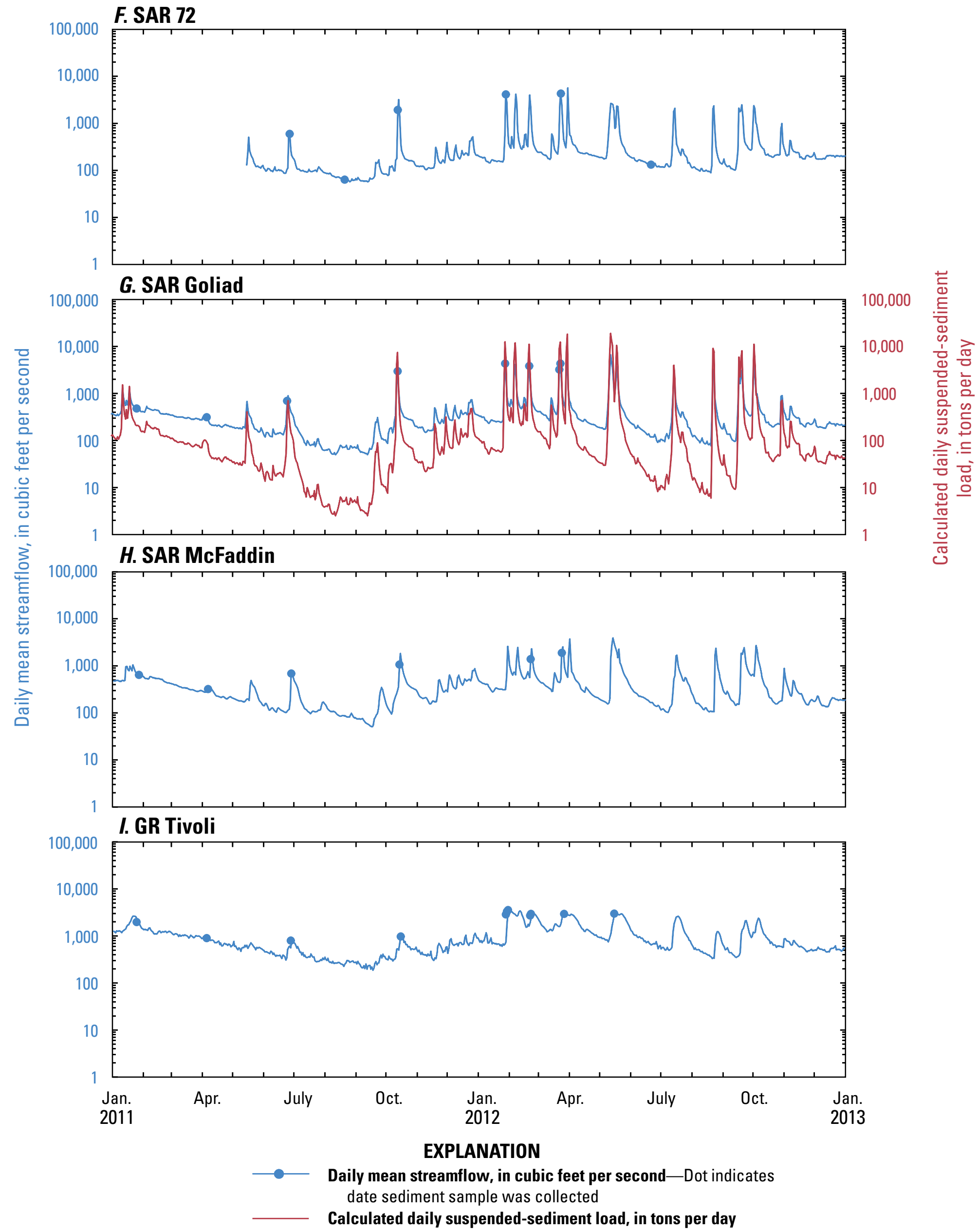


Figure 2. Daily mean streamflow with sediment sample collection dates and time-series suspended-sediment load estimated from daily mean streamflow and daily suspended-sediment concentration (from U.S. Geological Survey, 2013) for selected sites in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, January 2011–May 2013. *A*, SAR Elmendorf site (U.S. Geological Survey [USGS] station 08181800, San Antonio River near Elmendorf, Tex.); *B*, SAR Falls City site (USGS station 08183500 San Antonio River near Falls City, Tex.); *C*, Cibolo Selma site (USGS station 08185000, Cibolo Creek at Selma, Tex.); *D*, Cibolo Falls City site (USGS station 08186000, Cibolo Creek near Falls City, Tex.); *E*, Ecleto Runge site (USGS station 08186500, Ecleto Creek near Runge, Tex.); *F*, SAR 72 site (USGS station 08188060, San Antonio River at State Highway 72 near Runge, Tex.); *G*, SAR Goliad site (USGS station 08188500 San Antonio River at Goliad, Tex.); *H*, SAR McFaddin site (USGS station 08188570, San Antonio River near McFaddin, Tex.); *I*, GR Tivoli site (USGS station 08188800, Guadalupe River near Tivoli, Tex.)



Note: Short names for sampling sites (table 1) are listed above the upper left corners of figures 2*A*–2*I*. For analysis, data collected at USGS station numbers 08186500 and 08186550 were combined and reported under short name "Ecleto Runge."

Figure 2. Daily mean streamflow with sediment sample collection dates and time-series suspended-sediment load estimated from daily mean streamflow and daily suspended-sediment concentration (from U.S. Geological Survey, 2013) for selected sites in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, January 2011–May 2013. *A*, SAR Elmendorf site (U.S. Geological Survey [USGS] station 08181800, San Antonio River near Elmendorf, Tex.); *B*, SAR Falls City site (USGS station 08183500 San Antonio River near Falls City, Tex.); *C*, Cibolo Selma site (USGS station 08185000, Cibolo Creek at Selma, Tex.); *D*, Cibolo Falls City site (USGS station 08186000, Cibolo Creek near Falls City, Tex.); *E*, Ecleto Runge site (USGS station 08186500, Ecleto Creek near Runge, Tex.); *F*, SAR 72 site (USGS station 08188060, San Antonio River at State Highway 72 near Runge, Tex.); *G*, SAR Goliad site (USGS station 08188500 San Antonio River at Goliad, Tex.); *H*, SAR McFaddin site (USGS station 08188570, San Antonio River near McFaddin, Tex.); *I*, GR Tivoli site (USGS station 08188800, Guadalupe River near Tivoli, Tex.)—Continued

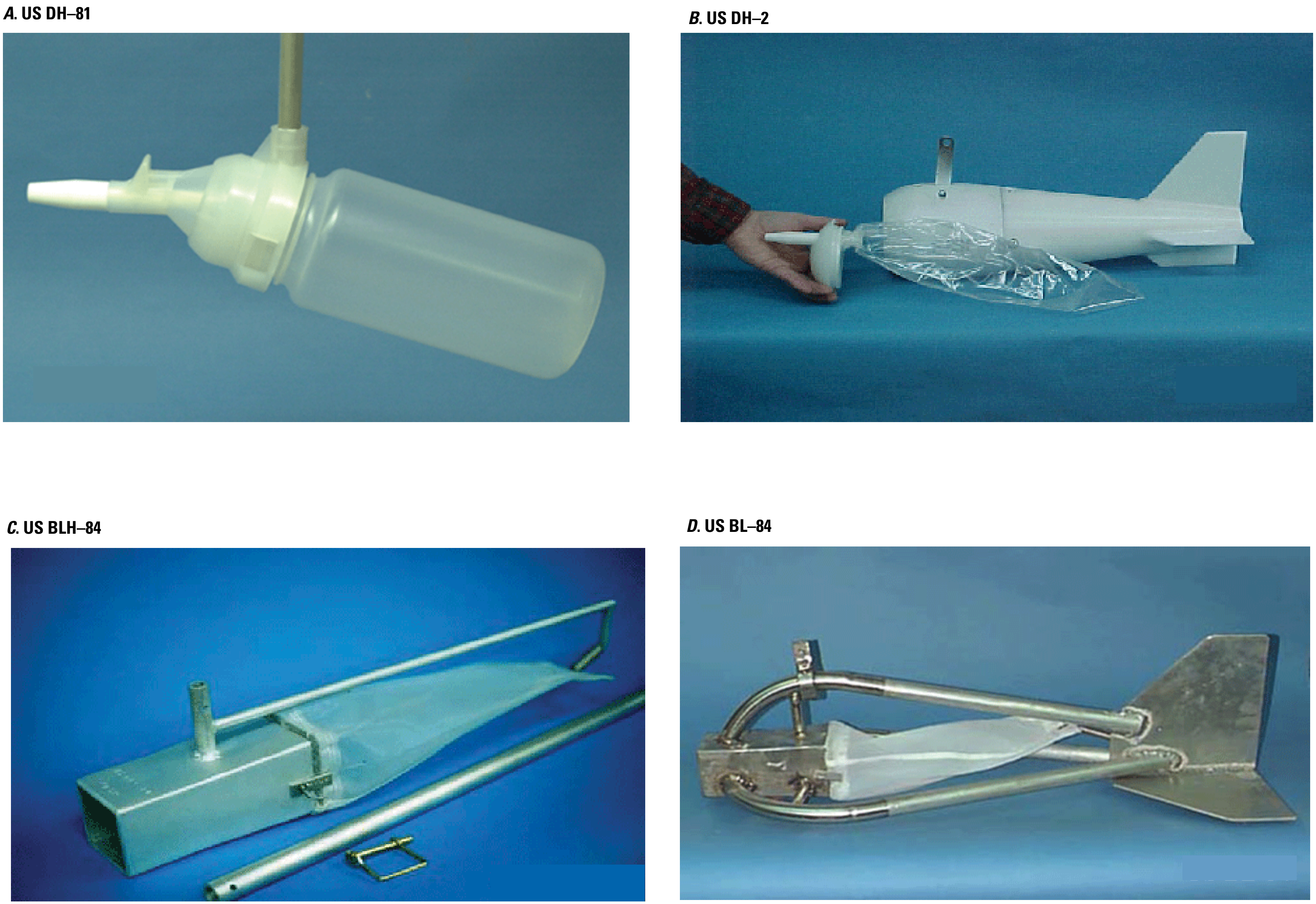


Figure 3. Samplers used to collect suspended-sediment and bedload samples at sites in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, January 2011–May 2013. *A*, US DH-81; *B*, US DH-2; *C*, US BLH-84; and *D*, US BL-84; modified from Davis (2005).

