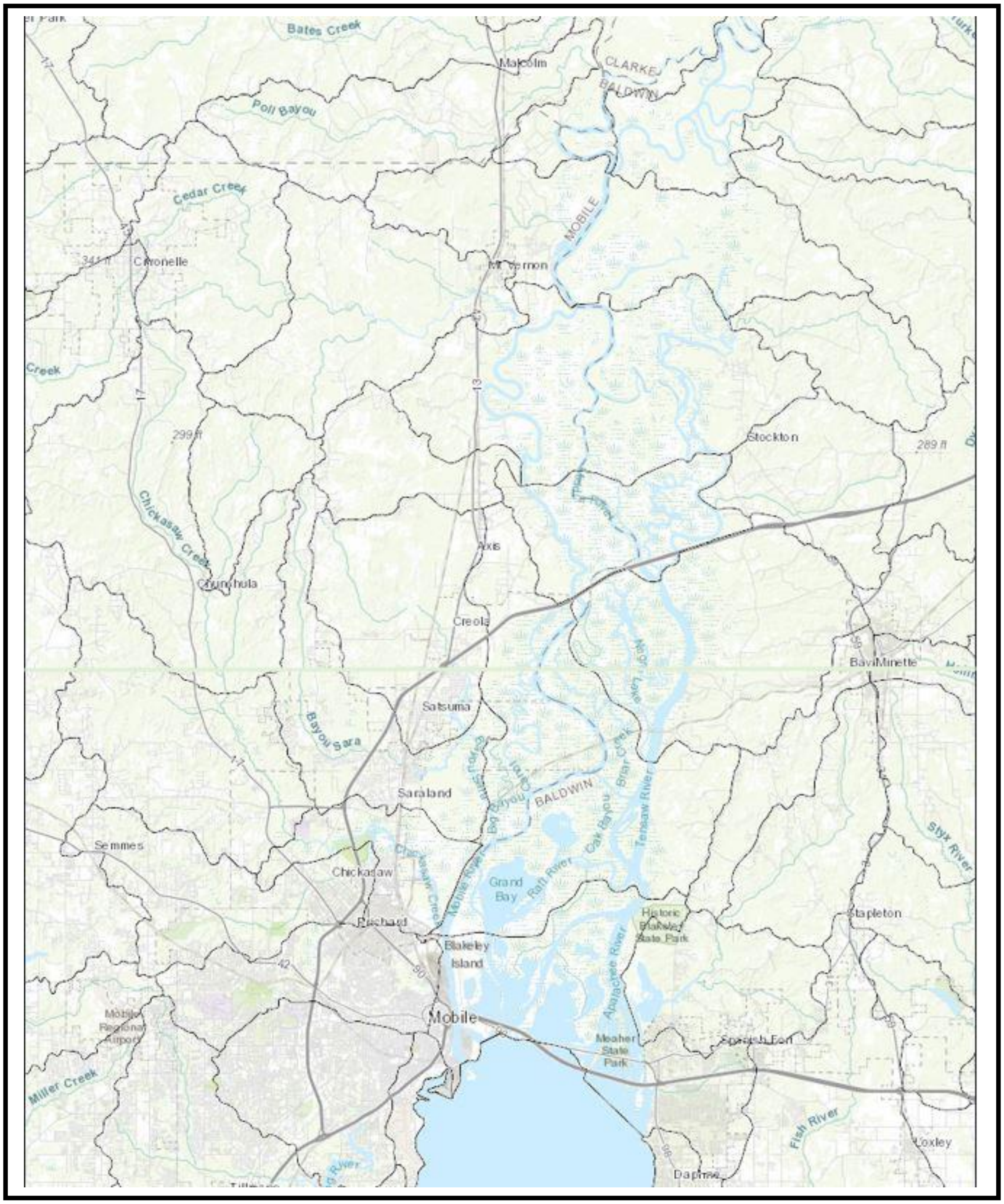
ANALYSIS OF DISCHARGE, SEDIMENT TRANSPORT RATES, WATER QUALITY, AND LAND-USE IMPACTS IN TRIBUTARIES OF THE MOBILE-TENSAW-APALACHEE DELTA WATERSHED, BALDWIN AND MOBILE COUNTIES, ALABAMA



ANALYSIS OF DISCHARGE, SEDIMENT TRANSPORT RATES, WATER QUALITY, AND LAND-USE IMPACTS IN TRIBUTARIES OF THE MOBILE-TENSAW-APALACHEE DELTA WATERSHED, BALDWIN AND MOBILE COUNTIES, ALABAMA

By

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INTRODUCTION

The Mobile-Tensaw-Apalachee Delta (MTA) receives water that drains through about 65 percent of the state of Alabama and parts of Mississippi, Georgia, and Tennessee. Average discharge through the delta is 62,000 cubic feet per second (cfs) (Mobile Bay National Estuary Program (MBNEP, 2019). Regionally, the Black Warrior, Tombigbee, Sipsey, Cahaba, Coosa, Tallapoosa, and Alabama Rivers drain into the delta. Locally, the delta consists of large areas of forested wetlands and several large streams including the Mobile, Tensaw, Middle, Apalachee, and Blakeley Rivers (fig. 1). Five major tributaries flow eastward through Mobile County into the Mobile River along the western boundary of the delta and nine major tributaries flow westward through Baldwin County into the delta along its eastern boundary (fig. 1). The MTA contains critical habitats and a diverse assemblage of species and performs critical environmental functions that support Mobile Bay and the Gulf of Mexico.

The following watershed assessment by Marlon Cook, Poly, Inc., characterizes general water quality, erosion and sediment transport, and nutrient concentrations in tributaries that flow into the delta from Mobile and Baldwin Counties. Land use data and aerial imagery were utilized to identify sources of sediment and other water-quality impacts. Data and conclusions in this report may be used to assist development of watershed management plans and remedial actions and to establish baseline data and regression curves for nutrients and sediment that can be used to evaluate future changes in erosion, sediment transport, and nutrient concentrations. The monitoring project includes 16 monitoring sites on 14 streams from the confluence of the Tombigbee and Alabama Rivers in extreme northern Baldwin and Mobile Counties, southward to the cities of Mobile and Spanish Fort at the head of Mobile Bay (figs. 1, 2). Monitoring is based on precipitation and resulting stream discharge and includes basic field acquired physical and water-quality parameters, including measurements of stream discharge and flow velocity, specific conductance, pH, temperature, turbidity, and dissolved oxygen (DO), as well as sediment transport rates, and nitrogen and total phosphorus concentrations. These data may be used to determine watershed management strategies and to focus resources in areas of greatest need for remedial action.

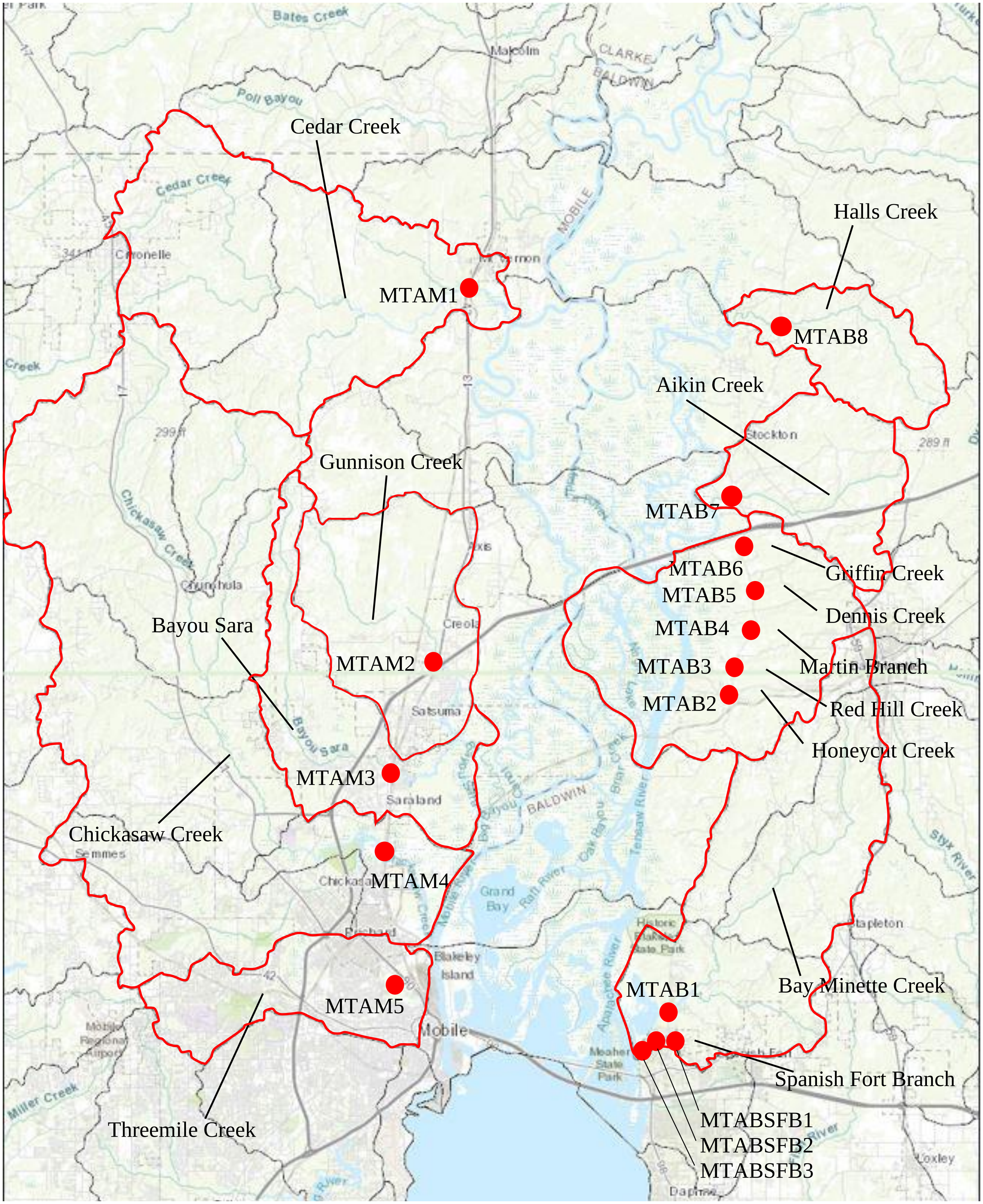

Figure 1.—Twelve-digit HUCs and monitored streams in the MTA Delta watershed in Mobile and Baldwin Counties.

ACKNOWLEDGMENTS

Ms. Roberta Swann, Director and Mr. Jason Kudulis, Monitoring and Science Coordinator, Mobile Bay National Estuary Program provided project coordination and administrative assistance for the project; Mr. Bruce Bradley, President, Polyengineering, Inc., provided administrative assistance and laboratory facilities.

PROJECT AREA

The MTA is the second largest river delta in the United States, containing about 400 square miles (mi^2) of wetland and associated upland habitat in Mobile, Baldwin, Washington, Clarke, and Monroe Counties in southwest Alabama (MBNEP, 2019) (fig. 1). The MTA Delta contains many tributary streams and four major rivers: Tensaw, Mobile, Tombigbee, and Alabama (MBNEP, 2019) (fig. 1). The project area is in the southern part of the watershed, contained in Mobile and Baldwin Counties and covers about 160 mi^2 (fig. 1).

PROJECT MONITORING STRATEGY AND SITE CHARACTERISTICS

The strategy employed for the MTA Delta tributary project was to select single monitoring sites on the major tributaries, as far downstream as possible. An additional goal was to monitor stormwater discharge from Spanish Fort Branch into the Blakeley River in the city of Spanish Fort. This task required upstream/downstream monitoring, utilizing three sites. Each stream reach was monitored over a wide range of measured discharge from base flow to high flow. Water samples were collected for measurement of specific conductance, pH, temperature, turbidity, and DO. Laboratory analyses was performed for total suspended solids (TSS), nitrogen, and total phosphorus. Bed sediment transport rates were measured where possible, and daily and annual loads were estimated for suspended and bed sediment and nitrogen. Sites on the Mobile side of the delta were designated MTAM along with the site number and sites on the Baldwin County side were designated MTAB along with the site number.

Site MTAM1 is on Cedar Creek at US Highway 43, at the Mt. Vernon town limit, about 2.3 miles upstream from the confluence with the Mobile River (latitude (lat) 31.07521, longitude (long) -88.02367). The watershed upstream from site MTAM1 drains 54,784 acres (85.6 mi^2) (USGS, 2019) (fig. 1).

Site MTAM2 is on Gunnison Creek at US Highway 43 near the I-65 intersection at the Creola town limit, about 3.9 miles upstream from the Bayou Sara confluence (lat

30.88307, long -88.04177). The watershed upstream from site MTAM2 covers 19,968 acres (31.2 mi^2) (USGS, 2019) (fig. 1).

Site MTAM3 is on Bayou Sara at US Highway 43 in the town of Saraland, about 9.2 miles upstream from the Mobile River confluence (lat 30.82509, long -88.06967). The watershed upstream from site MTAM3 covers 9,088 acres (14.2 mi^2) (USGS, 2019) (fig. 1).

Site MTAM4 is on Chickasaw Creek at US Highway 43, at the Chickasaw town limit, about 4.2 miles upstream from the Mobile River confluence (lat 30.78327, long -88.07283). The watershed upstream from site MTAM4 covers 117,440 acres (183.5 mi^2) (USGS, 2019) (fig. 1).

Site MTAM5 is on Three Mile Creek at Conception Street, about 1.8 miles upstream from the Mobile River confluence (lat 30.71884, long -88.06578). The watershed upstream from site MTAM5 covers 17,728 acres (27.7 mi^2) (USGS, 2019) (fig. 1).

Site MTAB1 is on Bay Minette Creek at Alabama Highway 225, 0.4 mile upstream from the Bay Minette Basin in the Tensaw Delta (lat 30.69974, long -87.90222). The watershed upstream from site MTAB1 covers 45,440 acres (71 mi^2) (USGS, 2019) (fig. 1).

Site MTAB2 is on Honeycut Creek at Alabama Highway 225, about 2.2 miles upstream from the Tensaw River confluence (lat 30.86276, long -87.86488). The watershed upstream from site MTAB2 covers 3,008 acres (4.7 mi^2) (USGS, 2019) (fig. 1).

