

**PRE-RESTORATION ANALYSIS OF DISCHARGE,
SEDIMENT TRANSPORT RATES, WATER QUALITY,
AND LAND-USE IMPACTS IN
THE BAYOU LA BATRE WATERSHED,
MOBILE COUNTY, ALABAMA**



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By

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INTRODUCTION

Commonly, land-use and climate are major contributors to non-point source contaminants that impact surface-water quality. In parts of Baldwin and Mobile Counties, population growth and economic development are critical issues leading to land-use change. When combined with highly erodible soils and Alabama's coastal climate, characterized by cyclonic storms that produce high intensity rainfall events, deleterious water-quality and biological habitat impacts can be severe. Previous investigations of sediment transport and general water quality have shown dramatic increases in sediment loading and loss of biological habitat in streams downstream from areas affected by rapid runoff and resulting erosion from particular types of land uses. Other areas are virtually unimpacted by land-use change and are characterized by natural landscapes dominated by forests and wetlands. Results of these investigations are valuable in quantifying impacts so that limited regulatory and remedial resources may be focused to remediate problem areas or to preserve relatively pristine watersheds.

The purpose of this investigation is to assess general hydrogeologic and water quality conditions and to estimate sediment loads for Bayou La Batre and its tributaries. These data will be used to quantify water quality impacts and to support development of a watershed management plan, designed to preserve, protect, and restore the Bayou La Batre watershed.

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PROJECT AREA

The Bayou La Batre watershed covers 19,584 acres (30.6 square miles (mi²) (US Geological Survey (USGS), 2016) in southern Mobile County (fig. 1). The project area includes monitoring sites on three tributaries and the main stem of Bayou La Batre. Bayou La Batre flows southwestward from its headwaters about one and three quarters miles northeast of the town of Bayou La Batre to its mouth in Portersville Bay in the

Mississippi Sound (fig 2). Elevations in the project area vary from about 15 feet above mean sea level (ft MSL) at the headwaters to sea level at the mouth. The three monitored tributaries include two unnamed streams, and Carls Creek. Carls Creek is the largest subwatershed, containing 13,248 acres (20.7 mi²) (USGS, 2016) and two tributaries; Hammar Creek and Bishops Manor Creek with maximum elevations of about 140 ft MSL.



Figure 1.— Bayou La Batre project area.

PROJECT MONITORING STRATEGY AND SITE CHARACTERISTICS

The monitoring strategy employed for the Bayou La Batre project was to collect water samples at each site over a wide range of discharge from base flow to high flow for analyses of total suspended solids, nitrate, and total phosphorus, and constituent load estimation. A number of factors, including site accessibility in a rural, wetlands dominated setting, extensive wetlands and tidal influence that constrains stream flow and impacts water chemical character, and selection of sites as far downstream as possible, were considered during selection of monitoring sites.

Site BLB1 is on the main stem of Bayou La Batre at Wintzell Avenue, the most downstream access point, flowing southwestward, 2.5 mi from the mouth (latitude (lat) 30.40572, longitude (long) -88.24798). The watershed upstream from site BLB1 covers 14,848 acres (23.2 mi²) (USGS, 2016) (fig. 2).

Site BLB2 is on an unnamed tributary on the northwest side of the town of Bayou La Batre at the Little River Road crossing (lat 30.40706, long -88.25691). The watershed upstream from site BLB2 covers 3,200 acres (5.0 mi²) (USGS, 2016) (fig. 2).

Sites BLB3 and BLB4 are on Carls Creek, which is formed by two tributaries, Hammar Creek and Bishops Manor Creek, that join to form Carls Creek 2.5 miles upstream from Site BLB3 (fig. 2). One mile downstream from the tributary confluence, the Carls Creek channel splits (fig. 2). Site BLB3 is on a man-made channel at the Arnette Street crossing, about 1.5 miles downstream from the split (lat 30.41066, long -88.24566) (fig. 2). The man-made channel rejoins the natural channel 400 ft downstream from site BLB3 and flows into Bayou La Batre 2,600 ft downstream from the site (fig.2).

Site BLB4 is on a natural channel at the Arnette Street crossing (lat 30.41060, long -88.24496), 150 ft east of the BLB3 site and 1.5 mi downstream from the Carls Creek channel split. The watershed upstream from sites BLB3 and BLB4 contains 13,248 acres (20.7 mi²) (USGS, 2016) (fig. 2).

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. The CDL is produced using satellite imagery from the Landsat 5 TM sensor, Landsat 7 ETM+ sensor, the