Suspended-sediment samples were analyzed at the USGS Kentucky Water Science Center Sediment Laboratory in Louisville, Ky., by using methods described in Guy (1969) and in accordance with the quality assurance plan documented in Shreve and Downs (2005). All 67 suspended-sediment samples were analyzed by using filtration or evaporation methods and reported in milligrams per liter (mg/L). Seventeen suspended-sediment samples were analyzed to determine the percentage of particles less than 0.0625 mm, which generally corresponds to the particle size separating sand-sized (0.0625 to 2.0 mm in diameter) particles from finer-size particles of silts and clays (less than 0.0625 mm in diameter), commonly referred to as the sand/fine break (Guy, 1969). The sand/fine break analysis was done using a process known as wet-sieving filtration where the sample was washed through a wetted 0.0625-mm mesh sieve. The sand/fine break data were reported as the percentage of sediment less than 0.0625 mm. The remaining 50 suspended-sediment samples were analyzed to determine the amount of sediment distributed between 11 size classes ranging from less than 0.002 to 2 mm in diameter (commonly referred to as particle-size distribution). Particle-size distribution analyses were done using a combination of sieve, visual-accumulation tube, and pipet methods as described by Guy (1969) and by Shreve and Downs (2005). Particle-size distributions in suspended-sediment samples were reported as the percentage of sediment less than 0.002, 0.004, 0.008, 0.016, 0.031, 0.0625, 0.125, 0.25, 0.5, 1, and 2 mm.

Bedload Sample Collection and Laboratory Analysis

Bedload samples were collected using standard USGS methods as described in Edwards and Glysson (1999). Samples were collected using pressure-difference samplers fitted with mesh bags designed to capture sediment moving along the streambed (bedload sediment) while allowing water to pass through the bag. As bedload sediment collected in the bag, the size of the mesh openings decreased, resulting in the collection of particle sizes less than the mesh size of the sample bag (0.25 mm) (Hubbell, 1964). When stream depths were shallow enough to be waded, a US BLH–84 sampler (Davis, 2005) attached to a wading rod was used to collect bedload samples (fig. 3). When the stream was too deep to be waded, bedload samples were collected using a US BL–84 sampler (Davis, 2005) attached to a reel and crane system (fig. 3). Depending on the site and hydrologic conditions, the bedload sampler rested on the streambed at 20–40 equal-width increments across the stream for a period of 1–2 minutes each, resulting in a composited sample with total collection times of 32–80 minutes.

Bedload samples were analyzed at the USGS sediment laboratory in Louisville, Ky., for total mass and particle-size distribution. In accordance with methods described by Guy (1969), samples were sieved to determine particle sizes ranging from less than 0.0625 to less than 16 mm in diameter. Quality assurance procedures documented in Shreve and Downs (2005) were followed during the analyses. Total mass for 22 bedload samples was determined by using the evaporation method described in Guy (1969) and reported in grams (g) of dry mass. Ten of the 22 bedload samples were analyzed for particle-size distribution by dry-sieving followed by a combination of sieve, visual-accumulation tube-pipet, and sieve-pipet methods (Guy, 1969). Particle-size distributions in bedload samples were reported as the percentage of sediment less than 0.0625, 0.125, 0.25, 0.5, 1, 2, 4, 8, 16, and 32 mm.

Quality Control

Six replicate suspended-sediment samples (table 2) were collected from four sites to evaluate potential bias and variability introduced during sample processing or laboratory analysis. Replicate samples were split from the same churn and compared to the associated environmental samples by calculating the relative percent difference (RPD) for each sample pair of detected constituents (table 2). RPD was computed using the equation:

$$RPD = |C1 - C2| / [(C1 + C2)/2] \times 100, \qquad (1)$$

where

$C1$ is the concentration or percentage from the environmental sample; and

$C2$ is the concentration or percentage from the replicate sample.

The median RPD for SSC was 4.0 percent for the six sample pairs, and 1.1 percent for the particle-size distribution. RPDs exceeded 15 percent for one SSC sample pair and two particle-size distribution pairs, which indicates that bias might have been introduced to these three results during sample collection and processing (for example, while splitting the sample with a churn splitter as previously described in this section) or during laboratory analysis.

Table 2. Relative percent difference for replicate suspended-sediment data from sites sampled in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, January 2011–May 2013.

[mg/L, milligrams per liter; mm, millimeter; Env, environmental sample; Rep, replicate sample; --, not measured; RPD, relative percent difference; nc, not computed]

U.S. Geological Survey station number	U.S. Geological Survey station name	Short name for sampling site (table 1)	Sample date	Sample start time	Sample type	Suspended sediment concentration (mg/L)	Suspended sediment (percent less than 0.002 mm)	Suspended sediment (percent less than 0.004 mm)	Suspended sediment (percent less than 0.008 mm)	Suspended sediment (percent less than 0.016 mm)	Suspended sediment (percent less than 0.031 mm)
08181800	San Antonio River near Elmendorf, Tex.	SAR Elmendorf	6/22/2011	1900	Env	625	60	73	87	93	94
				1905	Rep	531	--	--	--	--	--
					RPD	16.3	nc	nc	nc	nc	nc
08181800	San Antonio River near Elmendorf, Tex.	SAR Elmendorf	2/18/2012	1130	Env	1,430	62	69	74	79	88
				1230	Rep	1,420	62	69	75	81	88
					RPD	0.7	0	0	1.3	2.5	0
08186500	Ecleto Ck near Runge, Tex.	Ecleto Runge	3/21/2012	1030	Env	789	97	99	100	--	--
				1035	Rep	760	96	97	99	99	99
					RPD	3.7	1.0	2.0	1.0	nc	nc
08188500	San Antonio River at Goliad, Tex.	SAR Goliad	10/13/2011	945	Env	1,690	58	77	81	87	89
				1000	Rep	1,620	73	81	86	91	95
					RPD	4.2	23	5.1	6.0	4.5	6.5
08188500	San Antonio River at Goliad, Tex.	SAR Goliad	3/23/2012	1200	Env	1,450	81	84	88	90	92
				1235	Rep	1,330	67	80	89	96	97
					RPD	8.6	19	4.9	1.1	6.5	5.3
08188800	Guadalupe River near Tivoli, Tex.	GR Tivoli	2/23/2012	1020	Env	317	89	93	96	97	98
				1118	Rep	322	89	92	96	97	98
					RPD	1.6	0	1.1	0	0	0

Table 2. Relative percent difference for replicate suspended-sediment data from sites sampled in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, January 2011–May 2013.—Continued

[mg/L, milligrams per liter; mm, millimeter; Env, environmental sample; Rep, replicate sample; --, not measured; RPD, relative percent difference; nc, not computed]

U.S. Geological Survey station number	U.S. Geological Survey station name	Short name for sampling site (table 1)	Sample date	Sample start time	Sample type	Suspended sediment (percent less than 0.0625 mm)	Suspended sediment (percent less than 0.125 mm)	Suspended sediment (percent less than 0.25 mm)	Suspended sediment (percent less than 0.5 mm)	Suspended sediment (percent less than 1 mm)	Suspended sediment (percent less than 2 mm)
08181800	San Antonio River near Elmendorf, Tex.	SAR Elmendorf	6/22/2011	1900	Env	96	98	99	100	--	--
				1905	Rep	99	--	--	--	--	--
					RPD	3.1	nc	nc	nc	--	--
08181800	San Antonio River near Elmendorf, Tex.	SAR Elmendorf	2/18/2012	1130	Env	92	98	100	--	--	--
				1230	Rep	93	98	100	--	--	--
					RPD	1.1	0	0	nc	--	--
08186500	Ecleto Ck near Runge, Tex.	Ecleto Runge	3/21/2012	1030	Env	--	--	--	--	--	--
				1035	Rep	99	100	--	--	--	--
					RPD	nc	nc	nc	nc	--	--
08188500	San Antonio River at Goliad, Tex.	SAR Goliad	10/13/2011	945	Env	92	95	98	100	--	--
				1000	Rep	95	97	99	100	--	--
					RPD	3.2	2.1	1.0	0	--	--
08188500	San Antonio River at Goliad, Tex.	SAR Goliad	3/23/2012	1200	Env	95	96	98	100	--	--
				1235	Rep	97	98	99	100	--	--
					RPD	2.1	2.1	1.0	0	--	--
08188800	Guadalupe River near Tivoli, Tex.	GR Tivoli	2/23/2012	1020	Env	98	99	100	--	--	--
				1118	Rep	99	99	100	--	--	--
					RPD	1.0	0	0	nc	--	--

Turbidity Measurements

Turbidity, the measure of water clarity, was measured from January 6, 2011, through September 30, 2013, at the SAR Elmendorf site (map identifier 1; fig. 1; table 1) by using a YSI 6920 multi-sensor water-quality monitor equipped with a YSI 6136 optical turbidity sensor (Xylem Analytics, 2014a). Turbidity was measured at the time of sample collection from the centroid of the stream. In addition, a real-time turbidity probe was deployed and measured turbidity every 15 minutes that was recorded by a data-collection platform (DCP) and transmitted to the USGS's National Water Information System (NWIS) database (U.S. Geological Survey, 2013) every hour. The monitor was cleaned and calibrated, and the data were processed following methods described by Wagner and others (2006). The time between visits for cleaning and calibration ranged from 6 to 32 days with an average time between visits of about 18 days. Turbidity sensor calibration occurred in a laboratory environment and consisted of a visual inspection of the probe to ensure the wiper used to clean the optical surface of the probe was parking in the correct location in relation to the optical surface, replacement of the wiper pad, and a two-point calibration using deionized water as a 0 formazin nephelometric unit (FNU) standard and a commercial 100 FNU formazin standard. The YSI 6136 optical turbidity sensor has a reported range of 0 to 1,000 FNU (Xylem Analytics, 2014b); field measurements indicate that the sensor reaches a maximum at approximately 1,100–1,200 FNU, depending on the individual sensor. The accuracy of YSI 6136 optical turbidity sensor is plus or minus 2 percent of the reading or 0.3 FNU, whichever is greater (Xylem Analytics, 2014b). Additionally, turbidity measurements made prior to May 23, 2012, were affected by a programming problem in the DCP that caused turbidity measurements greater than 330 FNU to be recorded as 330 FNU. Daily mean turbidity values were calculated from the 15-minute turbidity measurements. Missing daily mean turbidity values represent days in which 17 or more 15-minute turbidity measurements (about 18 percent) were missing from the daily record. In this instance, daily mean turbidity values were not computed or reported. The time-series turbidity data described in this report are available from the USGS NWIS (U.S. Geological Survey, 2013).