Site MTAB3 is on Red Hill Creek at Alabama Highway 225, about 1.9 miles upstream from the Tensaw River confluence (lat 30.88080, long -87.86203). The watershed upstream from site MTAB3 covers 2,880 acres (4.5 mi^2) (USGS, 2019) (fig. 1).

Site MTAB4 is on Martin Branch at Alabama Highway 225, about 1.8 miles upstream from the Red Hill Creek confluence (lat 30.89992, long -87.85095). The watershed upstream from site MTAB4 covers 3,904 acres (6.1 mi^2) (USGS, 2019) (fig. 1).

Site MTAB5 is on Dennis Creek at Alabama Highway 225, about 2.5 miles upstream from the Dennis Lake confluence in the Tensaw Delta (lat 30.91999, long

-87.85356). The watershed upstream from site MTAB5 covers 2,624 acres (4.1 mi^2) (USGS, 2019) (fig. 1).

Site MTAB6 is on Griffin Creek at Alabama Highway 225, about 1.1 miles upstream from the Dennis Lake confluence in the Tensaw Delta (lat 30.94146, long -87.86062). The watershed upstream from site MTAB6 covers 1,920 acres (3.0 mi^2) (USGS, 2019) (fig. 1).

Site MTAB7 is on Aikin Creek at Alabama Highway 59, about 0.8 miles upstream from the Hastie Lake confluence in the Tensaw Delta and 0.8 mile south of the Stockton community (lat 30.98510, long -87.85086). The watershed upstream from site MTAB7 covers 5,120 acres (8.0 mi^2) (USGS, 2019) (fig. 1).

Site MTAB8 is on Halls Creek at Alabama Highway 59, about 3.1 miles upstream from the Tensaw Lake confluence and about 4.1 miles north of the Stockton community (lat 30.05270, long -87.83707). The watershed upstream from site MTAB8 covers 12,544 acres (19.6 mi^2) (USGS, 2019) (fig. 1).

Site MTABSF1 is on Spanish Fort Branch at Alabama Highway 225, 0.8 mile north of US Highway 31 in the town of Spanish Fort. The site is 1.5 miles upstream from the Blakeley River confluence (lat 30.67968, long -87.90225). The watershed upstream from site MTABSF1 covers 166 acres (0.26 mi^2) (USGS, 2019) (fig. 1).

Site MTABSF2 is on Spanish Fort Branch at Spanish Main, 0.4 mile upstream from the Blakeley River confluence (lat 30.67411, long -87.91511). The watershed upstream from site MTABSF2 covers 582 acres (0.91 mi^2) (USGS, 2019) (fig. 1).

Site MTABSF3 is on Spanish Fort Branch near Cannonade Boulevard, 750 ft upstream from the Blakeley River confluence (lat 30.68002, long -87.90265). The watershed upstream from site MTABSF3 covers 621 acres (0.97 mi^2) (USGS, 2019) (fig. 1).

LAND USE

Land use is directly correlated with water quality, hydrologic function, ecosystem health, biodiversity, and the integrity of streams and wetlands. Land-use classification for the project area was calculated from the USDA National Agricultural Statistics Service 2013 Alabama Cropland Data Layer (NASS CDL) raster dataset (fig. 2). The CDL is produced

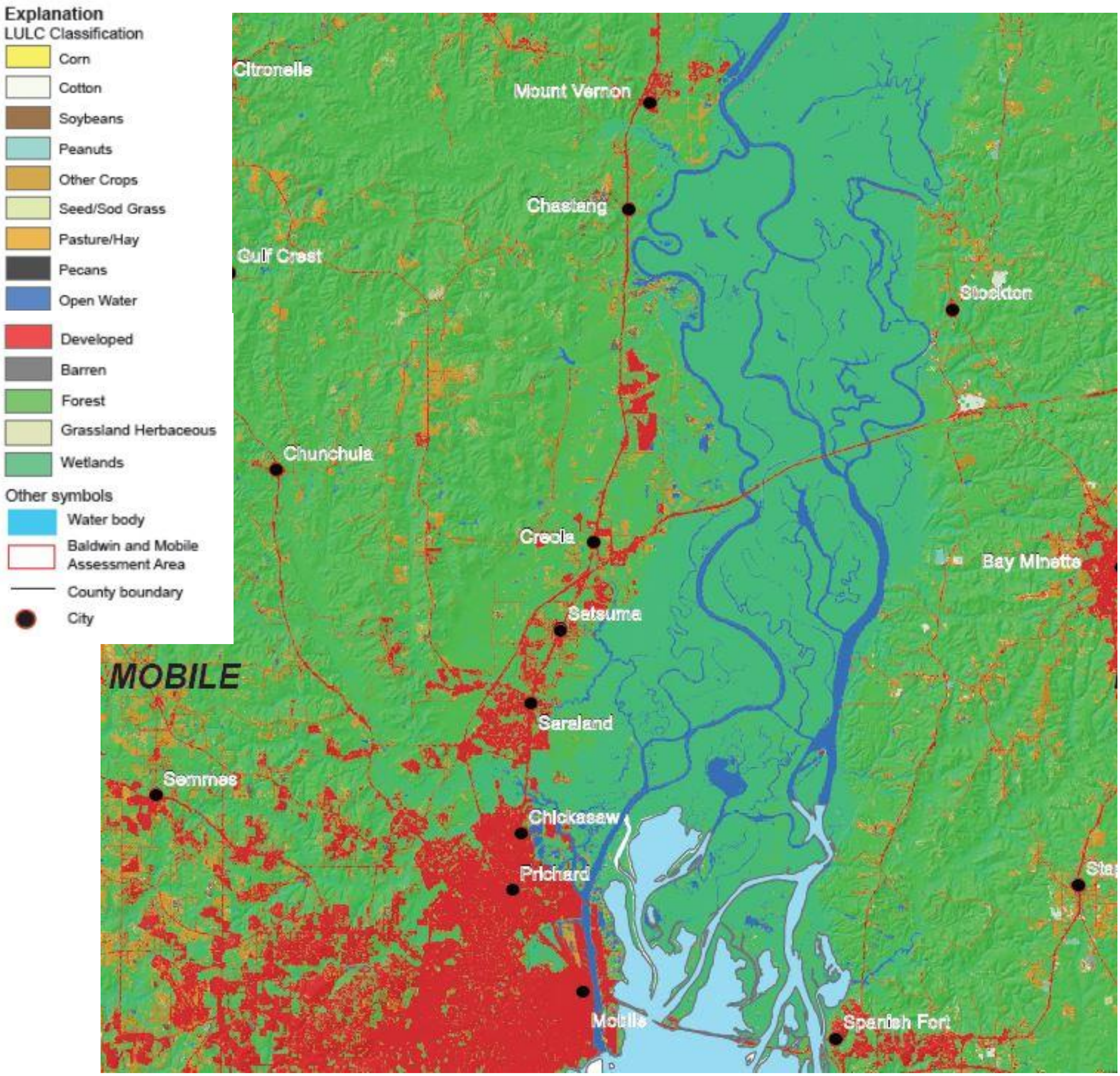

Fig. 2.—Land use in the MTA Delta watershed project area.

using satellite imagery from the Landsat 5 TM sensor, Landsat 7 ETM+ sensor, the Spanish DEIMOS-1 sensor, the British UK-DMC 2 sensor, and the Indian Remote Sensing RESOURCESAT-1 (IRS-P6) Advanced Wide Field Sensor (AWiFS) collected during growing seasons (USDA, 2013). Figure 2 shows land use, subdivided into 15 classified types defined as developed, forested, grassland, wetlands, barren areas, open water, and agriculture, subdivided into eight specific crops (fig. 2).

Although the MTA Delta only has three land-use classifications; forest, wetlands, and open water, upland areas along the margins of the delta containing tributary streams have diverse land uses including forests, wetlands, open water, agriculture, and developed land related to residential and urban uses. The dominant land use category in the monitored part of the watershed is forest, which covers about 70 percent of the watershed (fig. 2). Wetlands are also prominent in stream valleys and are important because they provide water quality improvement and management services such as: flood abatement; storm water management; water purification; shoreline stabilization; groundwater recharge; and streamflow maintenance.

Developed land is dominated by residences and residential developments and commercial development, primarily along roadways and in municipalities, including Creola, Satsuma, Saraland, Chickasaw, Prichard, and the northern part of the city of Mobile on the Mobile County side and Stockton, Bay Minette, and Spanish Fort on the Baldwin County side. Developed land covers about 20 percent of the monitored area on the Mobile County side and about 5 percent on the Baldwin County side (fig. 2).

Agriculture is limited to headwaters and areas of higher elevation, covering about 15 percent of the monitored area. Crops are primarily cotton and pasture and hay (fig. 2). Land uses and their specific impacts are discussed in more detail in the Summary, Conclusions and Probable Sources of Water-Quality Impacts section of this report.

STREAM FLOW CONDITIONS

Stream flow characteristics are determined by a number of factors including climate, topography, hydrogeology, land use, and land cover. Tributary streams to the MTA Delta exhibit a variety of flow characteristics from downstream tidally influenced reaches to flashy upland discharge, due to relatively high topographic relief and urbanization. Stream channels in the upland part of the monitored area, near headwaters, are characterized by relatively high elevation (maximum 300 ft MSL) and decreases to near sea level near the delta. Except for Threemile Creek and Spanish Fort Branch, which are primarily urban, all monitored streams have floodplains dominated by forest and wetlands (fig. 2). Stream gradients, upstream from monitoring sites, varied widely due to variable topography and ranged from 11 to 32 ft per mile (ft/mi) on the Mobile County side of the delta and 5 to 135 ft/mi on the Baldwin County side of the delta (table 1).

A wide range of discharge events are required to adequately evaluate hydrologic conditions and water quality in monitored streams. Table 1 shows that sampling occurred in MTA Delta tributaries during discharge conditions from base flow to flood. For example, minimum discharge measured for Aikin Creek (site MTAB7) was 1.4 cfs (May 16, 2018) and the maximum was 50 cfs, on February 11, 2018. Minimum discharge measured for Spanish Fort Branch (site MTABSFB3) was 0.9 cfs (March 3, 2018) and the maximum was 280 cfs, on April 14, 2018. Average daily discharge for each monitored stream is required to adequately estimate constituent loading. Discharge data collected at the USGS stream gaging sites 02378500, Fish River near Silver Hill, Alabama and 02471001, Chickasaw Creek near Kushla, Alabama were used as a basis for average daily discharge estimation for each monitored stream.

Table 1.—Stream-flow characteristics for monitored sites in the MTA Delta watershed.

Monitored site	Montitored watershed drainage area (mi^2)	Average measured/ estimated discharge (cfs)	Maximum measured/ estimated discharge (cfs)	Minimum measured/ estimated discharge (cfs)	Average discharge per unit area (cfs/mi)	Stream gradient (ft/mi)
MTAM1	85.6	619	1,674	118	7.2	17
MTAM2	31.2	250	617	44	8.0	32
MTAM3	14.2	130	289	55	9.2	21
MTAM4	183.5	1,487	3,758	706	8.1	11
MTAM5	27.7	243	587	40	8.8	17
MTAB1	71.0	N/A	N/A	N/A	N/A	5
MTAB2	4.7	72	179	9.1	15.3	18
MTAB3	4.5	56	225	12.6	12.4	18
MTAB4	6.1	92	216	13.4	15.1	18
MTAB5	4.1	51	142	9.0	12.4	20
MTAB6	3.0	74	208	5.8	24.6	22
MTAB7	8.0	48	237	1.4	6.0	11
MTAB8	19.6	320	1,326	31.9	16.3	32
MTABSFB1	0.26	6	27	0.3	22.3	25
MTABSFB2	0.91	23	168	0.4	25.3	135
MTABSFB3	0.97	48	382	0.9	49.5	93

Stream discharge characteristics provide information related to water quality, erosion and sediment transport, and groundwater contributions. Monitored stream gradients and average discharge per unit area in table 1 shows that tributaries to the MTA Delta on the Baldwin County side have steeper gradients, on average, due to greater topographic relief along the eastern shore, except for Bay Minette Creek (MTAB1) and Aikin Creek (MTAB7), which have relatively long reaches on the floodplain of the delta upstream from the monitoring sites. This also impacts precipitation infiltration and runoff, expressed in significantly higher average discharge per unit area (table 1). This is particularly true for Spanish Fort Branch, where stream gradients ranged from 25 ft/mi for the upstream segment (MTABSFB1), 135 ft/mi for the mid-stream segment, and 93 ft/mi for the downstream segment.

SPECIFIC CONDUCTANCE

Surface water in each project watershed is characterized by a unique specific conductance (SC) profile based on physical and chemical properties. The variability of SC is influenced by differences in stream temperature, discharge, total dissolved solids, local geology, soil conditions, and ionic influxes from nonpoint sources of pollution or from seawater in reaches of streams with tidal influence. Streams without significant contaminant sources exhibit increased SC values with decreasing discharge due to increasing volumes of relatively high SC groundwater inflow and decreased SC with increasing discharge due to increasing volumes of relatively low SC runoff. The opposite SC character is exhibited for streams with significant contaminant sources where relatively high conductance runoff causes increasing SC with increasing discharge. Fluctuations of SC in streams with tidal influence correspond to tidal cycles with relatively high SC (saltwater) at high tide and relatively low SC (fresh water) at low tide. However, this relationship may be altered, depending on precipitation and runoff at the time of measurement. Table 2 shows SC in monitored streams in the MTA Delta watershed. Sites MTAM4 (Chickasaw Creek), MTAM5 (Three Mile Creek), and MTAB1 (Bay Minette Creek) are influenced by tidal influx (table 2). Bay Minette Creek was so impacted by saline water that data collected at the site was not included in this report. Sites MTAM4 and MTAM5 had maximum SC values of 7,190 and 1,350 micro siemens/centimeter (μS/cm), respectively (table 2). Generally, SC was relatively low due to no significant contaminant sources in the watershed and most SC measurements were made immediately after precipitation events (table 2). The highest non-tidally influenced values were measured at sites MTAM4 (136 µS/cm) and MTABSFB1 (135 µS/cm) (table 2). ADEM established reference sites on streams throughout Alabama to determine reference water-quality standards for selected level IV ecoregions (ADEM, 2010). No reference standards were found for the MTA Delta. Therefore, the ADEM reference standards for ecoregion 65f, which is adjacent to the MTA Delta watershed, were used. The reference concentration for SC is 20.4 µS/cm. Average SC for all sites except MTAB5 (Dennis Creek) and MTAB8 (Halls Creek) exceeded the ADEM standard (table 2).