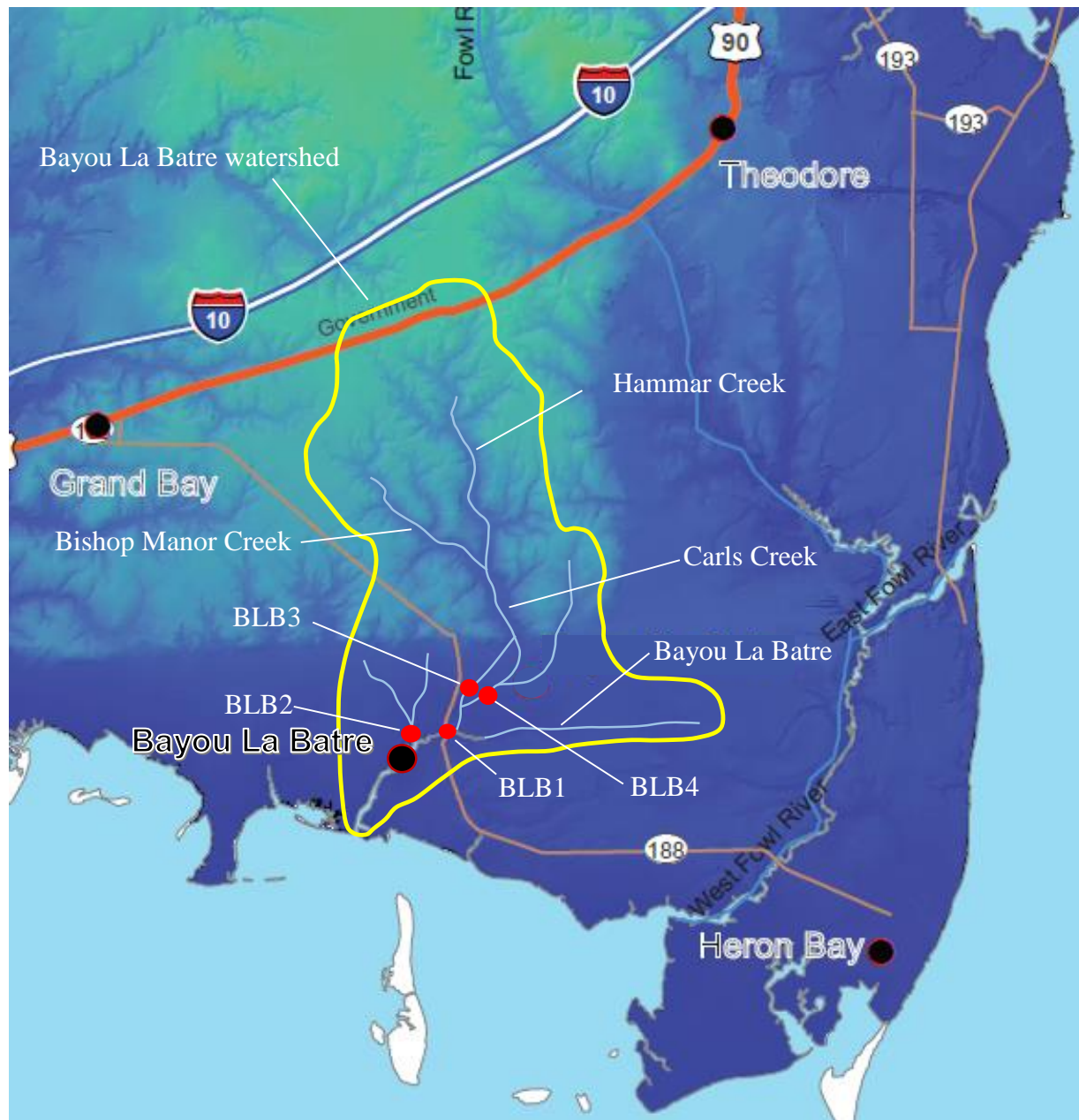


Figure 2.—Bayou La Batre watershed, streams, and monitored sites.

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 recent growing seasons (USDA, 2013). Figure 3 shows land use, subdivided into 17 classified types defined as developed, forested, grassland, wetlands, barren areas, open water, and agriculture, subdivided into eight specific crops (fig. 3).