Instantaneous Suspended-Sediment Load, Bedload, and Total Sediment Load

Streams transport sediment by maintaining the finer particles in suspension with turbulent currents (SSL) and by intermittent entrainment and movement of coarser particles along the streambed (bedload) (Ellison and others, 2014). Instantaneous streamflow data were obtained from stage-discharge rating curves at the streamflow-gaging station (Rantz and others,1982; Turnipseed and Sauer, 2010) where suspended-sediment samples were collected or at the streamflow-gaging station directly upstream from the sample site (as was the case for the SAR Falls City and Ecleto Runge sites). The SSL transported by the stream past a site at the time of sample collection (hereinafter referred to as instantaneous SSL) was estimated using equation 2 (modified from Porterfield, 1972):

$$SSL = Q_i \times SSC \times k, \qquad (2)$$

where

SSL is the suspended-sediment load, in tons per day;
Q_i is the instantaneous streamflow, in cubic feet per second;
SSC is the suspended-sediment concentration, in milligrams per liter; and
k is a unit conversion factor of 0.0027 in tons per day per cubic foot per second-milligrams per liter.

Bedload refers to the sediment transported by rolling, saltating, or bouncing along a riverbed or the component of sediment in transport from the surface of the riverbed up to the height of the top of the sampler nozzle (Galloway and others, 2013). The bedload transported past a sampled site at the time of sampling (hereinafter referred to as instantaneous bedload) was calculated by using equation 3 (modified from Edwards and Glysson, 1999):

$$BL = K \times (W_T / t_T) \times M_T \qquad (3)$$

where

BL is the instantaneous bedload mass, in tons per day;
K is a unit conversion factor (0.381 for a 3-inch wide nozzle);
W_T is the total width of the stream, in feet, and is equal to the increment width multiplied by the total number of vertical samples measured in the stream cross section;
t_T is the total time the sampler remained on the streambed, in seconds, and is equal to the sample time multiplied by the total number of verticals from which samples were collected; and
M_T is the total mass of sample collected from all verticals sampled in the stream cross section, in grams.

Instantaneous total sediment load for a site, reported in tons per day, was calculated by summing the instantaneous SSL and instantaneous bedload. Instantaneous total sediment load was calculated for 21 sampling events at six sites for which both an instantaneous SSL and an instantaneous bedload were computed.

Estimating Suspended-Sediment Loads from Streamflow

To estimate SSLs for days when suspended-sediment samples were not collected, log-linear regressions were developed to estimate SSCs based on streamflow for the five sites for which sufficient data were available (SAR Elmendorf, SAR Falls City, Cibolo Falls City, Ecleto Runge, and SAR Goliad). The historical (appendix 1) and the 2011–13 data were included in the regression analyses. The measured SSC and instantaneous streamflow data were nonnormally distributed and, consequently, were log transformed before the regression lines were calculated. The regression equation for estimating SSC (retransformed into original units incorporating the bias correction factor [Helsel and Hirsch, 2002]) from streamflow is represented as:

$$SSC = \beta_0 \, x \, Q_d^{\beta 1} \, x \, \Phi \qquad (4)$$

where

SSC is estimated suspended-sediment concentration, in milligrams per liter;

β_0 and β_1 are regression coefficients;

Q_d is the daily mean streamflow, in cubic feet per second; and

Φ is the bias-correction factor.

Similar to instantaneous loads, the estimated SSCs were used with daily mean streamflow in equation 2 to estimate daily mean SSLs.

Summary statistics were computed for each of the regression equations and include a coefficient of determination (R^2), a root mean square error (RMSE), and a mean absolute error (MAE). R^2 values range from 0 to 1 and estimate the proportion of variability explained by a regression model. As the R^2 value approaches 1, the models approach perfect correlation. RMSE is an estimator that quantifies the difference between values estimated by a model and the actual values that were measured. MAE is a metric for measuring how far estimated values deviate from measured values. As RMSE and MAE values approach 0, the models approach perfect estimation (Helsel and Hirsch, 2002).

Limitations in Estimating Suspended-Sediment Load from Streamflow

Suspended-sediment loads estimated from log-linear regressions that relate SSC to streamflow provide a general characterization of the sources, timing, and quantity of SSLs in the study area. Limitations in the available suspended-sediment data and the effects of various assumptions might contribute to uncertainty in the development of the regression equations and the estimated SSLs produced from them.

The regression equations used to estimate SSCs incorporate historical and 2011–13 suspended-sediment sample data. Historical data from as early as 1966 to as late as 2004 are available from five sites (31 to 162 suspended-sediment samples per site) (table 1). The combination of these historical data with the 2011–13 suspended-sediment samples increases the robustness of the regressions by representing a wider range of hydrologic conditions for which suspended-sediment data were collected at the sites. The historical samples were collected during a wide range of streamflow conditions, including sampling during base-flow conditions. Most historical samples were collected on a routine schedule regardless of streamflow or sediment conditions; some were collected during storm runoff and represent different parts of storm hydrographs. In contrast, the 2011–13 samples were collected primarily during the rising limb to peak of the hydrograph during storm events, when SSLs often reach a maximum. Because the 2011–13 sampling plan intentionally targeted the rising limb to peak of the hydrograph during storm events, combination of the historical and 2011–13 data represents a wider range of hydrologic and antecedent conditions compared to those represented by the 2011–13 data alone. In addition to the historical samples potentially representing somewhat different hydrologic conditions compared to the 2011–13 samples, there are factors that might cause SSCs to change over time. These factors include (but are not limited to) (1) changes in the amount of urbanization and other changes in land use; (2) placement or removal of physical structures such as dams or levees; (3) implementation of best management practices within the contributing watershed; and (4) differences in sediment yields from land surfaces as a result of antecedent moisture conditions, time since last rainfall, rainfall intensity, and where the rainfall occurred within the basin (Glymph, 1951; Griffiths, 1981). At some sites, there are several years to several decades between the collection of historical and 2011–13 data. It was assumed that relations between streamflow and SSCs did not change at any of the sites because quantification of the factors that might cause SSCs to change over time was not possible when combining the historical and 2011–13 datasets. The combined dataset likely has a larger (and unquantified) degree of measurement uncertainty compared to the 2011–13 data because of the unknown magnitude of the factors previously mentioned in this paragraph that can affect SSC over time.

Another factor contributing to the estimated SSL uncertainty at two sites was that the sampling locations changed; the historical sampling locations were replaced with new sampling locations. Changes in the 2011–13 sampling locations at the SAR Falls City and Ecleto Runge sediment-sampling sites compared to their historical sampling locations at streamflow-gaging stations were made because the historical sediment-sampling sites were considered unsafe for the collection of sediment samples (the historical SAR Falls City and Ecleto Runge sampling sites continue to function as streamflow-gaging stations). No sediment samples were collected during 2011–13 at the historical SAR Falls City site because of safety considerations. Three samples were collected from January through March 2012 at the historical Ecleto Runge sampling site before this site was deemed unsafe for any additional sediment sampling. Replacement sampling sites were selected downstream as near as possible to the historical sampling sites and upstream from any tributaries. Land uses in the drainage areas upstream from the historical and 2011–13 sampling sites were similar, and no other notable factors were identified that might result in appreciable differences between the historical and 2011–13 suspended sediment concentrations. The SSLs in the study area are dominated by very fine suspended-sediment particle sizes that tend to remain in suspension during transport between the two sites, providing additional corroborating evidence that changes in SSLs between the historical and 2011–13 sampling sites were unlikely.

It was not practical to make streamflow measurements at the 2011–13 SAR Falls City and Ecleto Runge sampling sites; consequently, streamflows at these two sampling sites were estimated as the gaged streamflow measured at their respective upstream streamflow-gaging stations, taking into account the streamflow traveltime between the locations. To account for streamflow traveltime between the SAR Falls City gaging station and the 2011–13 sampling site (approximately 2 hours for streamflow greater than 1,000 ft^3/s), streamflow measured at the gaging station 2 hours before the sample collection was used to represent streamflow conditions at the 2011–13 sample sites during stormflow events. Streamflow was not adjusted during base-flow conditions. Similarly, during sampling events at the Ecleto Runge site, gaged streamflow recorded 2 hours before the sampling event was used to represent streamflow conditions during the sample collection.

The regression of SSCs to streamflow data (eq. 4) collected at each of the sampling sites exhibits generally reasonable correlations between observed data and the regression estimates; however, during increased streamflow (typically, greater than the 80th percentile daily streamflow), SSCs tend to approach an upper limit (concentrations remain constant with increasing streamflow), which is likely attributable to watershed limits to the supply of available sediment in runoff (Porterfield, 1972; Gao, 2008). Therefore, the regression equations tend to oversimulate sediment concentrations, compared with observed SSC values, during increased streamflow. Also, extrapolation of the regression equations to simulate SSCs and SSLs for streamflow values that are greater than observed SSCs and SSLs during sample collection results in (possibly extreme) overestimates of SSCs and SSLs. During major runoff events, particularly for large events that were not sampled for suspended sediment, prediction of SSCs by regression would potentially result in overestimation of daily and event SSLs; therefore, to avoid overestimation of SSCs and SSLs, the regression-estimated SSCs (eq. 4) used to calculate daily SSLs at each sampling location (eq. 2) were limited (truncated) at a maximum value when the observed (sampled) SSCs approached the upper concentration limit.

Estimating Suspended-Sediment Loads from Turbidity

A correlation between turbidity and SSC has been documented in numerous reports for different geographic settings in the United States and in other parts if the world. Studies in the United States were done in the Pacific Northwest (Kunkle and Comer, 1971), Vermont (Beschta, 1980), Kansas (Christensen and others, 2000; Rasmussen and others, 2005, 2009), Oregon (Uhrich and Bragg, 2003; Bragg and Uhrich, 2010), the Chesapeake Bay area (Jastram and others, 2009), and Kentucky (Williamson and Crawford, 2011). Additional studies in other parts of the world include Indonesia (Brabben, 1981) and Australia (Gippel, 1989). By developing a regression equation from the relation of turbidity and SSC at a sampling site, a time series of SSCs can be estimated from a time series of turbidity data. Once the regression equation is developed, the time series of estimated SSCs can be used with the time series of streamflow to estimate a time series of SSLs (eq. 2). Because sediment transport is complex and dependent on many factors, regression equations for estimating SSCs are usually site specific and subject to change over time. Data collected over time can help verify change in sediment load, type, and source (Leopold, 1997; Rasmussen and others, 2009).

Sediment Characteristics

Sediment characteristics in the study area are described by comparing the results from various types of historical sediment data collected during 1966–94 with recent sediment data collected during 2011–13 (table 1). Sediment data were historically collected by the U.S. Geological Survey between 1966 and 2004 at five sites in the study area. Much of this historical data was collected during routine sampling efforts that typically characterized low-flow conditions, and only infrequently were larger flow events characterized. Most of the historical data also did not include particle-size distributions, and no bedload data were collected. During 2011–13, SSC and particle-size distribution were measured in samples collected at all sites, and bedload mass and particle-size distribution were measured in samples collected at six sites. The sediment data, along with streamflow information, were used to describe the sediment loads at sites during the various flow conditions.