Table 2.—Measured specific conductance values for MTA Delta tributary monitoring sites.

Monitored site	No tide impact Average SC (µS/cm)	No tide impact Maximum SC (µS/cm)	No tide impact Minimum SC (µS/cm)	Tide impact Average SC (µS/cm)	Tide impact Maximum SC (µS/cm)	Tide impact Minimum SC (µS/cm)
MTAM1	43	77	28	N/A	N/A	N/A
MTAM2	26	30	20	N/A	N/A	N/A
MTAM3	33	41	21	N/A	N/A	N/A
MTAM4[1]	92	136	64	3,707	7,190	1,830
MTAM5[1]	70	70	70	467	1,350	198
MTAB2	35	40	24	N/A	N/A	N/A
MTAB3	22	34	17	N/A	N/A	N/A
MTAB4	26	30	20	N/A	N/A	N/A
MTAB5	17	18	16	N/A	N/A	N/A
MTAB6	23	26	19	N/A	N/A	N/A
MTAB7	33	52	17	N/A	N/A	N/A
MTAB8	19	27	15	N/A	N/A	N/A
MTABSFB1	82	135	52	N/A	N/A	N/A
MTABSFB2	44	57	24	N/A	N/A	N/A
MTABSFB3	52	63	35	N/A	N/A	N/A

[1] Tidally impacted stream at monitoring site.
N/A No tidal impact on stream at monitoring site.

TURBIDITY

Turbidity in water is caused by suspended and colloidal matter, such as clay, silt, finely divided organic and inorganic matter, and plankton and other microscopic organisms (Eaton, 1995). Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level through the stream (Eaton, 1995). Turbidity values measured in nephlametric turbidity units (NTU) from water samples may be utilized to formulate a rough estimate of long-term trends of total suspended solids (TSS) and therefore may be used to observe trends in suspended sediment transport in streams.

Analyses of turbidity and stream discharge provide insights into hydrologic, land-use, and general water-quality characteristics of a watershed. Figure 3 illustrates that sites MTAB7 (Aikin Creek), MTABSFB3 (Spanish Fort Branch downstream site), and MTAB5 (Dennis Creek) had the highest average turbidity during the monitoring period (87, 74, and 62 NTUs, respectively).

Commonly, excessive turbidity is closely tied to land uses that cause land disturbances that lead to erosion or to land uses that cause excessive runoff. Evaluation of land-use data indicates that watersheds with dominant urban development and/or agriculture are more likely to have streams with significant turbidity concentrations. However, except for Spanish Fort Branch and Dennis Creeks, these turbidity contributors have little impact in monitored MTA Delta tributaries. The watershed upstream from site MTAB7 (Aikin Creek) is impacted by large clear-cut forest areas, some replanted in pines, and dirt roads constructed for forest harvesting access. Spanish Fort Branch has a combination of substantial urban development and high stream gradient that facilitates channel scour and bank erosion. Dennis Creek has about 180 acres of row crop and a large area of recently cut forest upstream from the monitoring site that are probably the primary sources of turbidity. The ADEM reference concentration for turbidity is 9.7 NTU for ecoregion 65f. Average turbidity for all MTA Delta tributary monitored sites equaled or exceeded the ADEM standard (fig. 3, table 3).

SEDIMENTATION

Sedimentation is a process by which eroded particles of rock are transported primarily by moving water from areas of relatively high elevation to areas of relatively low elevation, where the particles are deposited. Upland sediment transport is primarily accomplished by overland flow and rill and gully development. Lowland or flood plain transport occurs in streams of varying order, where upland sediment joins sediment eroded from flood plains, stream banks, and stream beds. Erosion rates are accelerated by human activity related to agriculture, construction, timber harvesting, unimproved roadways, or any activity where soils or geologic units are exposed or disturbed.

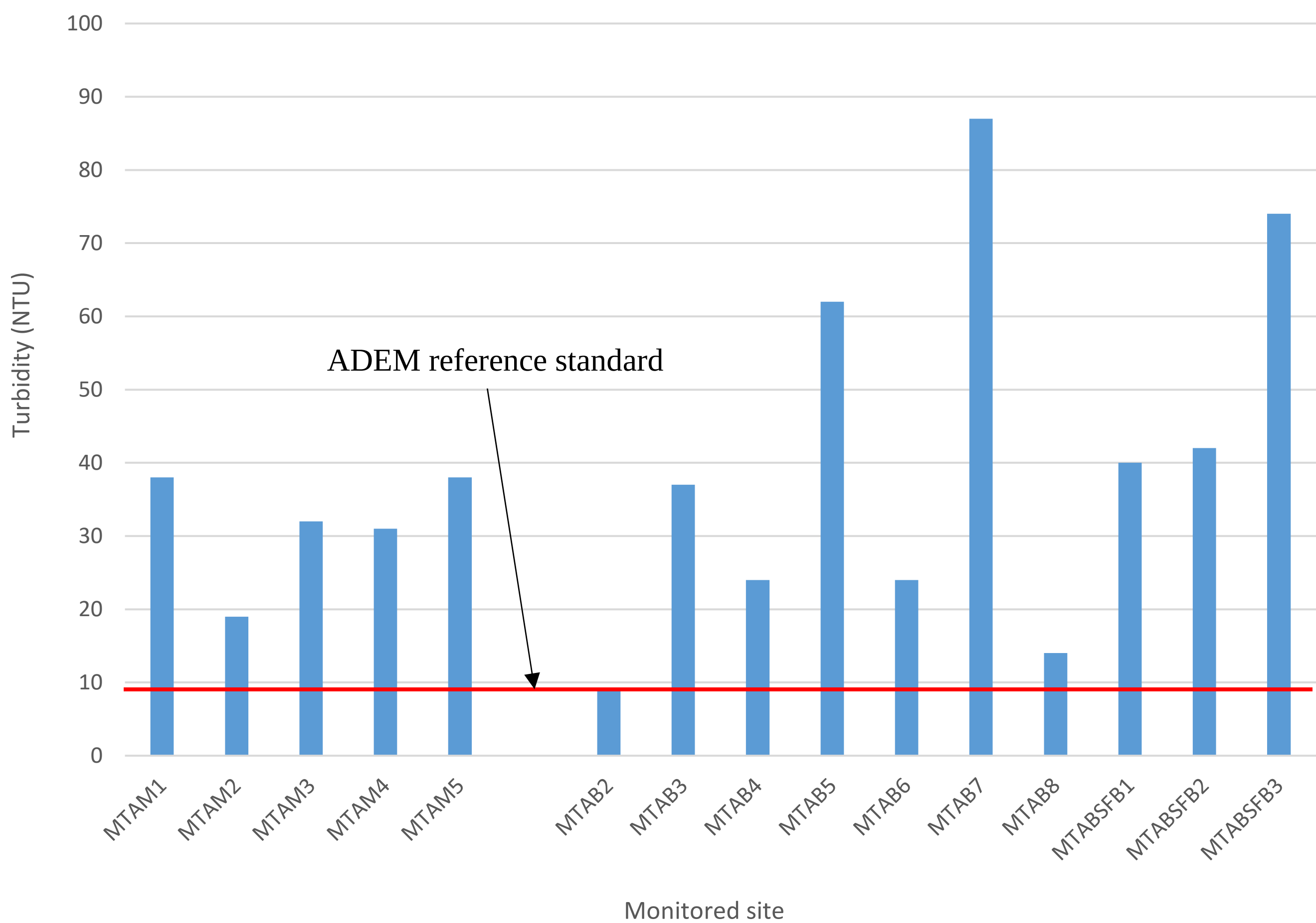

Figure 3.—Average turbidity for MTA Delta tributary monitoring sites.

Excessive sedimentation is detrimental to water quality, destroys biological habitat, reduces storage volume of water impoundments, impedes the usability of aquatic recreational areas, and causes damage to structures.

Precipitation, stream gradient, geology, soils, and land use are all important factors that influence sediment transport characteristics of streams. Sediment transport conditions in MTA Delta monitored tributary watersheds were evaluated and quantified to evaluate factors impacting erosion and sediment transport at a localized scale. In addition to commonly observed factors above, wetlands, vegetation, and tidal effects also play prominent roles in sediment transport and overall water quality in the MTA Delta watershed. Estimates of sediment loads for this assessment are based on measured sediment and stream discharge. Therefore, a stream flow dataset composed of values ranging from base flow to flood is desirable. Observed stream flow conditions are shown in table 1. High flow events not measured during the monitoring period were estimated using discharge data from USGS gaging sites on Chickasaw Creek and Fish River.

Sediment loads in streams are composed of relatively small particles suspended in the water column (suspended solids) and larger particles that move on or periodically near the streambed (bed load). Since this assessment focused on downstream monitoring sites, all five streams on the Mobile County side of the delta had deep water, so only suspended sediment loads were estimated. On the Baldwin County side, Bay Minette Creek was the only deep-water site. Sites MTAB3 (Red Hill Creek), MTAB7 (Aikin Creek), and MTABSFB3 (Spanish Fort Branch) had measurable bed sediment. Due to stream bed and flow velocity characteristics, total sediment loads at all seven other sites were assumed to be suspended.

SEDIMENT LOADS TRANSPORTED BY PROJECT STREAMS

The rate of sediment transport is a complex process controlled by a number of factors primarily related to land use, precipitation runoff, erosion, stream discharge and flow velocity, stream base level, and physical properties of the transported sediment. Deterrents to excessive erosion and sediment transport include wetlands, forests, vegetative cover and field buffers for croplands, limitations on impervious surfaces, and a number of constructed features to promote infiltration of precipitation and to store and slow runoff. The MTA Delta watershed is characterized by a relatively rural setting, extensive forest cover, floodplains dominated by abundant wetlands and anastomosing stream channels. Anthropogenic impacts to stream flow, sediment transport, and water quality include erosion from forest harvesting, agricultural fields, and increased runoff and land disturbance related to residential development and commercial areas of Prichard, north Mobile, Bay Minette, and Spanish Fort.

SUSPENDED SEDIMENT

The basic concept of constituent loads in a river or stream is simple. However, the mathematics of determining a constituent load may be quite complex. The constituent load is the mass or weight of a constituent that passes a cross-section of a stream in a specific amount of time. Loads are expressed in mass units (tons or kilograms) and are measured for time intervals that are relative to the type of pollutant and the watershed area for which the loads are calculated. Loads are calculated from concentrations of constituents obtained from analyses of water samples and stream discharge, which is the volume of water that passes a cross-section of the river in a specific amount of time.

Suspended sediment is defined as that portion of a water sample that is separated from the water by filtering. This solid material may be composed of organic and inorganic particles that include algae, industrial and municipal wastes, urban and agricultural runoff, and eroded material from geologic formations. These materials are transported to stream channels by overland flow related to storm-water runoff and cause varying degrees of turbidity. Figure 5 is an x-y plot of average turbidity and average total suspended solids (TSS) for each monitored MTA Delta tributary site. It shows an excellent correlation between turbidity and TSS, except for site MTAB8 (Halls Creek), which shows a higher TSS to turbidity ratio (fig. 4). This stream, at the monitoring site

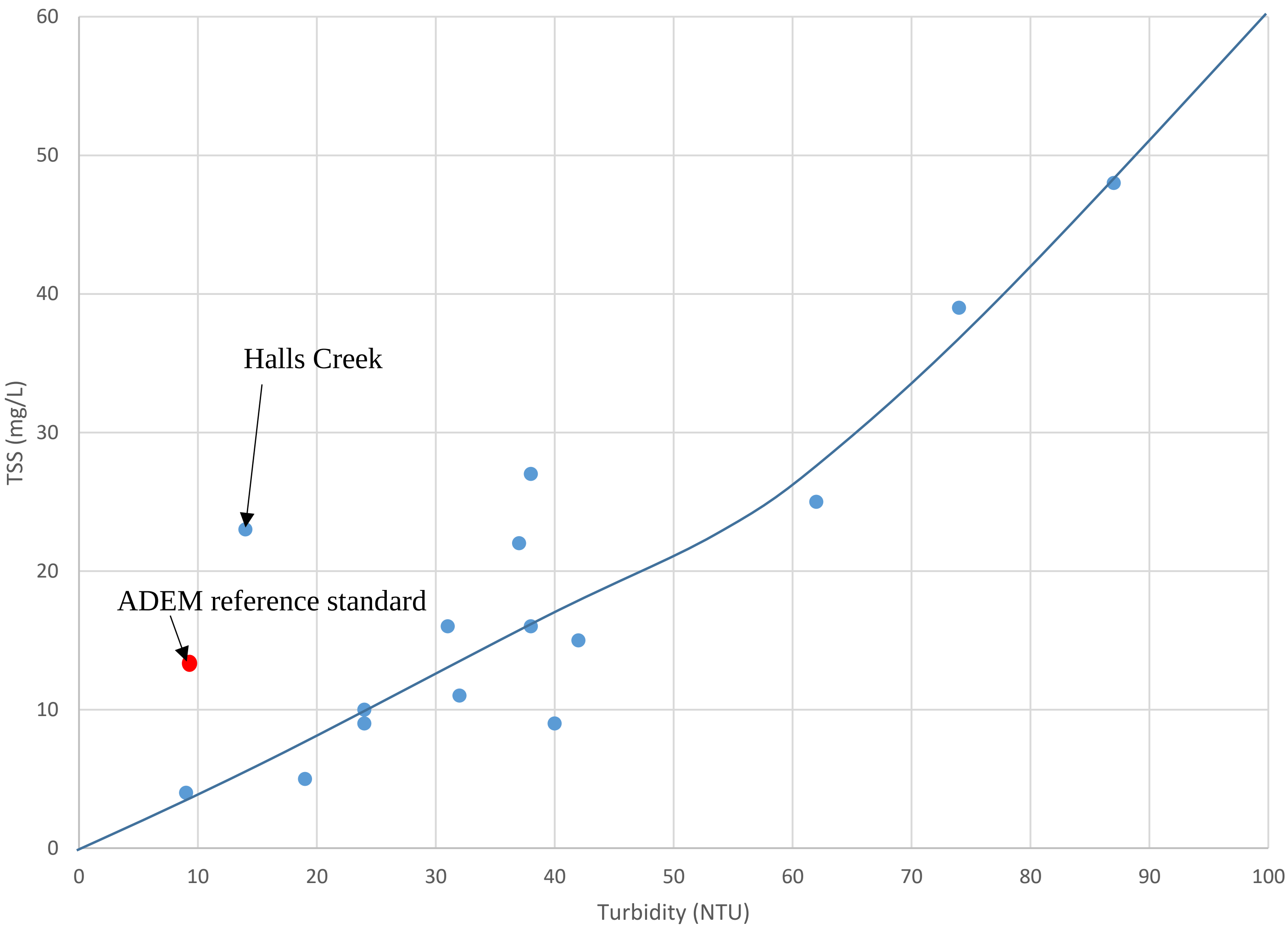

Figure 4.—Average turbidity and TSS for MTA Delta tributary monitoring sites.

has high velocity flow and indicates coarser-grained suspended sediment that has more measured mass for similar turbidity.