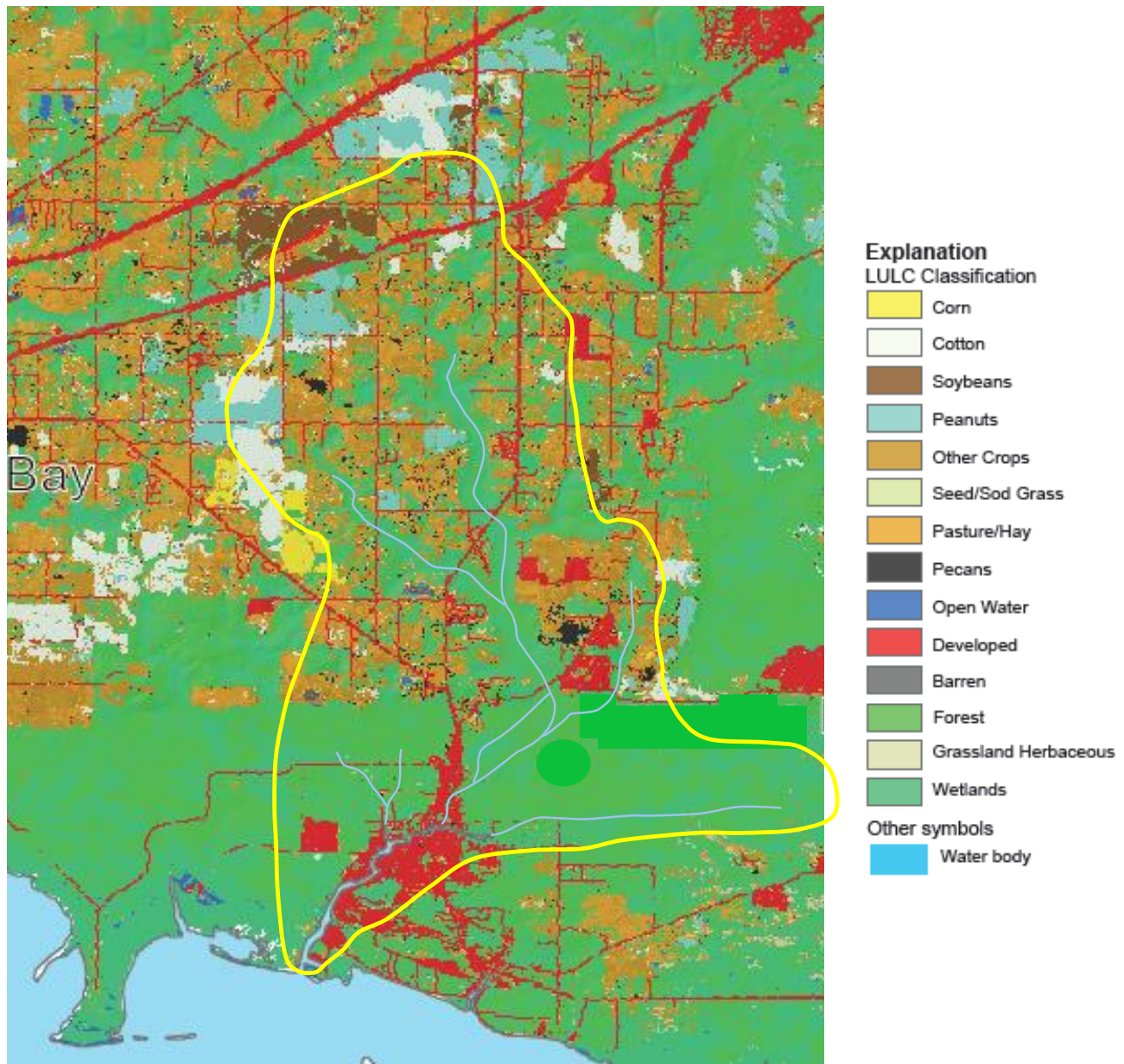


Figure 3.-Land use classifications for the Bayou La Batre area.

The dominant land use category in the Bayou La Batre watershed is pasture/hay and wetlands (fig. 3). Wetlands 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. The next largest land use categories are evergreen and mixed forest and surprisingly, developed land (fig. 3). Developed land in the northern part of the watershed (Carls Creek and tributaries) is dominated by residential development,

primarily along roadways (fig. 3). Developed land in the southern part of the watershed is primarily related to the town of Bayou La Batre (fig. 3). Agriculture is a dominant land use in the headwaters of Carls Creek tributaries (fig. 3). Crops consist of peanuts, soybeans, corn, cotton, and pecans. Land uses and their specific impacts are discussed in detail in the Conclusions and Sources of Water-Quality Impacts section of the report.

STREAM FLOW CONDITIONS

Numerous streams in Baldwin County exhibit flashy discharge due to relatively high topographic relief and land-use change. Most streams in the Dog River watershed, in and near the city of Mobile, are also flashy, with relatively high velocities and an average stream gradient of 48 ft/mi, due to channelization and urbanization. However, the character of stream flows in the Bayou La Batre watershed are quite different and influenced by a number of natural and anthropogenic factors. Stream channels in the northern part of the watershed, consisting of Carls Creek tributaries (Bishop Manor and Hammar Creeks) are characterized by relatively high elevation (maximum 140 ft MSL, average 48 ft MSL), with topography that decreases in relief from north (upstream) to south (downstream). The tributary flood plains are dominated by wetlands, channels that are in part, anastomosing, and stream gradients that decrease from upstream to downstream in three zones from 33 to 21 to 10 ft/mi (fig. 4). Prior to 1956, anthropogenic impacts influencing stream discharge in the downstream part of Carls Creek, include a relief channel 1.6 miles long along Padgett Switch Road and eight man-made channels constructed to drain a 300-acre low area between the Carls Creek relief channel and Padgett Switch Road (fig. 4). After 1985, much of the drained area was filled to construct Lucille Zirlott Park, a number of businesses, and a medical center along Padgett Switch Road. However, one of the drainage ditches and the Carls Creek relief channel remain. Other anthropogenic impacts to stream flow include a 6,800-foot-long constructed channel in the headwaters of Bayou La Batre, east of the town of Bayou La Batre (fig. 4). The Carls Creek natural channel, monitored unnamed tributary, and Bayou La Batre are in the Alabama Coastal Zone, where they flow through the eastern extent of Grand Bay Swamp, and have an average gradient of 7 ft/mi. The Carls Creek man-made channel has a gradient of 11 ft/mi. Conductance values for a number of monitoring events indicate tidal influence on volume and quality of stream flow.