Suspended-Sediment Concentration

Measured SSCs in the 67 samples collected during 2011–13 ranged from 14 mg/L during base-flow conditions at the SAR Falls City site on August 19, 2011, to 4,480 mg/L during a stormflow event at the same site on January 26, 2012 (table 3). It should be noted that not all samples were collected during the same storm events, same routine events, or even same parts of the storm hydrographs; therefore, comparisons of concentrations between sites should be considered qualitative. Boxplots created using historical and 2011–13 SSC data from the sites are shown in figure 4. Varying amounts of historical SSC data were available for the SAR Elmendorf, SAR Falls City, Cibolo Falls City, Ecleto Runge, and SAR Goliad sites. No historical data were available for the Cibolo Selma, SAR 72, SAR McFaddin, or GR Tivoli sites.

A comparison of the boxplot for the historical data and the 2011–13 data from the SAR Elmendorf site demonstrates that the 2011–13 samples represent a wide range of SSCs, including some of the largest concentrations measured at the site. This is likely, in part, because the samples targeted stormflow events that typically elevate SSCs (Wood, 1977; VanSickle and Beschta, 1983; Glysson, 1987; Clark and others, 2013). The 2011–13 samples from the SAR Falls City, Cibolo Falls City, and SAR Goliad sites exhibited SSCs that plotted outside of the historical interquartile ranges for these sites. These results were not surprising because samples collected at these sites during 2011–13 were collected during historically low base-flow conditions that produce very low SSCs or were collected during stormflow events; whereas, the historical data were obtained possibly during different hydrologic conditions and potentially during different periods of the storm hydrograph. For example, it is not known if specific parts of the hydrograph, such as the rising limb or peak, were targeted during historical sampling as was the case for the 2011–13 samples. The SSCs from 2011–13 samples collected at the Ecleto Runge site all plotted at the upper end of the interquartile range or higher. Drought conditions were common during 2011–13 in the study area; therefore, base flow past the Ecleto Runge site was seldom, and the stream typically flowed only during storm events.

Table 3. Suspended-sediment data collected at sites in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, January 2011–May 2013, showing the percentage of sand-sized and fine-sized particles in each sample.

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; mg/L, milligrams per liter; mm, millimeter; *, grab sample]

Date	Time	Instantaneous streamflow (ft^3/s)	Suspended-sediment concentration (mg/L)	Instantaneous suspended-sediment load (tons/day)	Suspended-sediment particle size: Less than 0.0625 mm (percent)	Suspended-sediment particle size: Equal to or greater than 0.0625 mm (percent)
USGS 08181800 San Antonio River near Elmendorf, Tex. (SAR Elmendorf)						
1/27/2011	0900	236	21	13	87	13
[1]4/7/2011	1100	138	71	26	65	35
5/13/2011	1030	714	131	253	96	4
6/22/2011	1900	1,830	625	3,090	96	4
10/9/2011	1430	4,720	2,630	33,500	98	2
1/25/2012	1230	8,800	2,010	47,800	92	8
1/25/2012	1800	8,570	1,530	35,400	94	6
2/18/2012	1130	3,350	1,430	12,900	92	8
5/11/2012	1000	4,910	1,090	14,500	98	2
9/14/2012	1300	5,360	1,160	16,800	99	1
USGS 08183550 San Antonio River at Highway 181 near Falls City, Tex. (SAR Falls City)[2]						
4/6/2011	1230	171	37	17	95	5
6/24/2011	1000	1,000	930	2,511	98	2
8/19/2011	1100	52	14	2.0	93	7
10/11/2011	0930	2,880	1,990	15,474	94	6
1/26/2012	1400	3,590	2,390	23,200	96	4

Table 3. Suspended-sediment data collected at sites in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, January 2011–May 2013, showing the percentage of sand-sized and fine-sized particles in each sample.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; mg/L, milligrams per liter; mm, millimeter; *, grab sample]

Date	Time	Instantaneous streamflow (ft^3/s)	Suspended-sediment concentration (mg/L)	Instantaneous suspended-sediment load (tons/day)	Suspended-sediment particle size	
					Less than 0.0625 mm (percent)	Equal to or greater than 0.0625 mm (percent)
USGS 08183550 San Antonio River at Highway 181 near Falls City, Tex. (SAR Falls City)[2]—Continued						
1/26/2012	1630	3,730	4,480	45,118	96	4
3/21/2012	1400	2,130	1,440	8,281	97	3
5/12/2012	1500	2,950	4,030	32,099	98	2
7/12/2012	1230	488	50	66	99	1
USGS 08185000 Cibolo Creek at Selma, Tex. (Cibolo Selma)						
9/17/2012	0815	1.9	71	0.36	100	0
9/29/2012	0915	37	262	26	100	0
5/25/2013	1200	10,600	486*	13,909	94	6
USGS 08186000 Cibolo Creek near Falls City, Tex. (Cibolo Falls City)						
[1]1/26/2011	1350	54	37	5.4	55	45
4/6/2011	1350	30	18	1.5	96	4
6/25/2011	1300	62	53*	9.0	97	3
1/26/2012	0930	1,020	985	2,710	91	9
2/19/2012	1100	2,540	1,480	10,100	94	6
3/21/2012	1200	3,380	1,140	10,400	93	7
9/30/2012	1630	1,820	982	4,830	96	4
USGS 08186500 Ecleto Creek near Runge, Tex. (Ecleto Runge)[3]						
1/26/2012	1335	7.0	399	7.5	99	1
2/19/2012	1430	122	1,180	389	98	2
3/21/2012	1030	140	789	298	100	0
USGS 08186550 Ecleto Creek at County Road 326 near Runge, Tex. (Ecleto Runge)[3]						
3/20/2012	1330	20	347	19	99	1
5/12/2012	1030	397	510	547	93	7
USGS 08188060 San Antonio River at State Highway 72 near Runge, Tex. (SAR 72)						
6/25/2011	1500	487	740	973	97	3
8/19/2011	0945	67	129	23	97	3
10/11/2011	1300	2,570	1,660	11,500	89	11
1/27/2012	1230	4,640	2,420	30,300	92	8
3/22/2012	1030	4,840	1,970	25,700	89	11
USGS 08188500 San Antonio River at Goliad, Tex. (SAR Goliad)						
1/26/2011	1050	438	69	82	84	16
4/6/2011	0800	311	81	68	98	2
6/25/2011	2000	1,180	811	2,580	95	5
10/13/2011	0945	3,280	1,690	15,000	92	8
1/28/2012	1130	4,650	1,970	24,700	90	10

Table 3. Suspended-sediment data collected at sites in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, January 2011–May 2013, showing the percentage of sand-sized and fine-sized particles in each sample.—Continued

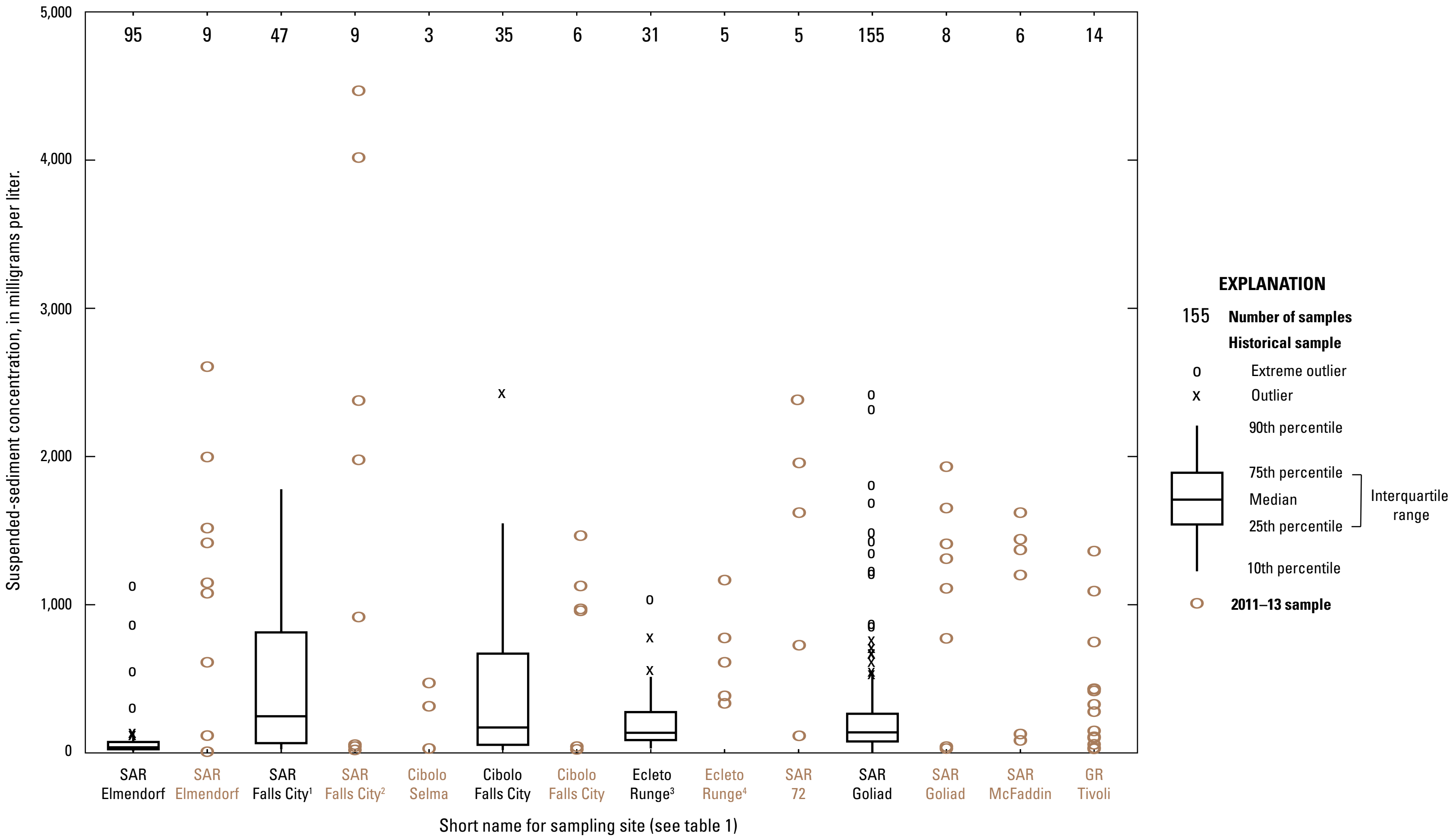
[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; mg/L, milligrams per liter; mm, millimeter; *, grab sample]