Annual suspended sediment loads were estimated for MTA Delta tributaries, using the computer regression model Regr_Cntr.xls (*Regression with Centering*) (Richards, 1999). The program is an Excel adaptation of the U.S. Geological Survey (USGS) seven-parameter regression model for load estimation in perennial streams (Cohn and others, 1992). The regression with centering program requires total suspended solids (TSS) concentrations and average daily stream discharge to estimate annual loads. Although average daily discharge for project streams was not available from direct measurement for the monitored sites, it was calculated by establishing a ratio between periodic measured discharge in project streams and discharge values for the same times obtained from USGS stream gaging sites (02378500, Fish River near Silver Hill, Alabama and 02471001, Chickasaw Creek near Kushla).

Concentrations of TSS in mg/L were determined by laboratory analysis of periodic water grab samples. These results were used to estimate the mass of suspended sediment for the period of stream flow (October 1, 2017 to September 30, 2018). Chickasaw Creek (MTAM4), Cedar Creek (MTAM1), Aikin Creek (MTAB7), Halls Creek (MTAB8), and Red Hill Creek (MTAB3) had the largest suspended sediment loads with 5,730, 3,652, 1,014, 939, and 759 tons per year (t/yr), respectively (fig. 5, table 3). Although Chickasaw and Cedar Creek did not have the largest TSS concentrations, they had by far the largest discharge, causing them to have the largest estimated suspended sediment loads (table 1, fig. 5). Aikin, Halls, and Red Hill Creeks had relatively large estimated suspended sediment loads and relatively small discharge, indicating excessive erosion in those watersheds.

Normalizing suspended loads to unit watershed area permits comparison of monitored watersheds and negates the influence of drainage area size and discharge on sediment loads. Normalized loads for tributary monitored sites in the MTA Delta watershed are portrayed on figure 6, which shows that the largest normalized suspended sediment loads are at sites MTAB7 (Aikin Creek), MTAB3 (Red Hill Creek), and MTABSFB3 (Spanish Fort Branch), with 127, 119, and 119 t/mi^2/yr, respectively (fig. 6).

Table 3.—Measured discharge, turbidity, TSS, and estimated suspended sediment loads in monitored MTA Delta tributary streams.

Monitored site	Average daily discharge (cfs)	Average turbidity (NTU)	Maximum turbidity (NTU)	Average TSS (mg/L)	ADEM Level IV Ecoregion 65f reference standard for TSS (mg/L)	Maximum TSS (mg/L)	Estimated suspended sediment load (t/yr)	Estimated normalized suspended sediment load (t/mi^2/yr)
MTAM1	178	38	85	27	13.2	71	3,652	43
MTAM2	51	19	30	5	13.2	9	160	5
MTAM3	25	32	65	11	13.2	22	160	11
MTAM4	381	31	76	16	13.2	33	5,730	31
MTAM5	54	38	56	16	13.2	27	637	23
MTAB2	13	9	18	5	13.2	20	67	14
MTAB3	25	37	71	22	13.2	50	759	119
MTAB4	16	24	55	10	13.2	35	124	20
MTAB5	11	62	156	25	13.2	71	288	70
MTAB6	9	24	70	9	13.2	23	54	18
MTAB7	15	87	255	48	13.2	142	1,014	127
MTAB8	53	14	24	23	13.2	90	939	48
MTABSFB1	1	40	75	9	13.2	23	12	47
MTABSFB2	3	42	140	15	13.2	71	45	50
MTABSFB3	4	74	235	39	13.2	152	116	119

The ADEM reference concentration for TSS for ecoregion 65f, which includes the Fish River watershed is 13.2 mg/L. Comparisons of average TSS concentrations for MTA Delta tributary monitor sites with the ADEM reference standard is shown on table 3.

Land use is a major factor in the magnitude of erosion and stream sediment loading. Figure 8 shows normalized suspended sediment loads and urban development as a percentage of total monitored watershed area. Only two of 15 monitored watersheds (Bayou Sara and Spanish Fort Branch) had significant urban development (greater than 30 percent). Bayou Sara urban development showed no impact on suspended sediment loads. The Bayou Sara reach, one mile upstream from the monitoring site, was deep water, which probably caused sediment to settle out upstream, so it was not detected at the monitoring site. Spanish Fort Branch has a relatively large suspended sediment load, showing the impact of urban development on erosion and sediment transport. (fig. 7).

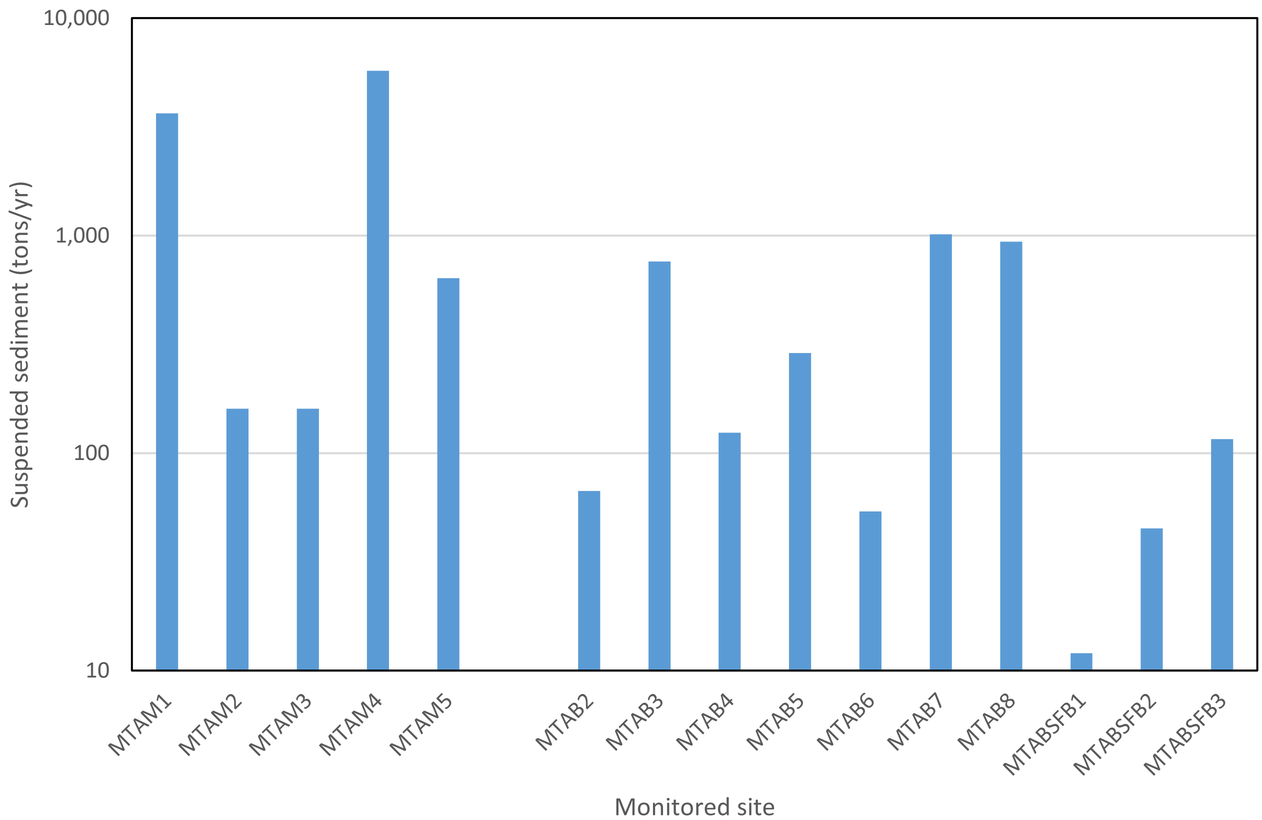

Figure 5.—Estimated suspended sediment loads for MTA Delta tributary monitoring sites.

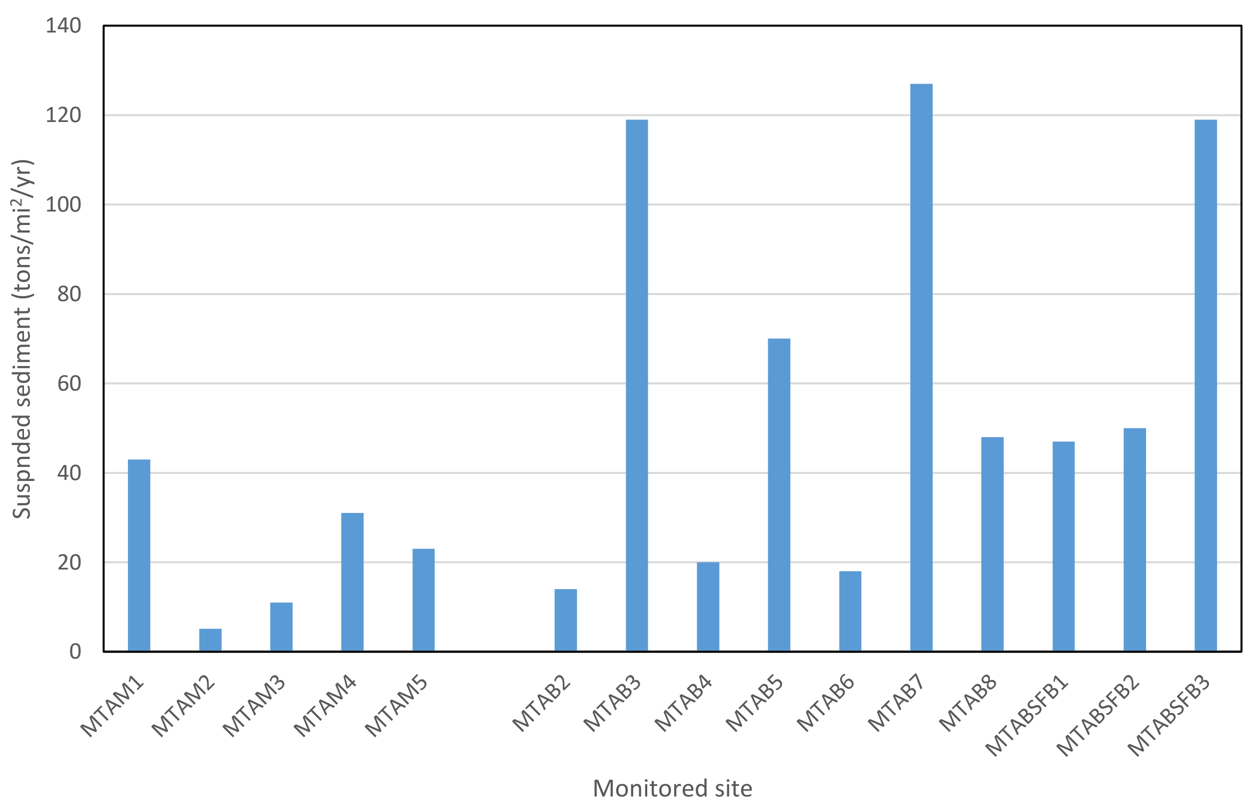

Figure 6.—Estimated normalized suspended sediment loads for MTA Delta tributary monitoring sites.

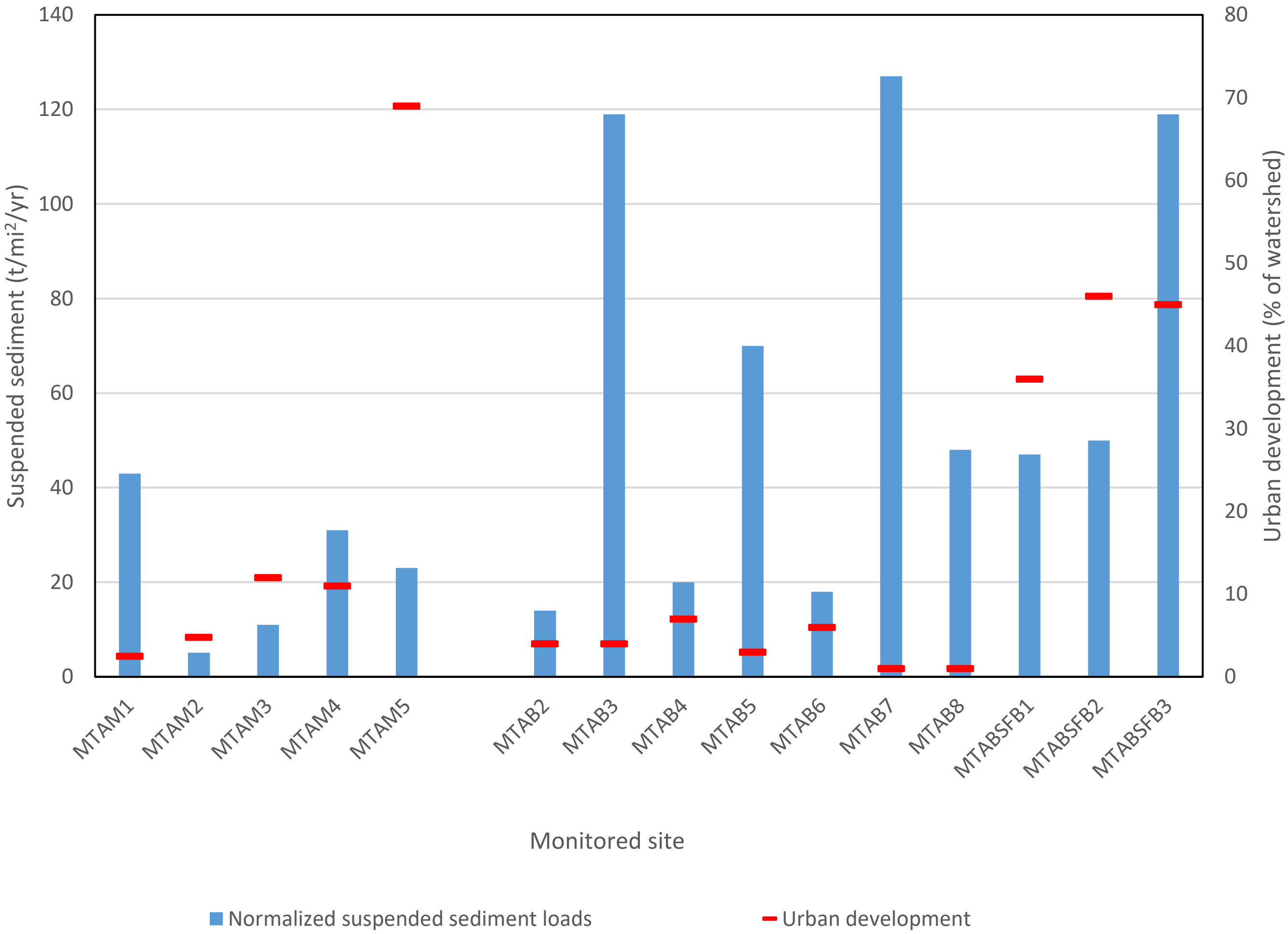

Figure 7.—Estimated normalized suspended sediment loads and percentage of urban development for MTA Delta tributary monitored watersheds.