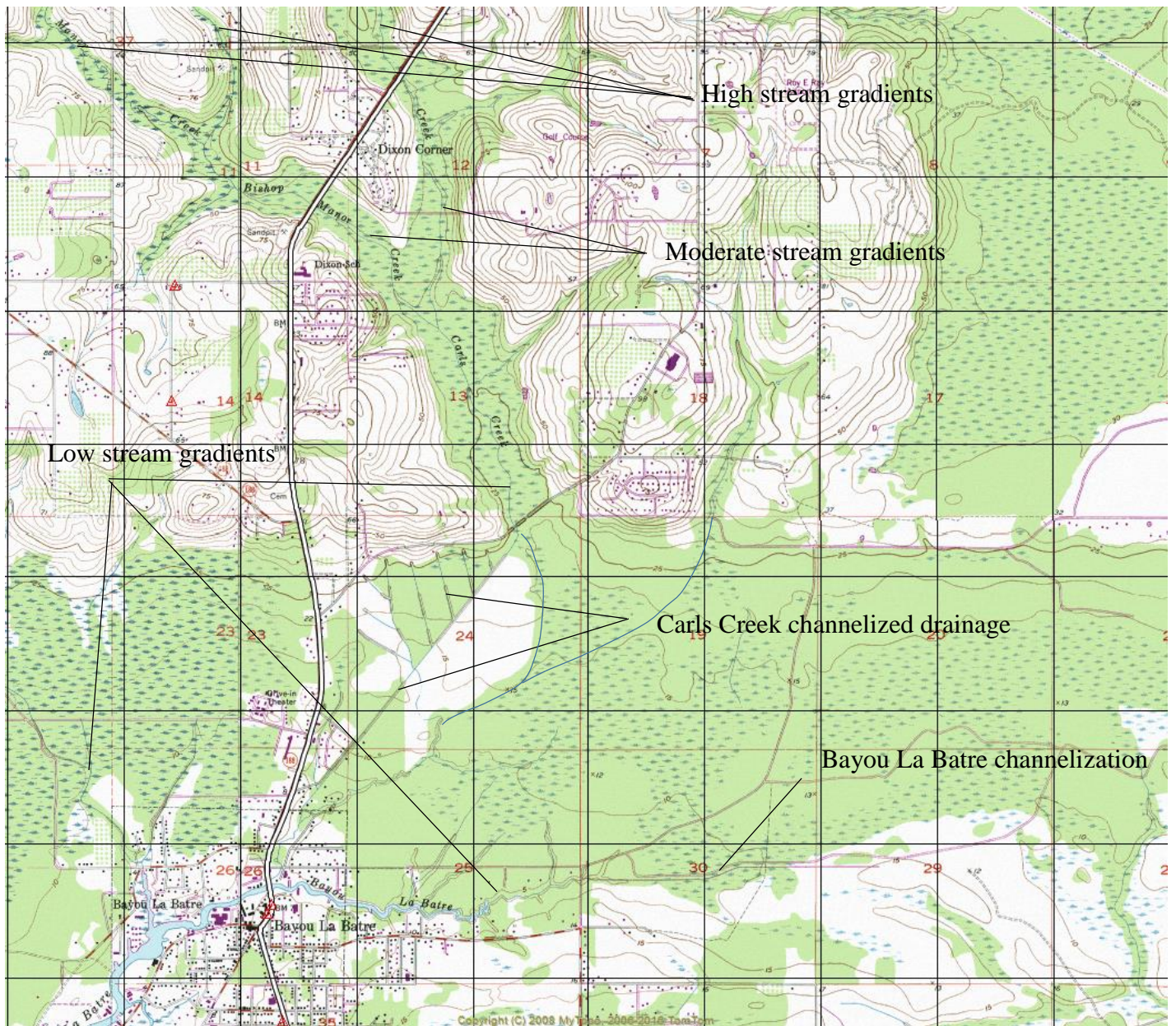


Figure 4.—USGS 7.5-minute topographic map of a selected area of the Bayou La Batre watershed, showing stream gradients and anthropogenic features.

A wide range of discharge events are required to adequately evaluate hydrologic conditions in Bayou La Batre. Table 1 shows that sampling occurred in the Bayou La Batre watershed during discharge conditions from base flow to flood. For example, minimum discharge measured for Carls Creek at Arnette Street (site 3) was 10.3 cfs (January 13, 2016) and the maximum was 444 cfs, measured on January 21, 2016 . Average daily discharge for each monitored stream is also required to adequately estimate constituent loading. Discharge data collected at the USGS stream gaging site 02471078, Fowl River at Half Mile Road, near Laurendine, Alabama was used as a basis for average daily discharge estimation for each monitored stream.

Table 1.—Stream-flow characteristics for monitored sites in the Bayou La Batre watershed.

Monitored site	Average discharge (cfs)	Maximum discharge (cfs)	Minimum discharge (cfs)	Average discharge per unit area (cfs/mi)	Average stream flow velocity (ft/s)	Stream gradient (ft/mi)
1	1,131	1,937 ¹	439 ¹	49	0.6	3.2
2	162	230 ¹	110	35	0.5	8.6
3	131	444	10		1.1	
4	160	281 ¹	17		0.9	
3 and 4	291	725	27	14	1.0	16.3

¹TI- tidal influence

SPECIFIC CONDUCTANCE

Surface water in each project watershed is characterized by a unique specific conductance (SC) (microseimens/centimeter ($\mu\text{S}/\text{cm}$)) profile based on physical and chemical properties. The variability of SC is influenced by differences in stream temperature, discharge, total dissolved solids, local geology and 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 (salt water) at high tide and relatively low SC (fresh water) at low tide. However, the relationship between runoff, discharge, tidal

cycles, and conductivity can be extremely complex, as was observed in data collected at sites BLB1 and BLB2. Table 2 shows SC in monitored streams in the Bayou La Batre watershed. Figure 5 shows the relationship between discharge and conductivity for samples collected at sites BLB 1 and 2. BLB1 samples are grouped by relatively high discharge and low conductivity and relatively low discharge and high conductivity. BLB2 samples are grouped by relatively high and low conductivity, but discharge does not appear to have an influence. This is most likely due to the dominance of wetlands and marsh upstream from site BLB2 that limits surface-water runoff and maximizes groundwater contributions to flow. However, it is clear that tidal cyclicity is a major influence on the chemical character of these waters.

Table 2.—Measured specific conductance values for the Bayou La Batre monitoring sites.

Monitoring site	Maximum conductivity (μS/cm)	Minimum conductivity (μS/cm)	Average conductivity (μS/cm)
1	22,100	101	11,880
2	21,700	42	9,982
3	630	39	230
4	1,690	37	388

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 nephelometric 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. This relationship is more complex in estuaries and streams with tidal influence, as is the case for streams in the Bayou La Batre watershed. Turbidity and TSS in marine settings originate from organic and