Date	Time	Instantaneous streamflow (ft^3/s)	Suspended-sediment concentration (mg/L)	Instantaneous suspended-sediment load (tons/day)	Suspended-sediment particle size: Less than 0.0625 mm (percent)	Suspended-sediment particle size: Equal to or greater than 0.0625 mm (percent)
USGS 08188500 San Antonio River at Goliad, Tex. (SAR Goliad)—Continued						
2/21/2012	1200	4,030	1,350	14,700	96	4
3/22/2012	1300	3,400	1,150	10,600	90	10
3/23/2012	1200	4,520	1,450	17,700	95	5
USGS 08188570 San Antonio River near McFaddin, Tex. (SAR McFaddin)						
1/26/2011	0850	544	1,420	2,090	100	0
4/5/2011	1830	329	166	147	98	2
6/27/2011	2000	783	124*	26	100	0
10/13/2011	1300	1,210	1,670	5,460	99	1
2/21/2012	1430	1,650	1,250	5,570	97	3
3/23/2012	1030	1,970	1,490	7,930	98	2
USGS 08188800 Guadalupe River near Tivoli, Tex. (GR Tivoli)						
1/25/2011	1440	1,980	67	358	81	19
4/5/2011	1400	941	75	191	95	5
6/28/2011	1200	913	96*	237	99	1
10/16/2011	1530	954	141	363	99	1
1/29/2012	1130	2,880	1,400	10,900	99	1
1/29/2012	1730	3,060	1,130	9,340	99	1
1/30/2012	1100	3,320	788	7,060	98	2
1/31/2012	0930	3,550	469	4,500	93	7
2/22/2012	1200	2,600	457	3,210	99	1
2/23/2012	1020	2,920	317	2,500	98	2
3/26/2012	1230	2,950	187	1,490	97	3
3/27/2012	0800	2,900	147	1,150	96	4
5/15/2012	1230	2,940	366	2,910	96	4
5/16/2012	0830	2,920	472	3,720	98	2

[1]Sample not included in analyses because of possible sampling issue but included in table for completeness of data set.

[2]For analysis, data collected at USGS station numbers 08183500 San Antonio River near Falls City, Tex., and 08183550 San Antonio River at Highway 181 near Falls City, Tex., were combined and reported under short name "SAR Falls City;" adjusted instantaneous streamflow from site 08183500 was reported for site 08183550.

[3]For analysis, data collected at USGS station numbers 08186500 Ecleto Creek near Runge, Tex., and 08186550 Ecleto Creek at County Road 326 near Runge, Tex., were combined and reported under short name "Ecleto Runge;" adjusted instantaneous streamflow from site 08186500 was reported for site 08186550.



[1]Data collected at USGS station number 08183500 reported under short name "SAR Falls City."
[2]Data collected at USGS station number 08183550 reported under short name "SAR Falls City."
[3]Data collected at USGS station number 08186500 reported under short name "Ecleto Runge."
[4]Data collected at USGS station number 08186550 reported under short name "Ecleto Runge."

Figure 4. Distribution of suspended-sediment concentrations at sites in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, 1966–2013.

The particle-size distribution data from the 2011–13 suspended-sediment samples were consistent with historical observations that the system is dominated by fine sediment particles less than 0.0625 mm in diameter. The elevated percentages of sand-sized or larger particles in the samples collected on April 4, 2011, at the SAR Elmendorf site and on January 26, 2011, at the Cibolo Falls City site were considered questionable especially at the streamflows at which the samples were collected. It is likely there was a problem with the sampling technique that allowed a small number of sand-sized or larger particles to enter the sampler during collection. These larger particles could easily skew the results at such low concentrations of suspended sediment, so these data were not used in any analyses for this report although they are shown in tables for completeness. Similarly, nine historical samples also were identified as potential outliers and were not used in the analyses from SAR Falls City, Cibolo Falls City, and SAR Goliad but are shown in appendix 1 for completeness. A summary of the sand/fine break data for the 2011–13 suspended-sediment samples indicates that, on average, about 94 percent of suspended-sediment particles in the samples were less than 0.0625 mm (silt and clay) (table 3). Furthermore, the data from the 50 samples for which a complete sediment-size analysis was performed indicate that an average of about 69 percent of the particles was less than 0.002 mm, the smallest size range for which the samples were analyzed (table 4).

Table 4. Suspended-sediment data collected at sites in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, January 2011–May 2013, showing complete distribution of particle size for each sample.

[ft^3/s, cubic feet per second; mm, millimeter; USGS, U.S. Geological Survey; --, no data]

Sample date	Sample start time	Instantaneous streamflow (ft^3/s)	Suspended-sediment diameter (percentage)										
			Less than 0.002 mm	Less than 0.004 mm	Less than 0.008 mm	Less than 0.016 mm	Less than 0.031 mm	Less than 0.0625 mm	Less than 0.125 mm	Less than 0.25 mm	Less than 0.5 mm	Less than 1 mm	Less than 2 mm
USGS 08181800 San Antonio River near Elmendorf, Tex. (SAR Elmendorf)													
6/22/2011	1900	1,830	60	73	87	93	94	96	98	99	100	--	--
10/9/2011	1430	4,720	56	72	83	91	96	98	99	100	--	--	--
1/25/2012	1230	8,800	64	71	77	83	88	92	97	99	100	--	--
1/25/2012	1800	8,570	50	65	73	80	89	94	98	99	100	--	--
2/18/2012	1130	3,350	62	69	74	79	88	92	98	100	--	--	--
5/11/2012	1000	4,910	66	78	84	90	95	98	99	100	--	--	--
9/14/2012	1300	5,360	66	79	84	90	97	99	100	--	--	--	--
USGS 08183550 San Antonio River at Highway 181 near Falls City, Tex. (SAR Falls City)[1]													
6/24/2011	1000	1,000	53	70	88	94	97	98	99	100	--	--	--
8/19/2011	1100	52	--	--	--	--	--	93	99	100	--	--	--
10/11/2011	930	2,880	59	69	76	84	90	94	98	100	--	--	--
1/26/2012	1400	3,590	58	65	72	82	94	96	99	100	--	--	--
1/26/2012	1630	3,730	67	76	83	89	94	96	99	99	100	--	--
3/21/2012	1400	2,130	53	63	75	86	94	97	99	100	--	--	--
5/12/2012	1500	2,950	59	73	86	95	96	98	99	100	--	--	--

Table 4. Suspended-sediment data collected at sites in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, January 2011–May 2013, showing complete distribution of particle size for each sample.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; mm, millimeter; --, no data]

Sample date	Sample start time	Instantaneous streamflow (ft^3/s)	Suspended-sediment diameter (percentage)										
			Less than 0.002 mm	Less than 0.004 mm	Less than 0.008 mm	Less than 0.016 mm	Less than 0.031 mm	Less than 0.0625 mm	Less than 0.125 mm	Less than 0.25 mm	Less than 0.5 mm	Less than 1 mm	Less than 2 mm
USGS 08185000 Cibolo Creek at Selma, Tex. (Cibolo Selma)													
9/29/2012	915	37	93	99	99	100	--	--	--	--	--	--	--
5/25/2013	1200	10,600	41	58	69	82	92	94	96	96	97	97	100
USGS 08186000 Cibolo Creek near Falls City, Tex. (Cibolo Falls City)													
6/25/2011	1300	62	--	--	--	--	--	97	98	99	100	--	--
1/26/2012	930	1,020	60	67	71	79	87	91	97	99	100	--	--
2/19/2012	1100	2,540	73	78	82	86	91	94	98	99	100	--	--
3/21/2012	1200	3,380	76	80	84	86	91	93	98	100	--	--	--
9/30/2012	1630	1,820	71	77	82	87	92	96	99	99	100	--	--
USGS 08186500 Ecleto Creek near Runge, Tex. (Ecleto Runge)[2]													
1/26/2012	1335	7	97	97	98	99	97	99	100	--	--	--	--
2/19/2012	1430	122	88	90	92	95	96	98	100	--	--	--	--
3/21/2012	1030	140	97	99	100	--	--	--	--	--	--	--	--
USGS 08186550 Ecleto Creek at County Road 326 near Runge, Tex. (Ecleto Runge)[2]													
3/20/2012	1330	20	93	95	98	98	99	99	100	--	--	--	--
5/12/2012	1030	397	63	80	84	90	91	93	97	98	99	100	--
USGS 08188060 San Antonio River at State Highway 72 near Runge, Tex. (SAR 72)													
6/25/2011	1500	487	60	73	87	93	96	97	98	99	100	--	--
8/19/2011	945	67	--	--	--	--	--	97	99	100	--	--	--
10/11/2011	1300	2,570	57	63	69	76	83	89	97	99	100	--	--
1/27/2012	1230	4,640	62	70	80	85	90	92	96	98	100	--	--
3/22/2012	1030	4,840	68	75	73	82	87	89	90	91	100	--	--
USGS 08188500 San Antonio River at Goliad, Tex. (SAR Goliad)													
6/25/2011	2000	1,180	42	51	65	78	90	95	98	99	100	--	--
10/13/2011	945	3,280	58	77	81	87	89	92	95	98	100	--	--
1/28/2012	1130	4,650	72	78	82	87	88	90	92	96	100	--	--
2/21/2012	1200	4,030	60	73	87	92	94	96	97	99	100	--	--

Table 4. Suspended-sediment data collected at sites in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, January 2011–May 2013, showing complete distribution of particle size for each sample.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; mm, millimeter; --, no data]

Sample date	Sample start time	Instantaneous streamflow (ft^3/s)	Suspended-sediment diameter (percentage)										
			Less than 0.002 mm	Less than 0.004 mm	Less than 0.008 mm	Less than 0.016 mm	Less than 0.031 mm	Less than 0.0625 mm	Less than 0.125 mm	Less than 0.25 mm	Less than 0.5 mm	Less than 1 mm	Less than 2 mm
USGS 08188500 San Antonio River at Goliad, Tex. (SAR Goliad)—Continued													
3/22/2012	1300	3,400	69	75	78	82	87	90	94	98	100	--	--
3/23/2012	1200	4,520	81	84	88	90	92	95	96	98	100	--	--
USGS 08188570 San Antonio River near McFaddin, Tex. (SAR McFaddin)													
10/13/2011	1300	1,210	62	71	78	90	98	99	100	--	--	--	--
2/21/2012	1430	1,650	56	62	69	77	91	97	100	--	--	--	--
3/23/2012	1030	1,970	60	66	72	78	90	98	100	--	--	--	--
USGS 08188800 Guadalupe River near Tivoli, Tex. (GR Tivoli)													
6/28/2011	1200	913	--	--	--	--	--	99	100	--	--	--	--
10/16/2011	1530	954	72	80	84	91	95	99	100	--	--	--	--
1/30/2012	1100	3,320	82	88	91	95	95	98	99	100	--	--	--
1/31/2012	930	3,550	74	79	82	85	90	93	96	99	100	--	--
2/22/2012	1200	2,600	82	88	91	96	98	99	99	100	--	--	--
2/23/2012	1020	2,920	89	93	96	97	98	98	99	100	--	--	--
3/26/2012	1230	2,950	82	88	89	94	96	97	98	100	--	--	--
3/27/2012	800	2,900	86	90	91	95	96	96	98	99	100	--	--
5/15/2012	1230	2,940	91	95	96	96	96	96	98	99	100	--	--
5/16/2012	830	2,920	81	95	98	98	98	98	99	100	--	--	--

[1]For analysis, data collected at USGS station numbers 08183500 San Antonio River near Falls City, Tex., and 08183550 San Antonio River at Highway 181 near Falls City, Tex., were combined and reported under short name "SAR Falls City;" adjusted instantaneous streamflow from site 08183500 was reported for site 08183550.