BED SEDIMENT

Transport of streambed material is controlled by several factors including stream discharge and flow velocity, erosion and sediment supply, stream base level, and physical properties of the streambed material. Most streambeds are in a state of constant flux in order to maintain a stable base level elevation. The energy of flowing water in a stream is constantly changing to supply the required power for erosion or deposition of bed load to maintain equilibrium with the local water table and regional or global sea level. Stream base level may be affected by regional or global events, including fluctuations of sea level or tectonic movement. Local factors affecting base level include fluctuations in the water table elevation, changes in the supply of sediment to the stream caused by changing precipitation rates, and/or land use practices that promote excessive erosion in the floodplain or upland areas of the watershed.

Bed sediment loads are composed of particles that are too large or dense to be carried in suspension by stream flow. These particles roll, tumble, or are periodically suspended as they move downstream. Traditionally, bed load sediment has been difficult to quantify due to deficiencies in monitoring methodology or inaccuracies of estimating volumes of sediment being transported along the streambed. This is particularly true in streams that flow at high velocity or in streams with excessive sediment loads.

In 1998, Marlon Cook developed a portable bed load sedimentation rate-monitoring device in response to the need for accurate bed sediment transport rates in shallow streams with sand or gravel beds (Cook and Puckett, 1998). The device was utilized to measure bed sediment transport rates periodically over a range of discharge events at four MTA Delta tributary monitoring sites (MTAB3 (Red Hill Creek), MTAB7 (Aikin Creek), MTAB8 (Halls Creek), and MTABSFB3 (Spanish Fort Branch)). All other sites had deep channels with slow moving water, anastomosing reaches with no sand bed, or hard surface beds where all sediment was assumed to be suspended.

As with suspended sediment, it is possible to use discharge/sediment relationships to develop regression models to determine mean daily bed load volumes and annual bed sediment loads. Figure 8 shows annual bed sediment loads and average daily discharge for sites with measurable bed sediment. Figure 9 shows estimated annual bed sediment loads normalized with respect to watershed drainage area and average daily discharge. Figures 8 and 9 show poor correlations between bed sediment loads and discharge, indicating that most bed sediment is moved by infrequent, large discharge events. Table 4 gives average measured stream discharge, annual bed sediment loads, and normalized annual bed sediment loads for monitoring sites in streams with measurable bed sediment in the project area. Site MTAB7 (Aikin Creek) had the largest bed sediment loads with 2,876 tons per year (t/yr). After normalization of bed sediment loads relative to drainage area, site MTABSFB3 (Spanish Fort Branch) had the largest load with 802 tons/mi^2/yr.

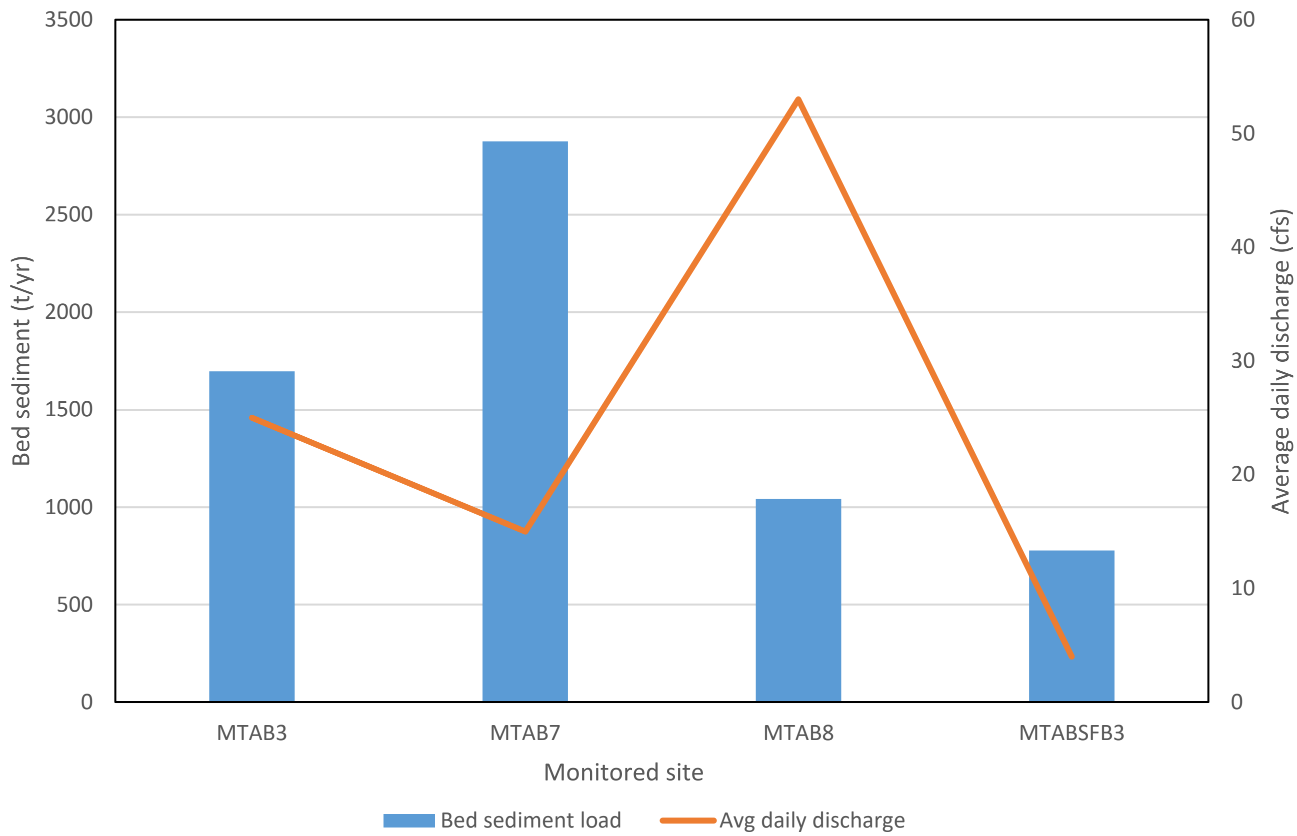

Figure 8.—Annual bed sediment loads and average annual daily discharge for MTA Delta monitoring sites during the project period (October 2017-September 2018).

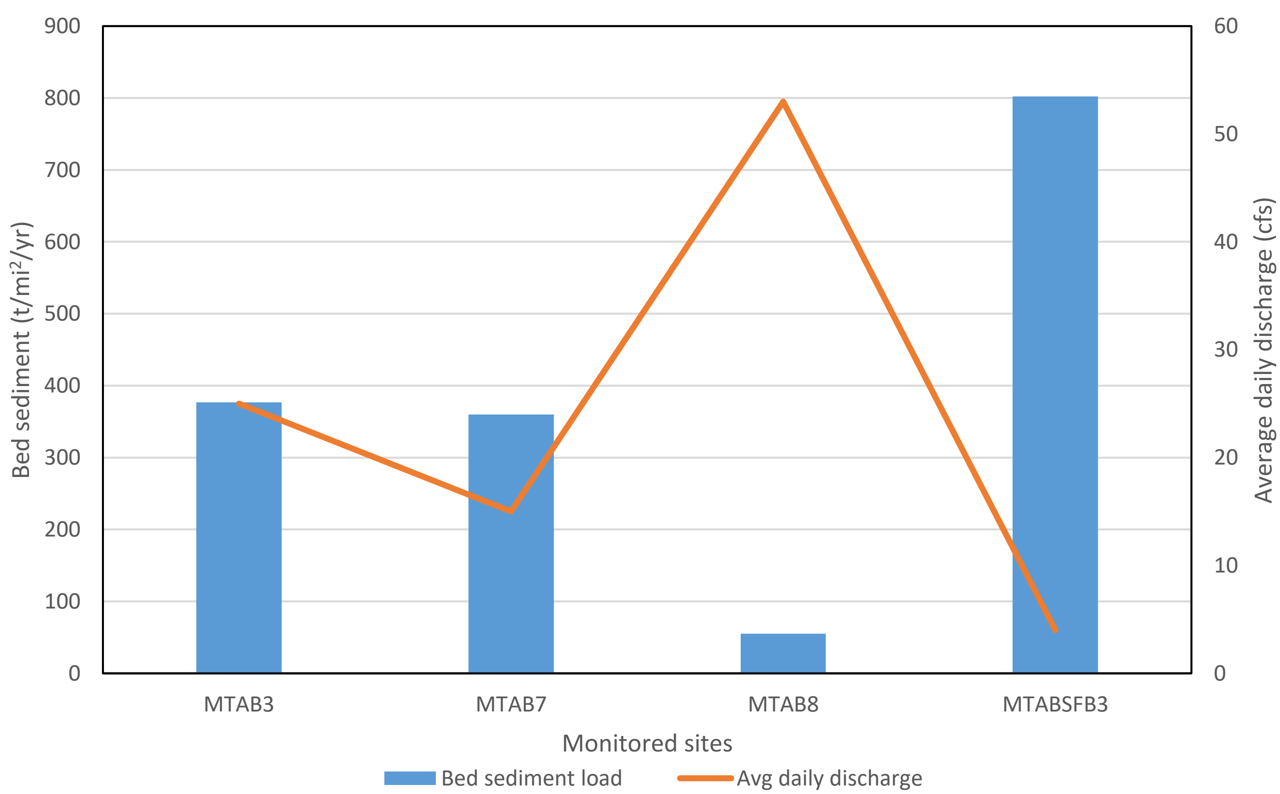

Figure 9.—Annual normalized bed sediment loads and average annual daily discharge for MTA Delta monitoring sites during the project period (October 2017-September 2018).

Table 4—Average measured discharge and estimated bed sediment loads for monitoring sites on streams with measurable bed sediment in the project area.

Monitored site	Average daily discharge (cfs)	Estimated annual bed sediment loads (tons/yr)	Estimated Normalized annual bed sediment loads (tons/mi ^{2}/yr)
MTAB3	25	1,696	377
MTAB7	15	2,876	360
MTAB8	53	1,042	55
MTABSFB3	4	778	802

TOTAL SEDIMENT LOADS

The total sediment loads in a stream is composed of suspended and bed sediment. Six monitored sites had both suspended and bed sediment loads. On average, bed sediment makes up 71% of the total sediment loads for streams with measurable suspended and bed sediment. Table 5 and figures 10 and 11 show total sediment loads for monitored sites in MTA Delta tributaries. As expected, due to relatively large drainage area, discharge, and cumulative sediment, Chickasaw Creek site MTAM4 and Cedar Creek site MTAM1 have large sediment loads (table 5, fig. 11). However, sites in much smaller watersheds on Red Hill, Aikin, and Halls Creeks and Spanish Fort Branch in Baldwin County have large loads (table 5, fig. 10). When total sediment loads are normalized relative to drainage area, the Baldwin County streams have the largest loads (table 5, fig. 11).

Without human impact, watershed erosion rates, called the geologic erosion rate, would be 64 t/mi^2/yr (Maidment, 1993). Normalized sediment loads show that five of 15 monitored watersheds were from 1.1 to 14.4 times greater than the geologic erosion rate (fig. 12).

Comparisons of sediment loads from other watersheds, estimated using similar methodologies, are helpful in determining the severity of erosion problems in a watershed of interest. Figure 13 shows comparisons of estimates of normalized total sediment loads from MTA Delta tributary sites MTAB3 (Red Hill Creek), MTAB7 (Aikin Creek), and MTABSFB3 (Spanish Fort Branch) with sites in eight previously monitored watersheds in Mobile and Baldwin Counties, including Fowl River site FR2 (Half-Mile Road) (Cook and others, 2012); Dog River tributary, Spencer Branch site DR2 (Cottage Hill Road city

Table 5—Watershed area, average measured discharge, and estimated total sediment loads for monitoring sites in the project area.