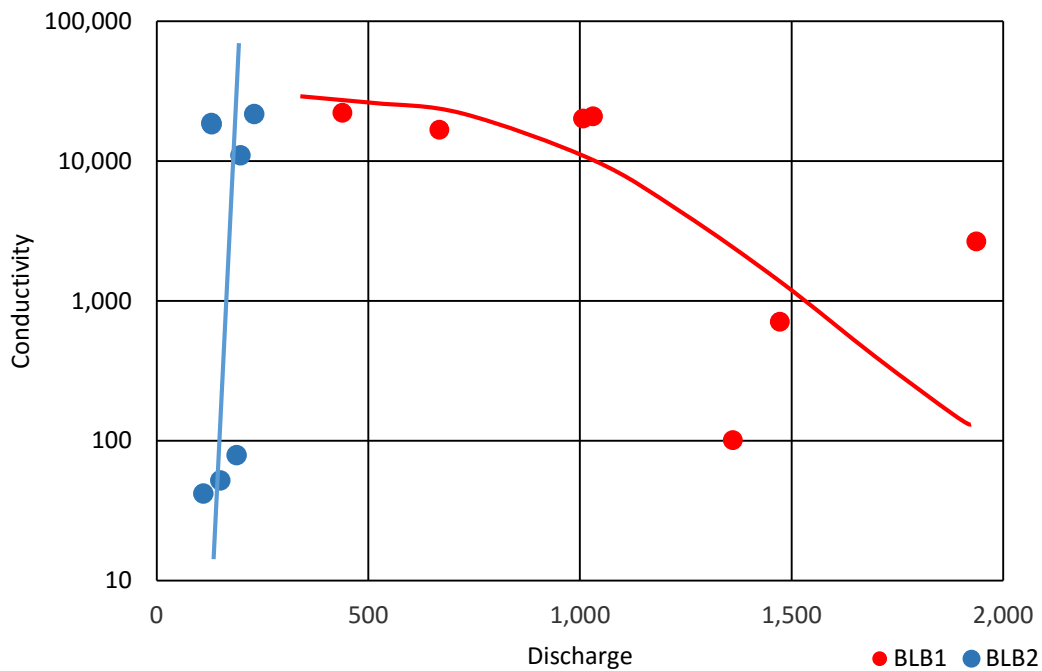


Figure 5.—Conductivity and discharge relationships for samples collected at sites BLB1 and BLB2.

inorganic material. Salinity of the ocean or estuary will cause suspended solids to aggregate, or combine. As the aggregate weight increases, the solids begin to sink and will settle on the seafloor or estuary bottom. This effect causes greater water clarity than is observed in most lakes and rivers. The higher the salinity, the greater the effect. In estuaries and tidal streams, turbidity values may be consistently high, due to the constant resuspension of settled solids as tides move in and out (Fondriest Environmental, Inc., 2014). However, turbidity and TSS in tidally influenced streams in the Bayou La Batre watershed correlate differently, depending on whether the samples are fresh or saline (fig. 6). Samples from Bayou La Batre streams with elevated conductivity (saline water) resulting from tidal influence, on average, have 43 percent higher TSS concentrations than fresh-water samples with the same turbidity values. Figure 6 shows fresh-water and saline-water turbidity and TSS correlations.

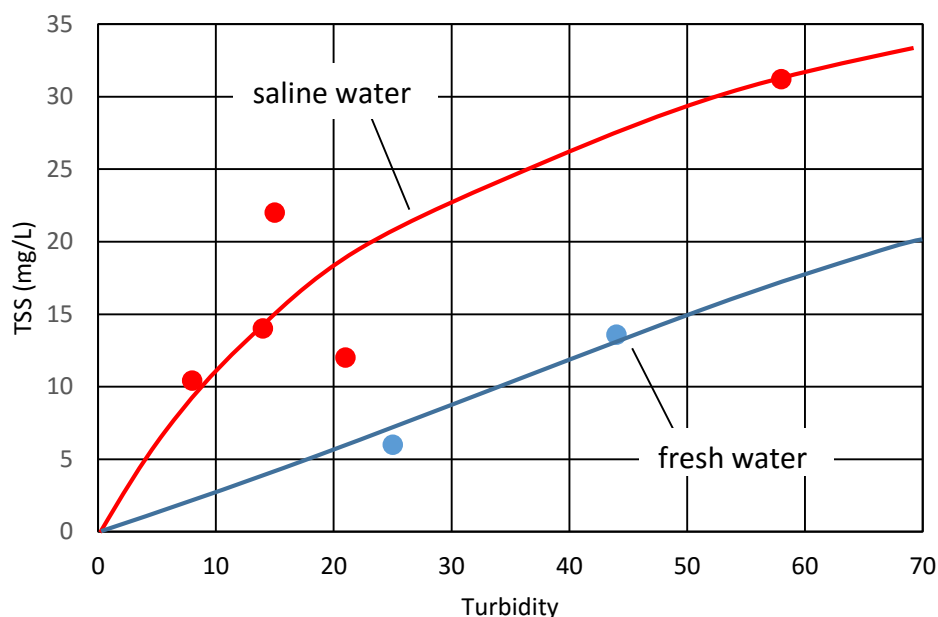


Figure 6.—Turbidity and TSS relationship showing difference between fresh- and saline-water samples at site BLB1.

Analyses of turbidity and stream discharge provide insights into hydrologic, land-use, and general water-quality characteristics of a watershed. Average measured turbidity and discharge, shown in figure 7, illustrates that generally, site BLB3 (channelized part of Carls Creek at Arnette Street) has the highest turbidity to discharge ratio (0.4 NTU/cfs),