[2]For analysis, data collected at USGS station numbers 08186500 Ecleto Creek near Runge, Tex., and 08186550 Ecleto Creek at County Road 326 near Runge, Tex., were combined and reported under short name "Ecleto Runge;" adjusted instantaneous streamflow from site 08186500 was reported for site 08186550.

Bedload

The mass from the 22 bedload samples collected during 2011–13 ranged from 12 g at the site furthest downstream (GR Tivoli) during base-flow conditions on April 5, 2011, to 8,900 g at the SAR Goliad site during a stormflow event on January 28, 2012 (table 5). The data from the particle-size analysis for 10 bedload samples collected during 2011–13 (table 6) indicated that, on average, about 91 percent of bedload was composed of sand-sized particles or smaller (less than 2 mm in size) with sediment in the 0.25–0.5-mm size range accounting for a majority (51 percent, on average) of bedload. The bedload samples collected at upstream sample sites exhibited a wider range of sediment sizes and included greater percentages of larger particle sizes than those collected at downstream sites, which showed a very narrow and uniform particle-size distribution despite streamflow variation. This distribution is common in most river systems as sediment matures (becomes finer) as it is exposed to ongoing erosion as it moves through a basin. In addition, energy available for transporting sediment generally decreases as the stream approaches a delta and slope decreases.

Sediment Loads

Instantaneous Suspended-Sediment Loads, Bedloads, and Total Loads

Instantaneous SSLs computed from the 67 SSC samples collected during 2011–12 ranged from 0.36 tons per day at the Cibolo Selma site during base flow conditions on September 17, 2012, to 47,800 tons per day at the SAR Elmendorf site during a stormflow event on January 25, 2012 (table 3). Instantaneous bedload transport computed for the 22 samples collected during 2011–12 ranged from 0.15 tons per day at SAR Elmendorf during base-flow conditions on January 27, 2011, to 155 tons per day at site SAR Goliad during a stormflow event on January 28, 2012 (table 5). Instantaneous total sediment loads computed for the 21 samples for which both instantaneous SSL and instantaneous bedload were computed ranged from 13.1 tons per day at the SAR Elmendorf site on January 27, 2011, to 47,828 tons per day at the same site on January 25, 2012 (table 5). The percentage of instantaneous total sediment load that was bedload ranged from 0 to 7.2 percent, with bedload accounting for less than 1 percent of total sediment load in 13 of the 21 samples (table 5). The small percentage of bedload is not unexpected in the basin because the SSL is dominated by the fine sediment fraction.

Guadalupe River near Tivoli, Texas.

Table 5. Bedload mass and instantaneous bedload transport for samples collected at sites in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, January 2011–May 2013.

[SSL, suspended sediment load; CR, County Road; --, no data]

U.S. Geological Survey station number	U.S. Geological Survey station name	Short name for sampling site	Sample date	Bedload sample mass (grams)	Composited samples in cross-sectional bedload measurement (number)	Stream width (feet)	Rest time on bed for bedload sample (seconds)	Instantaneous bedload transport (tons per day)	Instantaneous SSL (tons per day)	Instantaneous total sediment load (tons per day)[1]	Percentage of total load	
											Suspended-sediment load	Bedload
08181800	San Antonio River near Elmendorf, Tex.	SAR Elmendorf	1/27/2011	32	40	44	90	0.15	13	13.1	98.9	1.1
08181800	San Antonio River near Elmendorf, Tex.	SAR Elmendorf	4/7/2011	112	40	36	120	0.32	26	26.3	98.8	1.2
08181800	San Antonio River near Elmendorf, Tex.	SAR Elmendorf	5/13/2011	5,450	40	45	120	20	253	273	92.8	7.2
08181800	San Antonio River near Elmendorf, Tex.	SAR Elmendorf	6/22/2011	3,060	40	62	60	30	3,090	3,120	99.0	1.0
08181800	San Antonio River near Elmendorf, Tex.	SAR Elmendorf	10/9/2011	1,050	40	117	60	20	33,500	33,520	99.9	0.1
08181800	San Antonio River near Elmendorf, Tex.	SAR Elmendorf	1/25/2012	1,360	40	130	60	28	47,800	47,828	99.9	0.1
08186000	Cibolo Creek near Falls City, Tex.	Cibolo Falls City	2/19/2012	313	40	68	60	3.4	10,100	10,103	100	0
08186500	Ecleto Creek near Runge, Tex.	Ecleto Runge[2]	2/19/2012	277	32	31	60	1.7	389	391	99.6	0.4
08186550	Ecleto Creek at CR 326 near Runge, Tex.	Ecleto Runge[2]	3/20/2012	42	38	34	60	0.24	19	19.2	98.8	1.2
08186550	Ecleto Creek at CR 326 near Runge, Tex.	Ecleto Runge[2]	5/12/2012	3,280	40	52	120	14	547	561	97.6	2.4
08188500	San Antonio River at Goliad, Tex.	SAR Goliad	6/25/2011	1,440	38	65	60	16	2,580	2,596	99.4	0.6
08188500	San Antonio River at Goliad, Tex.	SAR Goliad	8/18/2011	105	40	60	120	0.50	--	--	--	--

Table 5. Bedload mass and instantaneous bedload transport for samples collected at sites in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, January 2011–May 2013.—Continued

[SSL, suspended sediment load; CR, County Road; --, no data]

U.S. Geological Survey station number	U.S. Geological Survey station name	Short name for sampling site	Sample date	Bedload sample mass (grams)	Composited samples in cross-sectional bedload measurement (number)	Stream width (feet)	Rest time on bed for bedload sample (seconds)	Instantaneous bedload transport (tons per day)	Instantaneous SSL (tons per day)	Instantaneous total sediment load (tons per day)[1]	Percentage of total load	
											Suspended-sediment load	Bedload
08188500	San Antonio River at Goliad, Tex.	SAR Goliad	1/28/2012	8,900	40	110	60	155	24,700	24,855	99.4	0.6
08188800	Guadalupe River near Tivoli, Tex.	GR Tivoli	1/25/2011	485	40	127	60	10	358	368	97.3	2.7
08188800	Guadalupe River near Tivoli, Tex.	GR Tivoli	4/5/2011	12	20	138	120	0.27	191	191	99.9	0.1
08188800	Guadalupe River near Tivoli, Tex.	GR Tivoli	6/28/2011	66	40	126	60	1.3	237	238	99.4	0.6
08188800	Guadalupe River near Tivoli, Tex.	GR Tivoli	10/16/2011	25	40	125	120	0.24	363	363	99.9	0.1
08188800	Guadalupe River near Tivoli, Tex.	GR Tivoli	1/30/2012	1,270	40	130	60	26	7,060	7,086	99.6	0.4
08188800	Guadalupe River near Tivoli, Tex.	GR Tivoli	1/31/2012	518	40	130	60	11	4,500	4,511	99.8	0.2
08188800	Guadalupe River near Tivoli, Tex.	GR Tivoli	2/22/2012	425	40	132	60	8.9	3,210	3,219	99.7	0.3
08188800	Guadalupe River near Tivoli, Tex.	GR Tivoli	3/26/2012	735	40	130	60	15	1,490	1,505	99.0	1.0
08188800	Guadalupe River near Tivoli, Tex.	GR Tivoli	5/15/2012	641	40	130	120	6.6	2,910	2,917	99.8	0.2

[1]Instantaneous total sediment load is the sum of instantaneous bedload transport plus instantaneous SSL. Unrounded values are reported for the sum because rounding to three significant figures would result in 100 percent suspended-sediment load and 0 percent bedload at most of the sampling sites.

[2]Data collected at sites 08186500 and 08186550 were reported under sampling site short name “Ecleto Runge.”

Table 6. Bedload particle-size distribution for samples collected at sites in the San Antonio River Basin downstream from San Antonio, Texas, and at a site on the Guadalupe River downstream from the San Antonio River Basin, January 2011–May 2013.