Monitored site	Monitored watershed area (mi^2)	Average discharge (cfs)	Estimated annual total sediment loads (tons/yr)	Estimated normalized annual total sediment loads ($tons/mi^2/yr$)
MTAM1	85.6	178	3,652	43
MTAM2	31.2	51	160	5
MTAM3	14.2	25	160	11
MTAM4	183.5	381	5,730	31
MTAM5	27.7	54	637	23
MTAB2	4.7	13	67	14
MTAB3	4.5	25	2,455	496
MTAB4	6.1	16	124	20
MTAB5	4.1	11	288	70
MTAB6	3.0	9	54	18
MTAB7	8.0	15	3,890	487
MTAB8	19.6	53	1,981	103
MTABSFB1	0.26	1	12	47
MTABSFB2	0.91	3	45	50
MTABSFB3	0.97	4	894	921

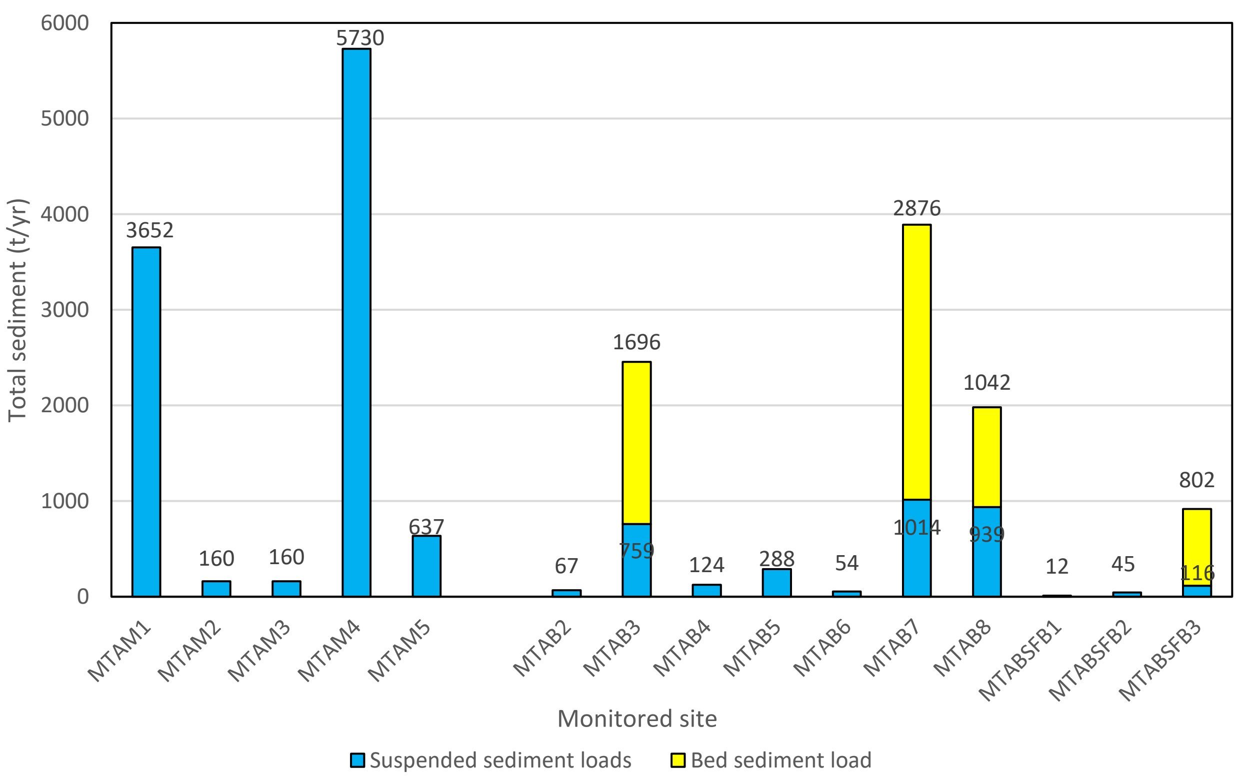

Figure 10.—Total sediment loads for monitored MTA Delta

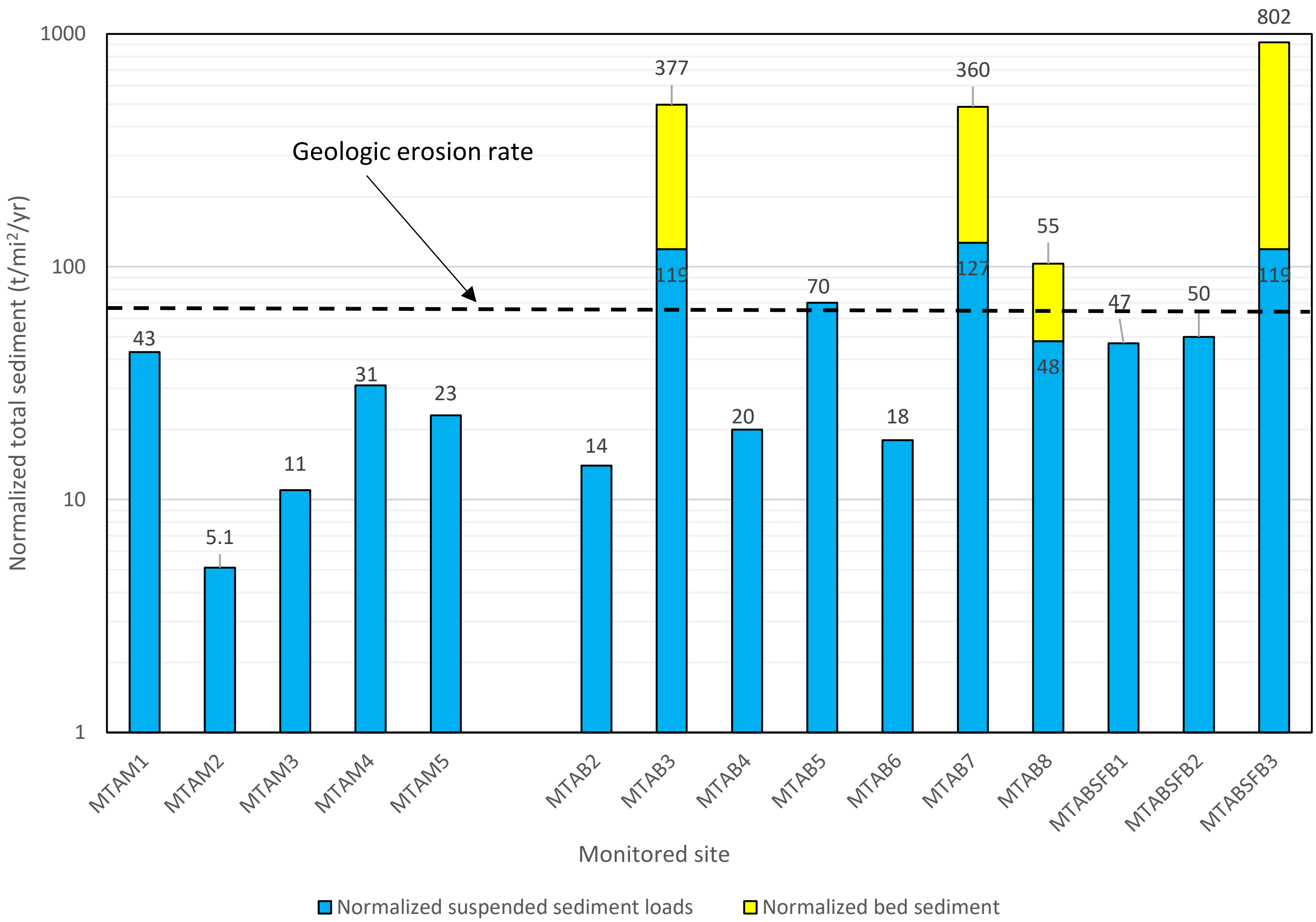

Figure 11.—Total normalized sediment loads for monitored MTA Delta tributaries.

of Mobile) (Cook and Moss, 2012); Magnolia River site FR4 (U.S. Highway 98) (Cook and others, 2009); D'Olive Creek site DC3 (U.S. Highway 90 Daphne) (Cook and others, 2008); Pensacola Branch site FR8 tributary to Fish River (Cook, 2016); D'Olive Creek tributary Joes Branch site JB9 (Town Center Blvd. Spanish Fort) (Cook, 2019); Bon Secour River site BSR3 (County Road 12 Foley) (Cook and others, 2014); and Wolf Creek site WC10 (Doc McDuffie Road Foley) (Cook, 2017) (fig. 12).

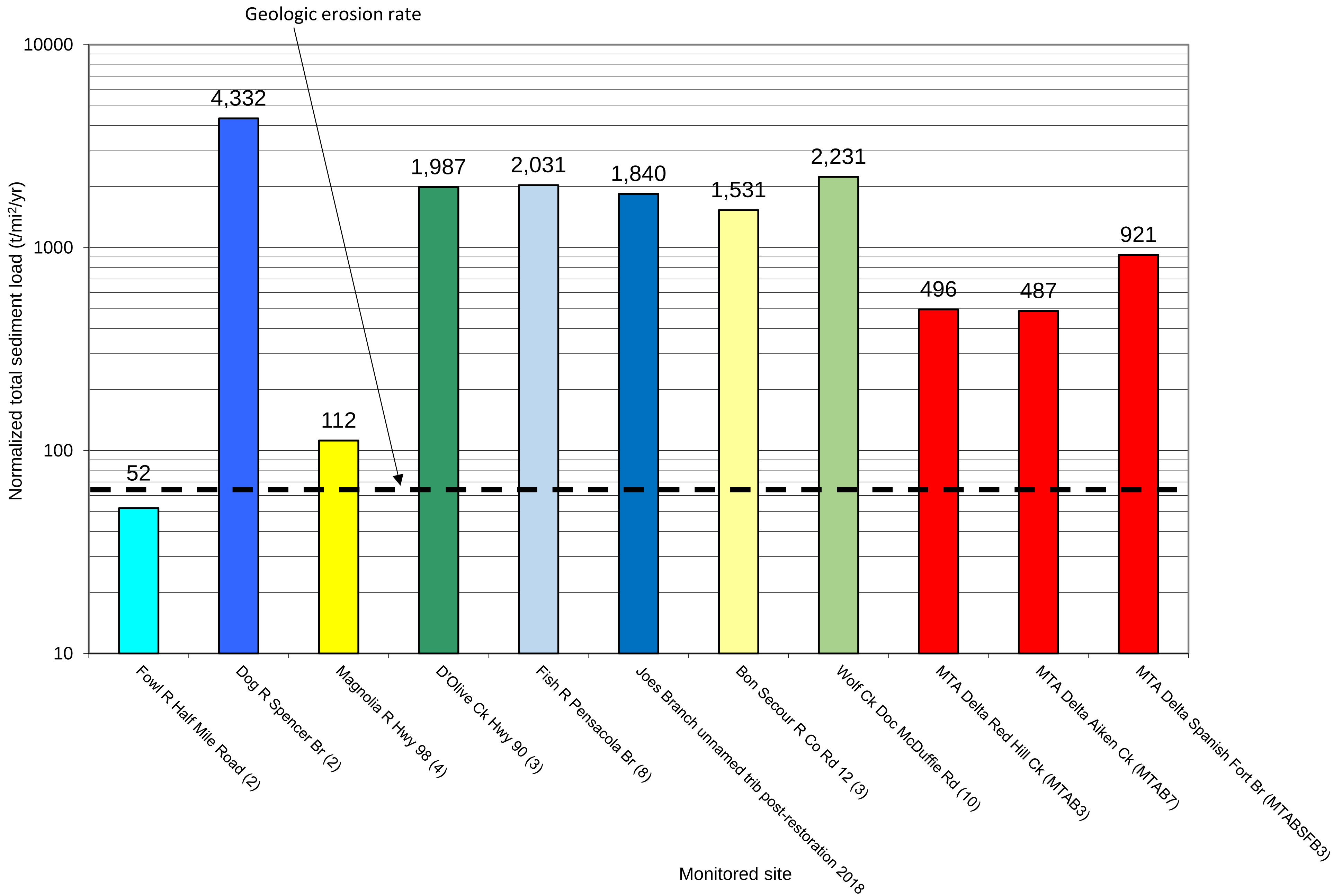

Figure 12.—Normalized total sediment loads for selected streams in Mobile and Baldwin Counties.

NUTRIENTS

Excessive nutrient enrichment is a major cause of water-quality impairment. Excessive concentrations of nutrients, primarily nitrogen and phosphorus, in the aquatic environment can lead to increased biological activity, increased algal growth, decreased dissolved oxygen concentrations at times, and decreased numbers of species (Mays, 1996). Nutrient-impaired waters are characterized by numerous problems related to growth of algae, other aquatic vegetation, and associated bacterial strains. Blooms of algae and associated bacteria can cause taste and odor problems in drinking water and decrease oxygen concentrations to hypoxic levels. Toxins also can be produced during blooms of particular algal species. Nutrient-impaired water can dramatically increase treatment costs required to meet drinking water standards. Nutrients discussed in this report are nitrate (NO_3-N) and phosphorus (P-total).

NITROGEN

The U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Level (MCL) for nitrate in drinking water is 10 mg/L. Typical nitrate (NO_3 as N) concentrations in streams vary from 0.5 to 3.0 mg/L. Concentrations of nitrate in streams without significant nonpoint sources of pollution vary from 0.1 to 0.5 mg/L. Streams fed by shallow groundwater draining agricultural areas may approach 10 mg/L (Maidment, 1993). Nitrate concentrations in streams without significant nonpoint sources of pollution generally do not exceed 0.5 mg/L (Maidment, 1993).

Water samples were collected from October 2017 through September 2018 at MTA Delta tributary watershed monitoring sites for discharge events from base flow to bank full. In order to compare MTA Delta tributary watershed samples to the ADEM reference concentration of 0.3258 mg/L nitrate+nitrite nitrogen, which equals the 90th percentile, for Ecoregion 65f, samples were analyzed for nitrate+nitrite nitrogen (NO^3+NO^2 as N).

Due to the dominance of forest cover in the monitored watersheds, nitrogen concentrations are generally low with most samples analyzed as non-detectable. Agricultural land is a small percentage of most monitored watersheds and the only watersheds with significant urban development are Threemile Creek and Spanish Fort Branch, with 69 and 45 percent urban, respectively. Both watersheds had all samples analyzed for nitrogen as non-detectable. All runoff from commercial development in the headwaters of Spanish Fort Branch flows through a large wetland immediately upstream from site MTABSFB1, which provides an opportunity for reduction of sediment and nutrients. The only monitored watersheds with significant nitrogen concentrations are MTAB4 (Martin Branch) and MTAB5 (Dennis Creek). The largest concentration of nitrate+nitrite nitrogen was 0.768 mg/L at site MTAB4 (Martin Branch), which receives runoff from the west side of Bay Minette, including wastewater from a sewage treatment plant in the headwaters (table 6). Dennis Creek receives runoff from a large row crop agriculture area immediately upstream from the monitoring site. Concentrations at all other monitoring sites were near or below the detection limit (0.3 mg/L).