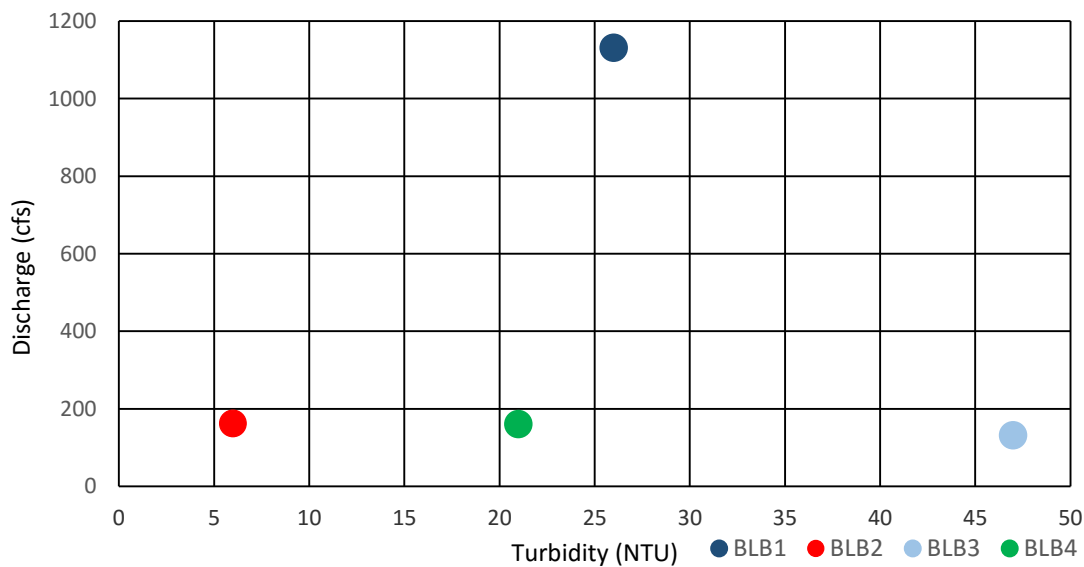


Figure 7.—Average turbidity and discharge relationships for Bayou La Batre monitored sites.

site BLB 4 (natural channel of Carls Creek at Arnette Street) is 0.1 NTU/cfs, site BLB2 (unnamed tributary at Little River Road) is 0.04 NTU/cfs, and site BLB1 (BLB at Wintzel Avenue) has the lowest (0.02 NTU/cfs).

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. Field observation indicate that a number of row crop fields in the headwaters of Bishop Manor Creek have intermittent drainage channels with no vegetative buffers. Although a majority of the monitoring data for Carls Creek (the largest tributary watershed in the Bayou La Batre system) was collected in the downstream part of the watershed in order to estimate constituent loading, additional data were collected at upstream sites to determine tributary and headwaters contributions to downstream water quality. Storm impacted flows were monitored in early August 2016 in the Bishop Manor and Hammar Creeks watershed. Turbidity for Bishop Manor Creek, 1.8 mi upstream from the confluence with Hammar Creek (Bishop Manor Creek at Argyle Road) was 114 NTU and for Hammar Creek, 1.2 mi upstream from the confluence with Bishop Manor Creek (Hammar Creek at 3 Mile Road) was 44 NTU. The highest turbidity measured during the project period was 375 NTU at an unnamed tributary to Hammar Creek at Tom Weller Road. This is a headwaters tributary, where part of the stream flows through row crop fields with no vegetative buffer.

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. 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 and soils, and land use are all important factors that influence sediment transport characteristics of streams. Sediment transport conditions in the Bayou La Batre watershed are evaluated and quantified by tributary, in order 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 Bayou La Batre 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.

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). A pre-monitoring assessment of sediment characteristics indicated that due to low elevation and topographic relief and extensive wetlands, relatively little bed sediment was present in the streams at selected Fowl River monitoring sites. Therefore, total sediment loads for all monitored sites were assumed to be suspended.

SEDIMENT LOADS TRANSPORTED BY PROJECT STREAMS

The rate of transport of sediment 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. Currently, the Bayou La Batre watershed maintains a relatively healthy hydrologic environment, characterized by a relatively rural setting, minimal row crop agriculture, low topographic relief, abundant wetlands, anastomosing stream channels, and forested flood plains. However, a number of anthropogenic impacts to stream flow and water quality were identified in the Bayou La Batre watershed that require evaluation and possible remediation (see Conclusions and Sources of Water-Quality Impacts section of the report).

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 8 shows that turbidity and suspended sediment are closely related in Carls Creek (site BLB3), where water is primarily fresh. Turbidity, TSS, suspended sediment loads, and discharge values for all monitoring sites are shown in table 2.

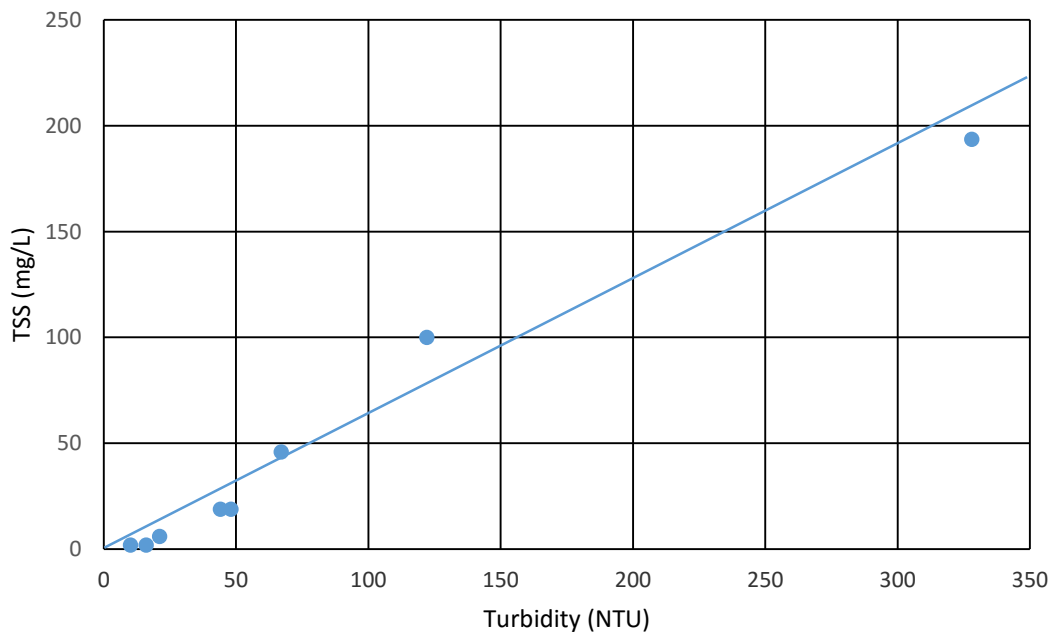


Figure 8.—Turbidity and TSS relationship for fresh-water samples from Carls Creek site BLB3.