[USGS, U.S. Geological Survey; mm, millimeter; --, no data; CR, County Road]

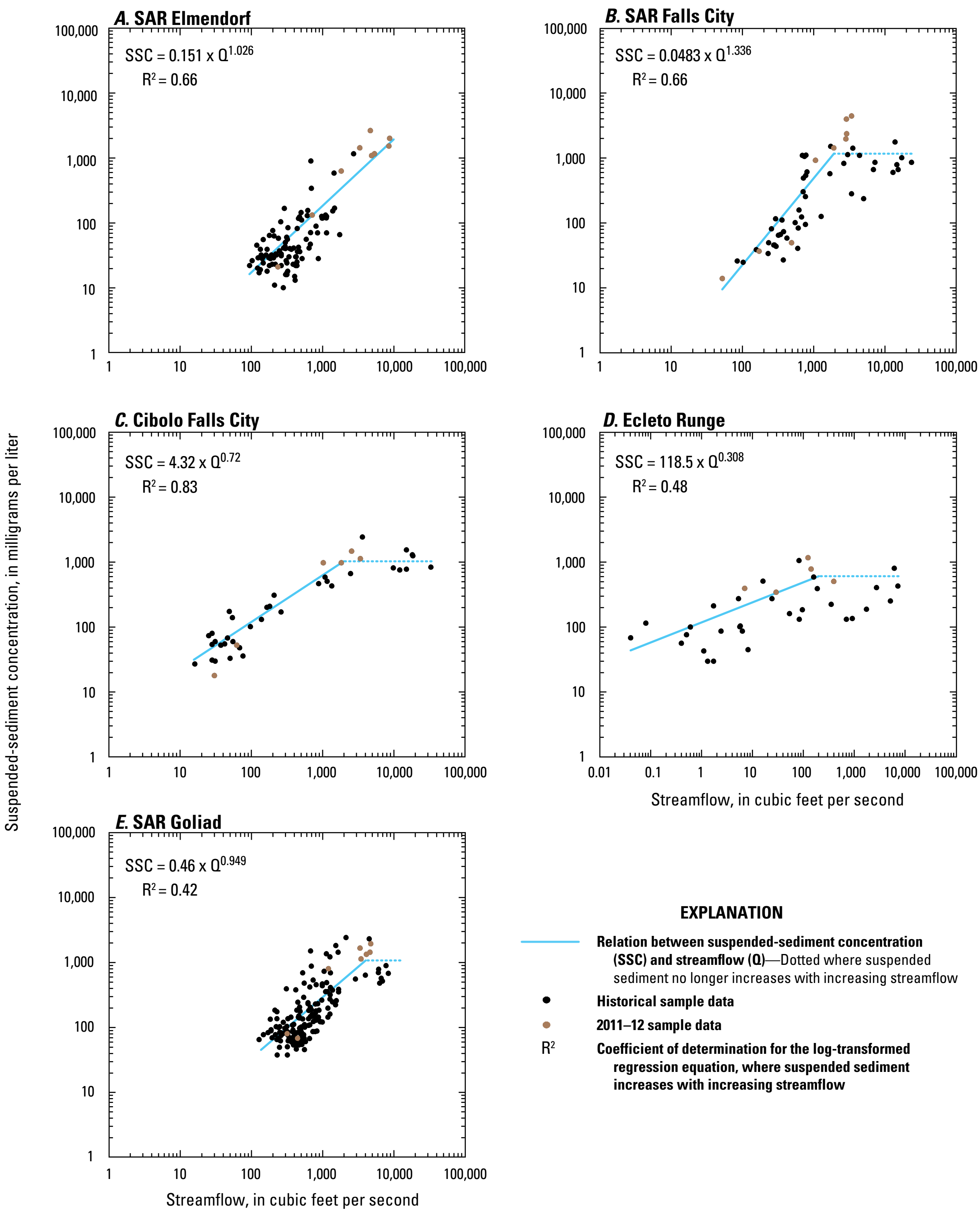
USGS station number	USGS station name	Short name for sampling site (table 1)	Sample date	Sample start time	Bedload sediment diameter (percentage)									
					Less than 0.0625 mm	Less than 0.125 mm	Less than 0.25 mm	Less than 0.5 mm	Less than 1 mm	Less than 2 mm	Less than 4 mm	Less than 8 mm	Less than 16 mm	Less than 32 mm
08181800	San Antonio River near Elmendorf, Tex.	SAR Elmendorf	1/25/2012	1330	0	1	2	18	56	86	96	99	100	--
08186000	Cibolo Creek near Falls City, Tex.	Cibolo Falls City	2/19/2012	1200	2	4	5	40	76	83	87	91	95	100
08186500	Ecleto Creek near Runge, Tex.	Ecleto Runge[1]	2/19/2012	1530	0	1	2	33	76	91	95	96	100	--
08186550	Ecleto Creek at CR 326 near Runge, Tex.	Ecleto Runge[1]	3/20/2012	1300	0	1	3	40	76	88	95	100	--	--
08186550	Ecleto Creek at CR 326 near Runge, Tex.	Ecleto Runge[1]	5/12/2012	1200	1	1	2	53	89	96	98	99	100	--
08188500	San Antonio River at Goliad, Tex.	SAR Goliad	1/28/2012	1500	0	0	3	54	89	95	97	98	100	--
08188800	Guadalupe River near Tivoli, Tex.	GR Tivoli	1/31/2012	1130	2	2	7	81	89	92	95	97	100	--
08188800	Guadalupe River near Tivoli, Tex.	GR Tivoli	2/22/2012	1400	1	2	5	80	92	95	98	100	--	--
08188800	Guadalupe River near Tivoli,	GR Tivoli	3/26/2012	1430	2	2	10	83	92	95	97	99	100	--
08188800	Guadalupe River near Tivoli, Tex.	GR Tivoli	5/15/2012	1400	1	2	6	73	81	85	91	100	--	--

[1]Data collected at USGS station numbers 08186500 and 08186550 were reported under sampling site short name “Ecleto Runge.”

Estimated Daily Suspended-Sediment Loads from Streamflow

Daily SSLs were estimated using the SSC to streamflow regression equations for each site (fig. 5; table 7; appendix 2). The regression equations and summary statistics are listed in table 7, and the residuals were approximately uniformly distributed. The estimated daily SSLs for each of the sites indicated that during 2011–12, the majority of the SSL in the basin originated upstream from the SAR Elmendorf site. The estimated average daily SSL was 237 tons per day at the SAR Elmendorf site and 454 tons per day at the SAR Goliad site during 2011–12. Downstream from the SAR Elmendorf site is the SAR Falls City site, where the estimated average daily SSL was 332 tons per day (table 7). This might be expected given that the majority of the streamflow at the SAR Falls City site originates upstream from the SAR Elmendorf site. Note that the estimated SSLs during 2011–12 at the SAR Elmendorf and SAR Falls City sites were based on independent streamflow measurements and independent SSCs measurements at the respective sites, indicating that the regression method used for estimating loads produces consistent results. Because the Cibolo Selma site often did not flow, the estimated average daily SSL at Cibolo Falls City (57 tons per day) likely originates from within the study watershed, except during large stormflow events when there is streamflow at the Cibolo Selma site. During 2011–12, Ecleto Runge had the lowest SSL of 9 tons per day, which is expected because it drains a smaller watershed and streamflow generally only occurs during storm events. Regression analyses were not performed and SSLs were not estimated for the SAR 72, SAR McFaddin, and GR Tivoli sites because the relatively small number of data available for these sites represents only a limited range of hydrologic conditions.

Cibolo Creek at Selma, Texas.



Note: Short names for sampling sites (table 1) are listed above the upper left corners of figures 5*A*–5*E*.
For analysis, data collected at USGS station numbers 08183500 and 08183550 were combined and reported under short name "SAR Falls City."
For analysis, data collected at USGS station numbers 08186500 and 08186550 were combined and reported under short name "Ecleto Runge."

Figure 5. Relations between suspended-sediment concentration and streamflow at sites *A*, SAR Elmendorf site (U.S. Geological Survey [USGS] station 08181800, San Antonio River near Elmendorf, Texas); *B*, SAR Falls City site (USGS station 08183500 San Antonio River near Falls City, Tex.); *C*, Cibolo Falls City site (USGS station 08186000, Cibolo Creek near Falls City, Tex.); *D*, Ecleto Runge site (USGS station 08186500, Ecleto Creek near Runge, Tex.); and *E*, SAR Goliad site (USGS station 08188500 San Antonio River at Goliad, Tex.).

Table 7. Regression equations, average estimated suspended-sediment load, and summary statistics for suspended-sediment concentration regressions.

[Tex., Texas; SSC, suspended-sediment concentration, in milligrams per liter; Q, streamflow, in cubic feet per second; ft^3/s, cubic feet per second]

U.S. Geological Survey station number	U.S. Geological Survey station name	Short name of sampling site (table 1)	Suspended-sediment concentration to streamflow regression equation[1]	Range of streamflow when linear regression is applicable[2] (ft^3/s)	Number of measurements (n)	Coefficient of determination (R^2)	Mean absolute error (MAE)	Root mean square error (RMSE)	Bias correction factor (Φ)	p-value	Average estimated suspended-sediment load (SSL) during 2011–12 (tons/day)
8181800	San Antonio River near Elmendorf, Tex.	SAR Elmendorf	$SSC = 0.151 \times Q^{1.026}$	0–1,000	104	0.66	0.25	0.31	1.27	<0.001	237
8183500 and 8183550	San Antonio River near Falls City, Tex., and San Antonio River at Highway 181 near Falls City, Tex.	SAR Falls City[3]	$SSC = 0.0483 \times Q^{1.336}$	0–1,910	38	0.66	0.27	0.33	1.32	<0.001	332
8186000	Cibolo Creek near Falls City, Tex.	Cibolo Falls City	$SSC = 4.32 \times Q^{0.72}$	0–2,000	30	0.83	0.16	0.20	1.11	<0.001	57
8186500 and 08186550	Ecleto Creek near Runge, Tex., and Ecleto Creek at County Road 326 near Runge, Tex.	Ecleto Runge[4]	$SSC = 118.5 \times Q^{0.308}$	0–200	27	0.48	0.28	0.33	1.32	<0.001	9
8188500	San Antonio River at Goliad, Tex.	SAR Goliad	$SSC = 0.46 \times Q^{0.949}$	0–3,500	149	0.42	0.22	0.28	1.20	<0.001	454

[1]Regression equations incorporate the bias correction factor.

[2]When streamflow exceeded the upper range limit, SSC was set to a constant value equal to the estimated SSC based on streamflow at the upper value of the range.

[3]For analysis, data collected at USGS station numbers 08183500 and 08183550 were combined and reported under short name "SAR Falls City."

[4]For analysis, data collected at USGS station numbers 08186500 and 08186550 were combined and reported under short name "Ecleto Runge."

Estimated Daily Suspended-Sediment Loads from Turbidity

Turbidity was measured every 15 minutes at the SAR Elmendorf site from January 6, 2011, through September 30, 2013. With the exception of two increases in turbidity (July 11, 2012, and January 9, 2013), the turbidity measurements truncated near the upper limit of the turbidity probe at approximately 1,100–1,200 FNU. The daily mean turbidity values (computed from the 15-minute turbidity values) at the SAR Elmendorf site ranged from 4.6 FNU on September 3, 2011, to 710 FNU on August 19, 2012 (fig. 6; appendix 3). The data truncated by the limitations of the turbidity probe and issues with the DCP program likely caused daily mean turbidity values to be underestimated, especially during storm events.

Measured SSCs and turbidity data collected at the time of sampling were used to develop linear regressions at three sites (SAR Elmendorf, SAR Goliad, and GR Tivoli) to be used for estimating SSCs based on turbidity values (fig. 7). Regressions were not developed at the other sites because too few samples were collected at those sites. The strong relation between SSC and turbidity established for the three sites (R^2 0.93 to 0.96) indicates the estimated SSC, used with a time-series of streamflow, could produce more accurate SSLs than using the SSC to streamflow regression relation (R^2 0.42-0.83).