Nitrogen and discharge form negative regressions, indicating that increased discharge contains increased quantities of relatively pristine rainwater and results in decreased concentrations of nitrate. Nitrogen loads were estimated using regressions generated from measured nitrate concentrations and discharge. The regressions were applied to average daily discharge for each site. Nitrogen loads were estimated for sites MTAB4 (Martin Branch) and MTAB5 (Dennis Creek), which had 16.0 and 10.8 tons/mi^2/yr, respectively (table 6).

PHOSPHORUS

Phosphorus in streams originates from the mineralization of phosphates from soil and rocks or runoff and effluent containing fertilizer or other industrial products. The principal components of the phosphorus cycle involve organic phosphorus and inorganic phosphorus in the form of orthophosphate (PO_4) (Maidment, 1993). Orthophosphate is soluble and is the only biologically available form of phosphorus. Since phosphorus strongly associates with solid particles and is a significant part of organic material, sediments influence water column concentrations and are an important component of the phosphorus cycle in streams.

The natural background concentration of total dissolved phosphorus is approximately 0.025 mg/L. Phosphorus concentrations as low as 0.005 to 0.01 mg/L may cause algae growth, but the critical level of phosphorus necessary for excessive algae is around 0.05 mg/L (Maidment, 1993).

Table 6.—Measured nitrate+nitrite nitrogen concentrations and estimated loads in monitored MTA Delta tributary streams.

Monitored site	Average NO^3+NO^2 as N (mg/L)	Maximum NO^3+NO^2 as N (mg/L)	Minimum NO^3+NO^2 as N (mg/L) (% samples BDL[1])	Samples above 0.3258 mg/L ADEM reference criterion (%)	Estimated NO^3+NO^2 as N load (t/yr)	Estimated normalized NO^3+NO^2 as N load ($t/mi^2/yr$)
MTAM1	BDL	BDL	BDL (100)	0	N/A[3]	N/A
MTAM2	BDL	BDL	BDL (100)	0	N/A	N/A
MTAM3	BDL	BDL	BDL (100)	0	N/A	N/A
MTAM4	BDL	BDL	BDL (100)	0	N/A	N/A
MTAM5	BDL	BDL	BDL (100)	0	N/A	N/A
MTAB2	BDL	BDL	BDL (100)	0	N/A	N/A
MTAB3	0.305	0.305	0.305 (87)	0	N/A	N/A
MTAB4	0.218	0.768	0.448 (62)	0	16.0	2.6
MTAB5	0.581	0.350	0.321 (75)	13	10.8	2.6
MTAB6	BDL	BDL	BDL (100)	13	0.16	N/A
MTAB7	BDL	BDL	BDL (100)	0	N/A	N/A
MTAB8	BDL	BDL	BDL (100)	0	N/A	N/A
MTABSFB1	BDL	BDL	BDL (100)	0	N/A	N/A
MTABSFB2	BDL	BDL	BDL (100)	0	N/A	N/A
MTABSFB3	BDL	BDL	BDL (100)	0	N/A	N/A

[1] Below detection limit

Although no official water-quality criterion for phosphorus has been established in the United States, total phosphorus should not exceed 0.05 mg/L in any stream or 0.025 mg/L within a lake or reservoir in order to prevent the development of biological nuisances (Maidment, 1993). ADEM established a reference standard of 0.04 mg/L for total phosphorus for level IV ecoregion 65f. In many streams phosphorus is the primary nutrient that influences excessive biological activity. These streams are termed "phosphorus limited."

Only three of 13 MTA Delta tributary watershed monitoring sites had detectable phosphorus. When phosphorus was detectable, the average of those concentrations was above the 0.05 mg/L published standard and ADEM reference standard of 0.04 mg/L (table 7). Sites MTABSFB2 (Spanish Fort Branch), MTAM5 (Threemile Creek), and MTAB4 (Martin Branch) have average phosphorus concentrations of 0.183, 0.122, and 0.071 mg/L, respectively. However, when individual concentrations were plotted with discharge, no usable regression could be established so that no annual phosphorus loads were estimated.

Table 7.—Measured total phosphorus concentrations in monitored streams in the MTA Delta watershed.

Monitored site	Average total phosphorus (mg/L)	Maximum total phosphorus (mg/L)	Minimum total phosphorus (mg/L) (% samples BDL)	Samples above 0.04 mg/L ADEM criterion (%)
MTAM1	BDL	BDL	BDL (100)	0
MTAM2	BDL	BDL	BDL (100)	0
MTAM3	BDL	BDL	BDL (100)	0
MTAM4	BDL	BDL	BDL (100)	0
MTAM5	0.122	0.174	BDL (50)	50
MTAB2	BDL	BDL	BDL (100)	0
MTAB3	BDL	BDL	BDL (100)	0
MTAB4	0.071	0.128	BDL (25)	50
MTAB5	BDL	BDL	BDL (100)	0
MTAB6	BDL	BDL	BDL (100)	0
MTAB7	BDL	BDL	BDL (100)	0
MTAB8	BDL	BDL	BDL (100)	0
MTABSFB1	BDL	BDL	BDL (100)	0
MTABSFB2	0.183	0.293	BDL (75)	25
MTABSFB3	BDL	BDL	BDL (100)	0

DISSOLVED OXYGEN

Dissolved oxygen (DO) concentration is an essential constituent that affects the biological health and the chemical composition of surface waters. Biological processes, oxidation, and sediment loads all contribute to depletion of DO in surface water. The ADEM standard for DO in surface water classified as Fish and Wildlife is 5.0 mg/L except under extreme conditions when it may be as low as 4.0 mg/L. ADEM established a reference standard for dissolved oxygen for level IV ecoregion 65f, which is 6.94 mg/L.

DO concentrations measured at MTA Delta tributary sites were all higher the regulatory criterion of 5.0 mg/L, except one measurement at site MTAM4 (Chickasaw Creek) in October 2017. All sites except MTAM1 (Cedar Creek) and MTABSFB3 (Spanish Fort Branch) had at least one measurement below the reference standard of 6.94 mg/L. DO concentrations for all sampled events are included in Appendix A.

SUMMARY, CONCLUSIONS, AND PROBABLE SOURCES OF WATER-QUALITY IMPACTS

Evaluations of sediment transport and water-quality analyses led to conclusions concerning which tributary streams in the MTA Delta have impairments and should be considered for further evaluation and possible remedial actions. Evaluations of land-use data, aerial imagery, and field assessments give insight to probable sources of water quality and habitat impairments. Stream flow conditions are important factors that influence erosion, sediment transport, and attenuation of nutrients and other contaminants that impact water quality in a watershed. Topographically, stream reaches immediately upstream from monitoring sites can be divided into two groups: reaches characterized by higher gradients and flow velocities; and those characterized by deep water, lower gradients and flow velocities, and tidal influence at some sites. Land use/cover is also an important factor influencing erosion, sediment transport, and overall water quality. Monitored watersheds are primarily rural, except for Threemile Creek (MTAM5), Spanish Fort Branch (MTABSF), and the headwaters of Martin Branch (MTAB4), with forested flood plains, extensive wetlands, and limited row crop agriculture in upland areas. Water samples were collected from October 2017 through September 2018 at 16 MTA Delta tributary monitoring sites. Stream discharge and flow velocity was measured for discharge events from base flow to bank full. Water quality parameters were measured, including specific conductance, pH, temperature, turbidity, and dissolved oxygen. Water samples were collected and analyzed for total suspended solids, nitrate+nitrite nitrogen, and total phosphorus

Two of the monitored streams are currently on the ADEM 303-D list of impaired waters. Chickasaw and Bay Minette Creeks are listed for metals (mercury) caused by atmospheric deposition (ADEM, 2018). Also, an unnamed tributary to Threemile Creek and Toulmens Spring Branch are listed as nutrient impaired (ADEM, 2018). However, water samples collected during the project period were not analyzed for metals and no detectable nitrogen or phosphorus was observed at the Threemile Creek monitoring site. No streams in the MTA Delta watershed are listed for excessive sedimentation.

Sediment loads in streams are composed of suspended and bed sediment. Chickasaw Creek (MTAM4), Cedar Creek (MTAM1), Aikin Creek (MTAB7), Halls Creek (MTAB8), and Red Hill Creek (MTAB3) had the largest estimated suspended sediment loads with 5,730, 3,652, 1,014, 939, and 759 t/yr, respectively. The largest normalized suspended sediment loads were estimated at sites MTAB7 (Aikin Creek), MTAB3 (Red Hill Creek), and MTABSFB3 (Spanish Fort Branch), with 127, 119, and 119 t/mi^2/yr, respectively.

Site MTAB7 (Aikin Creek) had the largest bed sediment loads with 2,876 tons per year (t/yr). After normalization of bed sediment loads relative to drainage area, site MTABSFB3 (Spanish Fort Branch) had the largest load, with 802 tons/mi^2/yr. On average, bed sediment makes up 71% of total sediment loads for streams with measurable bed sediment.

Sediment loads at MTA Delta tributary monitoring sites are relatively small, when compared to many previously monitored sites in Mobile and Baldwin Counties. This may be due, in part, to several monitoring sites characterized by deep, slow moving water, some with tidal impacts, that cause sediment to settle out upstream from the site. However, five of 16 sites (MTAB3 (Red Hill Creek), MTAB5 (Dennis Creek), MTAB7 (Aikin Creek), MTAB8 (Halls Creek), and MTABSFB3 (Spanish Fort Branch)) had total sediment loads that exceeded the published geologic erosion rate of 64 t/mi^2/yr. Sites MTABSFB3 (Spanish Fort Branch), MTAB3 (Red Hill Creek), and MTAB7 (Aikin Creek), have the largest normalized total sediment loads, with 921, 496, and 487 t/mi^2/yr, respectively.

Spanish Fort Branch has a combination of substantial urban development (45% of the watershed) and high stream gradient that facilitates channel scour and bank erosion. An evaluation of aerial imagery (Google Earth, 2019) indicates that Aikin Creek is impacted by large clear-cut forest areas, some replanted in pines, and dirt roads constructed for forest harvesting access. Dennis Creek has about 180 acres of row crop and a large area of recently cut forest upstream from the monitoring site that are probably the primary sources of turbidity and sediment.

Comparisons of sediment transport rates and water quality parameters in previously monitored watersheds in Baldwin and Mobile Counties indicate that monitored MTA Delta tributaries have small to moderate-sized sediment loads and generally good water quality. This is attributed to the relatively rural setting, extensive wetlands and forests, and limited agriculture.

The critical nitrate concentration in surface water for excessive algae growth is 0.5 mg/L. The ADEM reference concentration for Ecoregion 65f is 0.3258 mg/L nitrate+nitrite nitrogen, which equals the 90th percentile). The largest concentration of nitrate+nitrite nitrogen was 0.768 mg/L at site MTAB4 (Martin Branch). Nitrogen loads were estimated for sites MTAB4 (Martin Branch) and MTAB5 (Dennis Creek), which had 16.0 and 10.8 tons/mi^2/yr, respectively. Concentrations at all other monitoring sites were near or below the detection limit (0.3 mg/L).

Although no official water-quality criterion for phosphorus has been established in the United States, total phosphorus should not exceed 0.05 mg/L in any stream or 0.025 mg/L within a lake or reservoir in order to prevent the development of biological nuisances. ADEM established a reference standard of 0.04 mg/L for total phosphorus for level IV ecoregion 65f. Only three of 16 MTA Delta tributary watershed monitoring sites had detectable phosphorus. When phosphorus was detectable, the average of those concentrations was above the 0.05 mg/L published standard and ADEM reference standard of 0.04 mg/L. Sites MTABSFB2 (Spanish Fort Branch), MTAM5 (Threemile Creek), and MTAB4 (Martin Branch) have average phosphorus concentrations of 0.183, 0.122, and 0.071 mg/L, respectively.

Nutrient concentrations in monitored MTA tributaries are impacted by land use/cover. Generally, the monitored watersheds with limited anthropogenic impacts, dominated by forest and wetlands have no detectable nitrogen or phosphorus. Martin Branch receives runoff from the west side of Bay Minette, including wastewater from a sewage treatment plant in the headwaters. Dennis Creek receives runoff from a large row crop agriculture area immediately upstream from the monitoring site. Threemile Creek and Spanish Fort Branch have significant urban development (69 and 45 percent, respectively).

DO concentrations measured at MTA Delta tributary sites were all higher than the regulatory criterion of 5.0 mg/L, except MTAM4 (Chickasaw Creek). All sites except MTAM1 (Cedar Creek) and MTABSFB3 (Spanish Fort Branch) had at least one measurement below the reference standard of 6.94 mg/L.

Based on the findings of this assessment, with respect to water quality and potential remediation and restoration, Spanish Fort Branch, Aikin Creek, Red Hill Creek, Martin Branch, and Dennis Creek have the highest degree of impairment and should be considered for various types of remediation and restoration. However, additional field assessment will be required to refine particular sources of impairment and specific remedial strategies. Also, streams in larger watersheds and streams with sites on deep water reaches (Cedar Creek, Gunnison Creek, Chickasaw Creek, Bayou Sara, Threemile Creek, and Bay Minette Creek) will require evaluation of additional upstream monitoring sites and collection of additional sediment and water quality data to more accurately determine current conditions.