Annual suspended sediment loads were estimated for Bayou La Batre monitored streams using the computer regression model Repr_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 estimated by establishing a ratio between periodic measured discharge in project streams and discharge values for the same times obtained from USGS stream gaging site (02471078, Fowl River at Half Mile Road, near Laurendine, Alabama). The USGS gaging site is 7.4 mi northeast of Bayou La Batre and has similar hydrogeologic and hydrologic characteristics (Cook, 2014).

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 TSS for the period of stream flow (July 2015 to July 2016). Site BLB1 (Bayou La Batre at Wintzell Avenue), had a suspended sediment load of 22,277 tons per year (t/yr) (table 3). Site BLB2 (unnamed tributary at Little River Road) and the combined load for sites BLB3 and BLB4 (Carls Creek at Arnette Street) had suspended sediment loads of 2,921 and 7,604 t/yr, respectively. Figure 9 shows estimated average annual daily discharge and suspended sediment loads, which shows that generally, increased discharge results in increased suspended sediment loads for Bayou La Batre monitored sites.

Table 3.—Measured discharge, turbidity, and TSS and estimated suspended sediment loads in monitored streams in the Bayou La Batre watershed.

Monitored site	Average Discharge (cfs)	Average turbidity (NTU)	Maximum turbidity (NTU)	Average TSS (mg/L)	Maximum TSS (mg/L)	Estimated suspended sediment load (t/yr)	Estimated normalized suspended sediment load (t/mi ² /yr)
1	1,131	26	58	16	31	22,277	960
2	162	20	35	12	17	2,921	622
3	131	47	122	28	100		
4	160	21	42	9	26		
3&4 combined	291	34	122	37	106	7,604	367

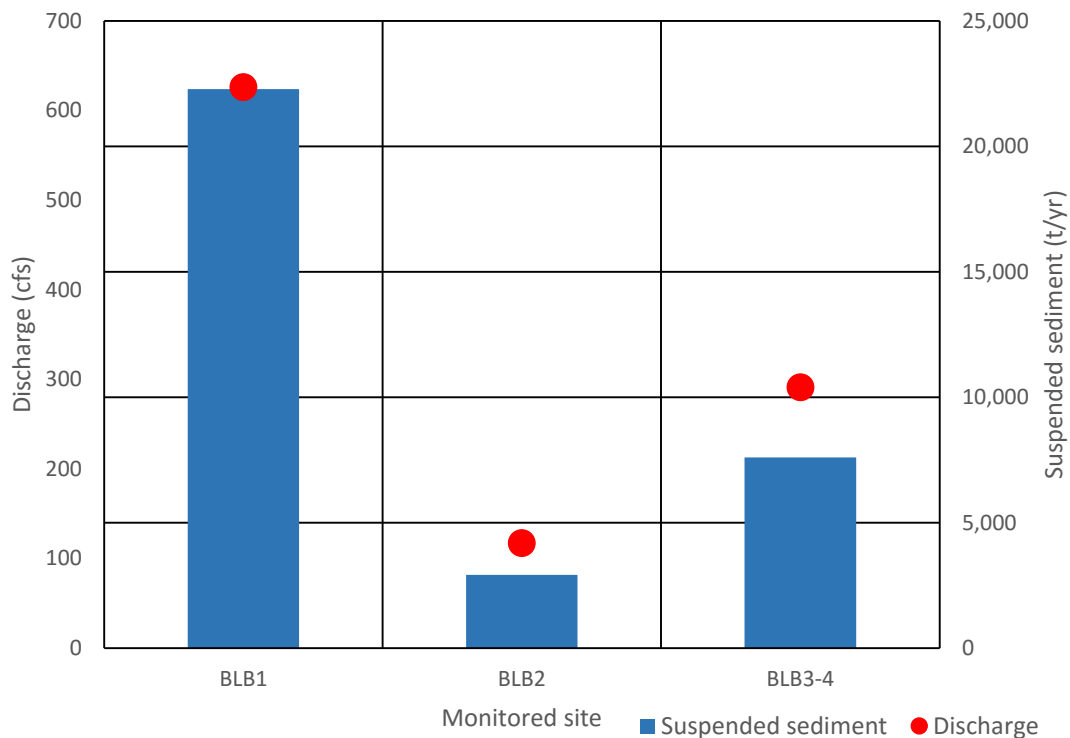


Figure 9.—Average annual daily discharge and suspended sediment loads for Bayou La Batre monitored sites.

For comparison with other watersheds in Mobile County, the largest suspended sediment loads in the Dog River watershed were urban streams, Eslave Creek, Spencer Branch, and Spring Creek with 10,803, 5,970, and 5,198 tons per year (t/yr), respectively (Cook, 2012) and Fowl River watershed streams, Dykes Creek and Fowl River with 1,139 and 795 t/yr, respectively (Cook, 2014). Discharge and watershed area are two of the primary factors that influence sediment transport rates in the Bayou La Batre watershed.

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 in the Bayou La Batre watershed are 960 t/mi²/yr for Bayou La Batre site BLB1 (Bayou La Batre at Wintzell Avenue), 622 t/mi²/yr for site BLB2 (unnamed tributary at Little River Road), and 367 t/mi²/yr for combined sites BLB3 and BLB4 (Carls Creek at Arnette Street). These loads can be compared to the largest normalized loads in Dog River streams, Spencer Branch, Spring Creek, and Eslava Creek with 4,332 and 2,985, and 1,662 t/mi²/yr, respectively (Cook, 2012). The

largest normalized loads in Fowl River streams were, unnamed tributary at Half Mile Road, Dykes Creek, and unnamed tributary at Bellingrath Road with normalized loads of 303 and 271, and 128 t/mi²/yr, respectively. When the contribution of Carls Creek is removed, the suspended sediment load upstream from site BLB1 (Bayou La Batre at Wintzell Avenue) is 14,673 t/yr (5,869 t/mi²/yr). This is a substantial sediment load and normally indicates significant upstream sources of sediment. However, it is suspected that a significant part of the suspended sediment is related to the tidal resuspension of sediment discussed previously.