The regression developed for the SAR Elmendorf site could be used to estimate a time series of SSCs from time-series turbidity data collected at the SAR Elmendorf site (fig. 6). The time series of estimated SSCs could subsequently be paired with the time series of streamflow at the site to produce a time series of estimated SSLs. Although the regression could have been applied to the time series of turbidity data collected at the SAR Elmendorf site to produce a time series of estimated daily SSLs for this study, truncation problems within the turbidity data likely would have caused the SSLs to be substantially underestimated. Time-series turbidity data currently are not collected at the SAR Goliad and GR Tivoli sites, so time series of SSLs could not be estimated for those sites. Future suspended-sediment samples and corresponding turbidity values incorporated into these regressions will increase the accuracy of the regressions.

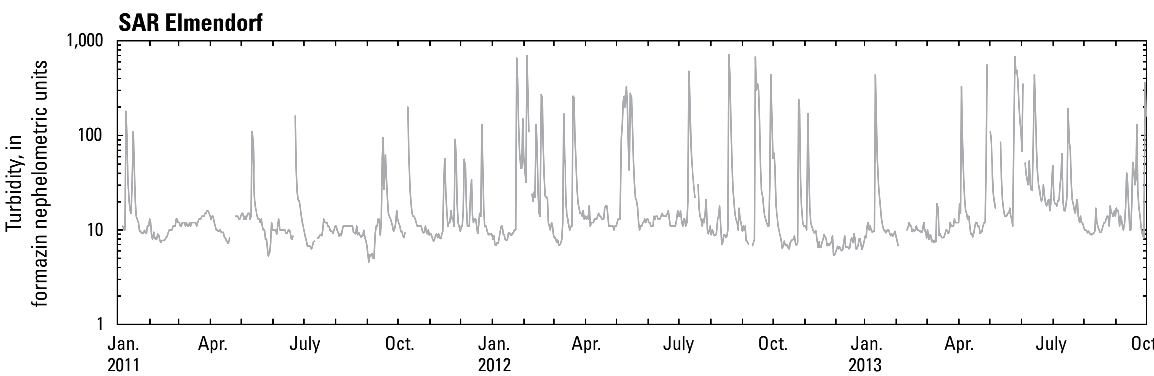


Figure 6. Daily mean turbidity from January 2011 through September 2013 at SAR Elmendorf site (U.S. Geological Survey station 08181800, San Antonio River near Elmendorf, Texas), in formazin nephelometric units (FNU).

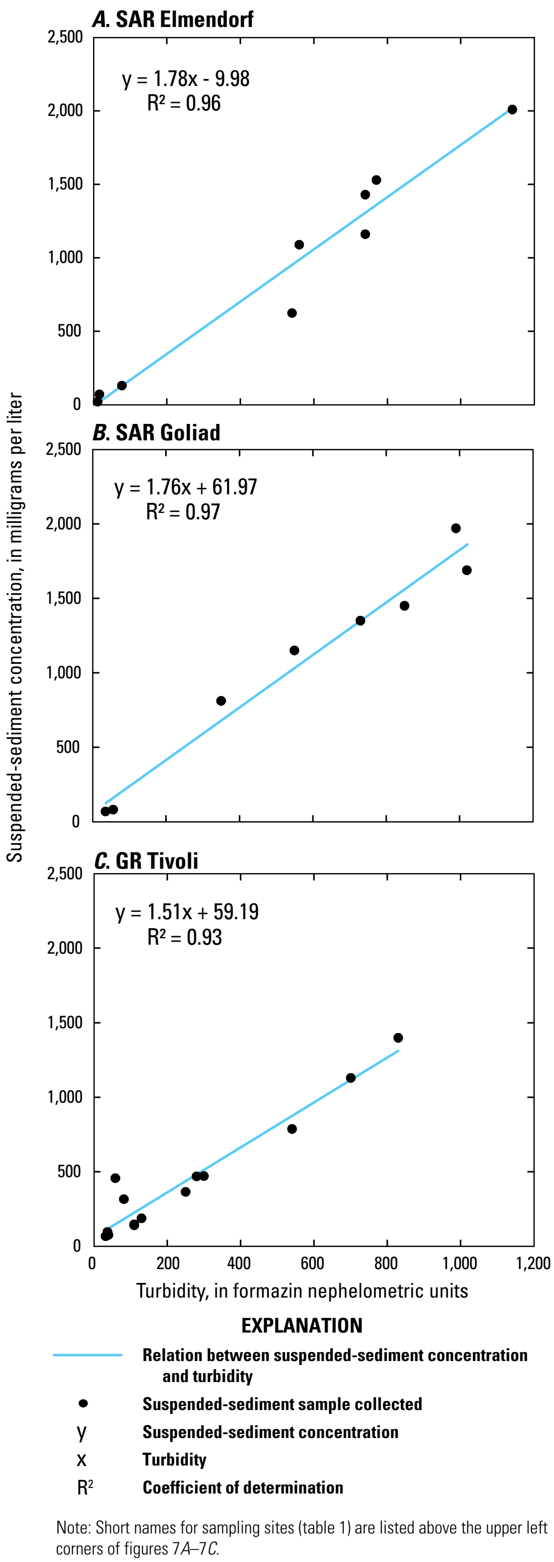


Figure 7. Relation between suspended-sediment concentrations and turbidity at *A*, SAR Elemendorf site (U.S. Geological Survey [USGS] station 08181800 San Antonio River near Elmendorf); *B*, SAR Goliad site (USGS station 08188500 San Antonio River at Goliad); and *C*, GR Tivoli site (USGS station 08188800 Guadalupe River near Tivoli, Texas).

Summary

To better understand sediment characteristics in the San Antonio River Basin downstream from San Antonio, the U.S. Geological Survey, in cooperation with the San Antonio River Authority and the Texas Water Development Board, collected and analyzed suspended-sediment, bedload, particle-size distribution, and turbidity data over a wide range of hydrologic conditions at sampling sites in the San Antonio River Basin downstream from San Antonio, Tex., and at one site on the Guadalupe River downstream from the San Antonio River Basin from January 2011 through May 2013 and combined that data with the available historical sediment data collected at the same sampling sites. Turbidity data collected in conjunction with suspended-sediment samples at a site were used to develop a regression that could be applied to time-series turbidity data collected at the site to develop an estimate of time-series suspended-sediment concentrations (SSCs) at the site.

During 2011–13, suspended-sediment samples were collected at 10 sites for the analysis of SSC and particle size distribution. In addition, samples of bedload material were collected at six sites for the analysis of bedload mass and particle-size distribution. Samples were collected over a variety of hydrologic conditions ranging from a minimum streamflow of 1.9 cubic feet per second (ft^3/s) at the Cibolo Selma site (Cibolo Creek at Selma, Tex.) on September 17, 2012, to a maximum streamflow of 10,600 ft^3/s at the same site on May 25, 2013.

SSCs in 67 samples collected during 2011–13 ranged from 14 milligrams per liter (mg/L) during base-flow conditions at the SAR Falls City site (San Antonio River near Falls City, Tex.) on August 19, 2011, to 4,480 mg/L during a stormflow event at the same site on January 26, 2012. The samples collected during 2011–13 represent a wide range of SSCs, including some of the largest concentrations ever collected at some of the sites. Conversely, the majority of the historical samples collected at this site were routine samples that produced a relatively narrow range of concentrations. The data from the suspended-sediment samples collected during 2011–13 support historical observations that the system is dominated by the transport of fine sediment particles. On average, about 94 percent of suspended-sediment particles in all of the samples was less than 0.0625 millimeter (mm) (silt and clay). Furthermore, the data from 50 samples for which a complete sediment-size analysis was performed indicate that an average of about 69 percent of the particles was less than 0.002 mm, the smallest size range for which the samples were analyzed.

The mass from 22 bedload samples collected during 2011–13 ranged from 12 grams (g) at the site furthest downstream (GR Tivoli [Guadalupe River near Tivoli, Tex.]) during base-flow conditions on April 5, 2011, to 8,900 g at the SAR Goliad (San Antonio River near Goliad, Tex.) site during a stormflow event on January 28, 2012. The data from the particle-size analysis for 10 bedload samples collected during

2011–13 indicate, on average, about 91 percent of sediment transported as bedload in the streams is sand-sized particles or smaller (less than 2 mm in size) with the greatest proportion (about 51 percent) being sediment in the 0.25–0.5-mm size range.

Instantaneous suspended-sediment loads (SSLs) computed from 67 SSC samples collected during 2011–12 ranged from 0.36 tons per day at the Cibolo Selma site during base-flow conditions on September 17, 2012, to 47,800 tons per day at the SAR Elmendorf site (San Antonio River near Elmendorf, Tex.) during a stormflow event on January 25, 2012. Instantaneous bedload transport computed for the 22 samples collected during 2011–12 ranged from 0.15 tons per day at SAR Elmendorf during base-flow conditions on January 27, 2011, to 155 tons per day at site SAR Goliad during a stormflow event on January 28, 2012. Instantaneous total sediment loads computed for the 21 samples for which both SSL and bedload transport were computed ranged from 13.1 tons per day at the SAR Elmendorf site on January 27, 2011, to 47,828 tons per day at the same site on January 25, 2012.

Daily SSLs were estimated using the SSC to streamflow regression equations for each site. The estimated daily SSLs for each of the sites indicated that during 2011–12, the majority of the SSL in the basin originated upstream from the SAR Elmendorf site. The estimated average daily SSL was 237 tons per day at the SAR Elmendorf site and 454 tons per day at the SAR Goliad site during 2011–12. Downstream from the SAR Elmendorf site is the SAR Falls City site, where the estimated average daily SSL was 332 tons per day. Because the Cibolo Selma site often did not flow, the estimated average daily SSL at Cibolo Falls City (Cibolo Creek near Falls City, Tex.) (57 tons per day) likely originates from within the study watershed, except during large stormflow events when there is streamflow at the Cibolo Selma site. During 2011–12, Ecleto Runge had the lowest SSL of 9 tons per day, which is expected because it drains a smaller watershed and streamflow generally only occurs during storm events.

Turbidity and SSC data collected at the SAR Elmendorf site were used in the development of a regression model for computing SSCs from instantaneous turbidity data. The regression could be used to estimate a time series of SSCs from time-series turbidity data collected at the SAR Elmendorf site. The time series of estimated SSCs could subsequently be paired with the time series of streamflow at the site to produce a time series of estimated SSLs. Although the regression could have been applied to the time series of turbidity data collected at the SAR Elmendorf site to produce a time series of estimated daily SSLs, truncation problems within the turbidity data likely would have caused the SSLs to be substantially underestimated. Future suspended-sediment samples and corresponding turbidity values incorporated into these regressions will increase the accuracy of the regressions.

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