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APPENDIX A

FIELD AND ANALYTICAL DATA

Cedar Creek at US Hwy 43 near			31.07521	Area							
			88.02367	85.6							
Site	Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	Dissolved Oxygen	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
MTAM1	10/8/17	1015	1674	24.2	38	85	4.5	7.4	71.2	<0.3	<.05
MTAM1	10/23/17	745	1157	20.2	31	61	4.8	7.5	48.4	<0.3	<.05
MTAM1	12/18/17	1245	326	14.5	53	19	4.8	10.6	11.2	<0.3	<.05
MTAM1	3/6/18	1150	118	18.8	77	6	5.1	11.5	4	<0.3	<.05
MTAM1	4/8/18	1015	349	15.2	40	32	5.1	9.9	12.8	<0.3	<.05
MTAM1	4/15/18	140	158	18.8	28	23	5.8	7.5	11.2	<0.3	<.05
MTAM1	7/17/18	1350	344	25	41	25	4.3	7.6	16	<0.3	<.05
MTAM1	9/6/18	130	829	24.8	38	52	4.6	62	37	<0.3	<.05
Gunnison Creek at US Hwy 43 r			30.88307	Area							
			88.04177	31.2							
Site	Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	Dissolved Oxygen	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
MTAM2	10/8/17	1030	617	24.1	26	30	5.7	6.3	9.2	<.3	<.05
MTAM2	10/23/17	815	424	20.2	20	29	5.5	7.1	4.8	<.3	<.05
MTAM2	12/18/17	1325	120	15.8	26	12	5.5	9.1	2	<.3	<.05
MTAM2	2/11/18	1945	233	14.9	27	18	5.6	10.2	6	<.3	<.05
MTAM2	4/8/18	1045	127	15.4	28	19	5.9	10.8	5.6	<.3	<.05
MTAM2	4/15/18	115	44	19.8	30	12	6.2	6.6	2	<.3	<.05
MTAM2	7/17/18	1200	136	23.2	28	13	5.9	6.3	3	<.3	<.05
MTAM2	9/6/18	150	302	23.7	26	22	5.7	6.2	6	<.3	<.05
Bayou Sara at US Hwy 43 in Sara			30.82509	Area							
			88.06967	14.2							
Site	Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	Dissolved Oxygen	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
MTAM3	10/8/17	1055	289	24.8	25	46	5.8	6	15.6	<.3	<.05
MTAM3	10/23/17	845	194	20.7	21	26	5.6	6.5	5.6	<.3	<.05
MTAM3	12/18/17	1340	55	18.9	40	20	5.9	7.2	6	<.3	<.05
MTAM3	2/11/18	2000	106	14.8	34	28	5.8	8.3	10	<.3	<.05
MTAM3	4/8/18	1115	58	15.5	35	17	6.2	9	7.2	<.3	<.05
MTAM3	4/15/18	45	135	19.3	41	65	6.6	8.7	21.6	<.3	<.05
MTAM3	7/17/18	1130	63	21.1	38	21	6.3	6.1	7	<.3	<.05
MTAM3	9/6/18	210	138	23.2	32	31	6.5	5.9	12	<.3	<.05
Chickasaw Creek at US Hwy 43			30.78327	Area							
			88.07283	183.5							
Site	Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	Dissolved Oxygen	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
MTAM4	10/8/17	1145	3758	26.3	7190	22	6.4	4.7	16	<.3	<.05
MTAM4	10/23/17	900	2510	20.5	86	76	6.1	8.6	32.8	<.3	<.05
MTAM4	12/18/17	1410	706	18.1	90	25	6.2	9.2	10	<.3	<.05
MTAM4	2/11/18	1915	1374	14.2	2100	42	6.4	10.3	20	<.3	<.05
MTAM4	4/8/18	1125	744	16.7	64	20	6.5	10.5	6.4	<.3	<.05
MTAM4	4/15/18	30	291	20	136	15	6.8	6.7	5.6	<.3	<.05
MTAM4	7/17/18	1350	738	26.3	1830	26	5.6	6.7	12	<.3	<.05
MTAM4	9/6/18	230	1776	25.8	85	25	5.7	6.3	24	<.3	<.05

Three Mile Creek at Conceptio			30.71884	Area							
			88.06578	27.7							
Site	Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	Dissolved Oxygen	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
MTAM5	10/8/17	1210	587	26.2	1350	56	6.8	5.4	24.4	<.3	0.123
MTAM5	10/23/17	920	379	20.9	287	54	6.7	6.1	18	<.3	0.092
MTAM5	12/18/17	1430	40	18.2	70	10	6.5	8	4	<.3	<.05
MTAM5	2/11/18	1930	207	16.1	405	40	6.8	8.8	17	<.3	<.05
MTAM5	4/8/18	1200	112	18.4	198	26	6.9	7	7.6	<3	0.097
MTAM5	4/15/18	0:10	240	20.8	412	43	6.1	6.8	26.8	<.3	0.174
MTAM4	7/17/18	1415	110	23.2	220	26	6.5	6.2	9	<.3	<.05
MTAM4	9/6/18	245	268	25.8	400	47	6.2	5.6	20	<.3	<.05
Honeycut Creek at State Hwy 2			30.86276	Area							
			87.86488	4.7							
Site	Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	Dissolved Oxygen	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
MTAB2	10/8/17	1545	126	25.1	39	15	6	6.5	4	<.3	<.05
MTAB2	10/23/17	1150	105	21.5	24	12	5.9	7.1	2.4	<.3	<.05
MTAB2	12/19/17	900	9.5	18.3	40	3	5.8	7.8	1	<.3	<.05
MTAB2	2/7/18	1700	11.1	15.2	39	4	6.1	8.6	2	<.3	<.05
MTAB2	2/11/18	1750	118	15.3	31	14	5.7	8.8	3	<.3	<.05
MTAB2	3/6/18	1630	9.1	16.5	40	3	6.1	7.8	1	<.3	<.05
MTAB2	6/5/18	1725	18.8	18.9	39	5	5.9	7.2	2	<.3	<.05
MTAB2	9/6/18	350	179	24.8	25	18	5.6	6.3	20	<.3	<.05
Red Hill Creek at State Hwy 225			30.8808	Area							
			87.86203	4.5							
Site	Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	Dissolved Oxygen	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
MTAB3	10/8/17	1600	45	24.8	22	47	5.6	6.3	24.4	<.3	<.05
MTAB3	10/23/17	1220	37	21.3	20	39	5.7	7.3	16.8	<.3	<.05
MTAB3	12/19/17	900	14.6	18	24	8	6.2	9.3	4	0.305	<.05
MTAB3	2/7/18	1700	40	18.4	34	40	5.5	6.5	29.6	<.3	<.05
MTAB3	2/11/18	1750	62	18.5	19	50	5.5	8.8	30	<.3	<.05
MTAB3	3/6/18	1630	12.6	18.7	20	11	6.9	10.4	7.2	<.3	<.05
MTAB3	6/5/18	1735	14.3	22.4	22	31	5.6	7.8	15.2	<.3	<.05
MTAB3	9/6/18	415	225	24.2	17	71	5.4	47.6	50	<.3	<.05
Martin Branch at State Hwy 225			30.89992	Area							
			87.85095	6.1							
Site	Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	Dissolved Oxygen	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
MTAB4	10/8/17	1615	159	25.3	28	24	5.8	7.8	8.8	0.528	0.056
MTAB4	10/23/17	1335	140	22.1	28	22	5.9	7.2	5.6	<.3	0.05
MTAB4	12/18/17	1635	13.4	16.9	25	14	5.7	9.1	4	0.768	0.051
MTAB4	2/7/18	1710	14.3	17.5	26	55	5.6	6.2	34.8	0.448	0.128
MTAB4	2/11/18	1740	153	15.8	20	27	5.6	8.9	15.6	<.3	<0.05
MTAB4	4/8/18	1300	18.8	16.4	30	7	6.7	11.3	3.6	<.3	<0.05
MTAB4	6/5/18	1750	24	17.3	28	14	5.9	41.6	2	<.3	<0.05
MTAB4	9/6/18	430	216	23.3	23	28	5.7	8.3	9	<.3	<0.05

Dennis Creek at State Hwy 225			30.91999	area							
			87.85356	4.1							
Site	Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	Dissolved Oxygen	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
MTAB5	10/8/17	1630	106	25.5	18	156	5.3	6.4	68.4	<.3	<.05
MTAB5	12/18/17	1620	9	16.4	17	28	5.6	9.4	5.2	0.321	<.05
MTAB5	2/7/18	1720	9.6	17.3	17	15	5.6	7.4	3.6	<.3	<.05
MTAB5	2/11/18	1730	103	16.2	16	90	5.2	10.1	35.2	<.3	<.05
MTAB5	3/6/18	1630	7.9	17.1	17	14	5.8	9.9	5	0.35	<.05
MTAB5	4/8/18	1320	12.5	17.7	17	18	5.6	8.2	6	<.3	<.05
MTAB5	6/5/18	1715	16.6	19.2	17	22	5.1	7.9	7	<.3	<.05
MTAB5	9/6/18	450	142	24.9	16	155	5.6	6.2	71	<.3	<.05
Griffin Creek at State Hwy 225			30.94146	area							
			87.86062	3							
Site	Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	Dissolved Oxygen	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
MTAB6	10/8/17	1645	77	25.9	24	19	6	5.9	6.4	<.3	<.05
MTAB6	12/18/17	1600	6.6	16	21	7	5.8	9.6	4	<.3	<.05
MTAB6	2/7/17	1730	201	16.1	23	62	5.8	6.1	22	<.3	<.05
MTAB6	2/11/18	1720	75	15.7	19	15	5.4	9.8	6	<.3	<.05
MTAB6	3/6/18	1630	5.8	16.3	26	4	5.3	8.5	3	<.3	<.05
MTAB6	4/8/18	1450	8.7	15.6	25	8	5.6	7.8	4	<.3	<.05
MTAB6	6/5/18	1715	12.2	23.2	25	10	5.8	6.9	5	<.3	<.05
MTAB6	9/5/18	1830	208	26.4	21	70	5.6	5.6	23	<.3	<.05
Aiken Creek at State Hwy 59			30.9851	area							
			87.85086	8							
Site	Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	Dissolved Oxygen	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
MTAB7	10/8/17	1250	237	27.9	17	255	5.5	6.1	142	<.3	<.05
MTAB7	12/18/17	1420	22	16.1	25	61	5.3	9.5	26.8	<.3	<.05
MTAB7	2/11/18	1705	50	15.8	20	121	5.4	10.1	82.4	<.3	<.05
MTAB7	3/6/18	1730	17	17.6	18	42	6.2	11.2	21.2	<.3	<.05
MTAB7	4/8/18	1450	17	16.7	32	27	6.1	9.7	10	<.3	<.05
MTAB7	5/16/18	1510	1.4	24.5	52	11	6.8	8.4	4	<.3	<.05
MTAB7	6/5/18	1515	7.7	24.4	51	63	4.7	8.2	35.6	<.3	<.05
MTAB7	7/18/18	1245	34	28.1	52	118	5.6	5.2	65	<.3	<.05
Halls Creek at State Hwy 59			30.0527	Area							
			87.83707	19.6							
Site	Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	Dissolved Oxygen	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
MTAB8	10/8/17	1250	581	24.2	17	16	5.5	7.5	38	<.3	<.05
MTAB8	12/18/17	1540	43	16.4	20	14	5.4	9.7	3.2	<.3	<.05
MTAB8	2/11/18	1655	486	16.1	18	18	5.2	10.1	31.2	<.3	<.05
MTAB8	3/6/18	1700	37	17.8	15	16	6.5	11.3	7.6	<.3	<.05
MTAB8	4/8/18	1335	39	16.6	22	10	6.2	10	3.2	<.3	<.05
MTAB8	5/18/18	1600	32	23.5	21	7	6.6	10	5	<.3	<.05
MTAB8	6/5/18	1600	12.7	23.8	27	8	5.2	7.7	2.8	<.3	<.05
MTAB8	9/5/18	1830	1326	25.1	15	24	6.1	7.1	90	<.3	<.05

Spanish Fort Branch at State Hwy 225				30.67968	Area						
				87.90225	0.26						
Site	Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	Dissolved Oxygen	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
MTABSFB1	10/8/17	1250	0.6	25.4	78	21	6.5	6.6	4	<.3	<.05
MTABSFB1	10/23/17	1115	0.1	21.7	56	18	6.4	6.9	3.2	<.3	<.05
MTABSFB1	12/19/17	730	2.2	18.2	90	40	6.3	8.5	8	<.3	<.05
MTABSFB1	2/11/18	1630	27	16.3	52	75	6.1	9.2	23	<.3	<.05
MTABSFB1	3/6/18	1700	2.2	17.5	92	38	6.5	9.1	7	<.3	<.05
MTABSFB1	4/8/18	1335	3.3	18.6	82	48	6.3	8.7	10	<.3	<.05
MTABSFB1	4/14/18	2330	10.4	19.3	70	55	6.5	8.5	13.6	<.3	0.099
MTABSFB1	6/5/18	1900	0.03	23.6	135	22	6.8	5.8	6.4	<.3	<.05
Spanish Fort Branch at Spanish Main				30.67411	Area						
				87.91511	0.91						
Site	Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	Dissolved Oxygen	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
MTABSFB2	10/8/17	1315	2.4	24.8	54	20	6.6	6.3	5.6	<.3	<.05
MTABSFB2	10/23/17	1000	2.1	21.4	54	22	6.6	6.7	2.4	<.3	0.293
MTABSFB2	12/19/17	730	0.4	17.4	57	7	6.4	10.8	2.8	<.3	<.05
MTABSFB2	2/11/18	1615	2.7	24	46	16	6	10.5	5.6	<.3	<.05
MTABSFB3	3/6/18	1700	1.8	26	24	22	6.3	9.8	8	<.3	<.05
MTABSFB4	4/8/18	1335	2.7	23	48	28	6.5	8.7	10	<.3	<.05
MTABSFB2	4/14/18	2300	168	19.3	33	140	6.5	7.2	71.3	<.3	0.073
MTABSFB2	6/5/18	1830	2.2	22.9	39	79	6.6	6.8	15.2	<.3	<.05
Spanish Fort Branch along Cannonade Blvd					30.68002	Area					
					87.90265	0.97					
Site	Date	Time	Discharge	Temperature	Conductance	Turbidity	pH	Dissolved Oxygen	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
MTABSFB3	10/8/17	1410	3.2	26.1	63	21	6.7	7	6	<.3	<.05
MTABSFB3	10/23/17	1040	3.5	21.3	60	24	6.7	7.4	4	<.3	<.05
MTABSFB3	12/19/18	800	1	17.3	61	8	6.6	8.5	4	<.3	<.05
MTABSFB3	2/11/18	1600	24	16.2	54	80	6.4	9.4	45	<.3	<.05
MTABSFB3	3/6/18	1500	0.9	19.5	53	14	7	9.7	4	<.3	<.05
MTABSFB3	4/14/18	2315	280	19.3	35	235	6.5	7.6	152	<.3	<.05
MTABSFB3	6/5/18	1810	2.2	22.8	43	83	6.6	7	20.4	<.3	<.05
MTABSFB3	9/5/18	1850	15.5	23.4	50	130	6.8	6.5	75	<.3	<.05