BED SEDIMENT

Transport of streambed material is controlled by a number of 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 load sediment is composed of particles that are too large or too 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.

Due to a number of factors including relatively small areas of development or land disturbance, limited sources of coarse-grained sediment, relatively low stream gradients and stream flow velocities, and extensive wetlands that slow stream flow velocities and detain sediment, no bed sediment was observed in Bayou La Batre streams except the man-made channel upstream from site BLB3, which was too small to measure. Therefore, all sediment loads are assumed to be suspended.

TOTAL SEDIMENT LOADS

Without human impact, erosion rates in the watershed, called the geologic erosion rate, would be 64 t/mi²/yr (Maidment, 1993). Normalized sediment loads for all three monitored watersheds were at least five times greater than the geologic erosion rate. Calculated non-normalized geologic erosion rate loads are compared to total estimated loads in figure 10.

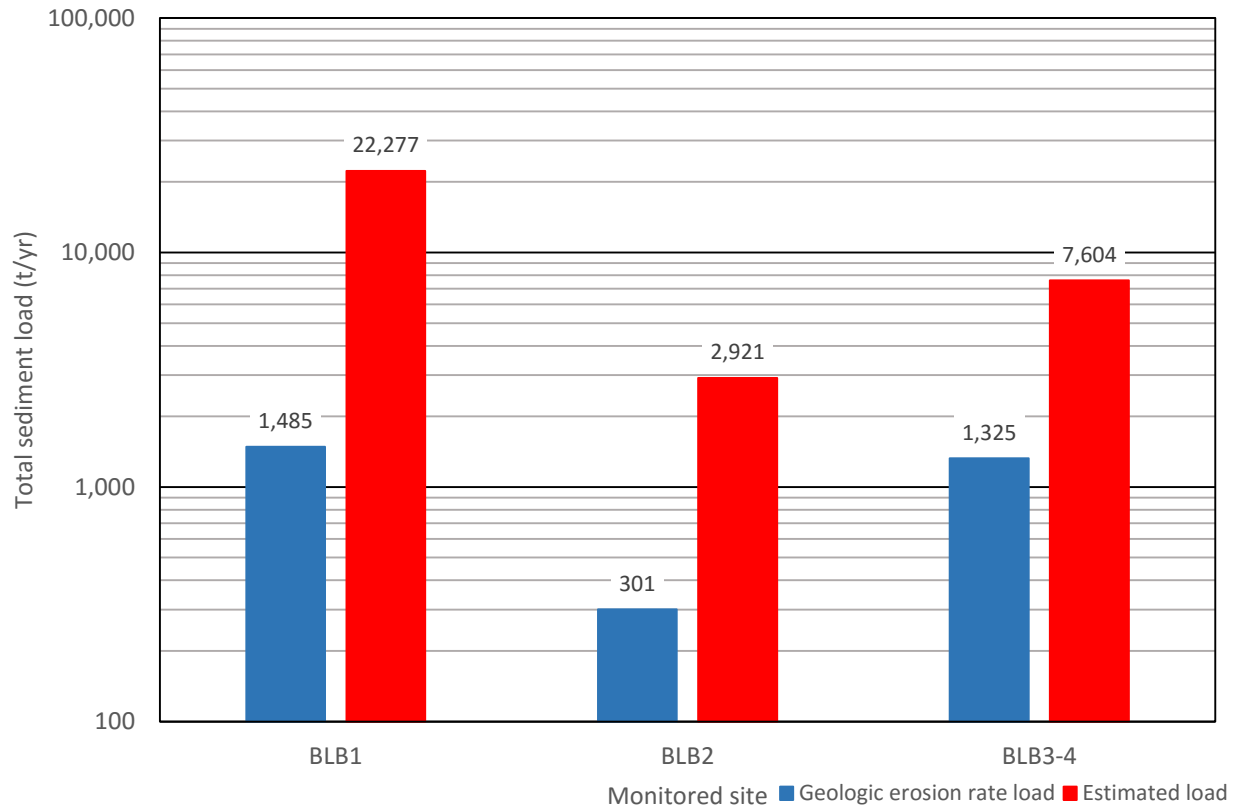


Figure 10.—Comparisons of total sediment geologic erosion rate loads with estimated total sediment loads for monitored Bayou La Batre watersheds.

Comparisons of sediment loads from other watersheds are helpful in determining the severity of erosion problems in a watershed of interest. Estimates of total sediment loads from Dog River site 2 (Spencer Branch at Cottage Hill Road in the city of Mobile) (Cook, 2012), D'Olive Creek site 3 (D'Olive Creek at U.S. Highway 90 in Daphne) (Cook, 2008), Tiawasee Creek site 7 (Tiawasee Creek upstream from Lake Forest) (Cook, 2008), in Baldwin County, Joes Branch site 10 (at North Main Street in Daphne)

(Cook, 2008), Magnolia River site 4 (at U.S. Highway 98) (Cook, 2009), and Bon Secour River site 3 (County Road 12 in Foley) (Cook, 2013) are compared to Bayou La Batre monitored sites in figure 11. GSA estimated sediment loads for more than 60 streams in Alabama. Fowl River at Half Mile Road (site FR2), three miles northeast of the Bayou La Batre watershed, is an excellent reference site for streams in south Mobile County. Fowl River, upstream from site FR2 is characterized by geology, topography, soils, wetlands, and land use is similar to other streams in the region. The estimated sediment load at site FR2 was 53 t/mi²/yr (20 percent lower than the geologic erosion rate).

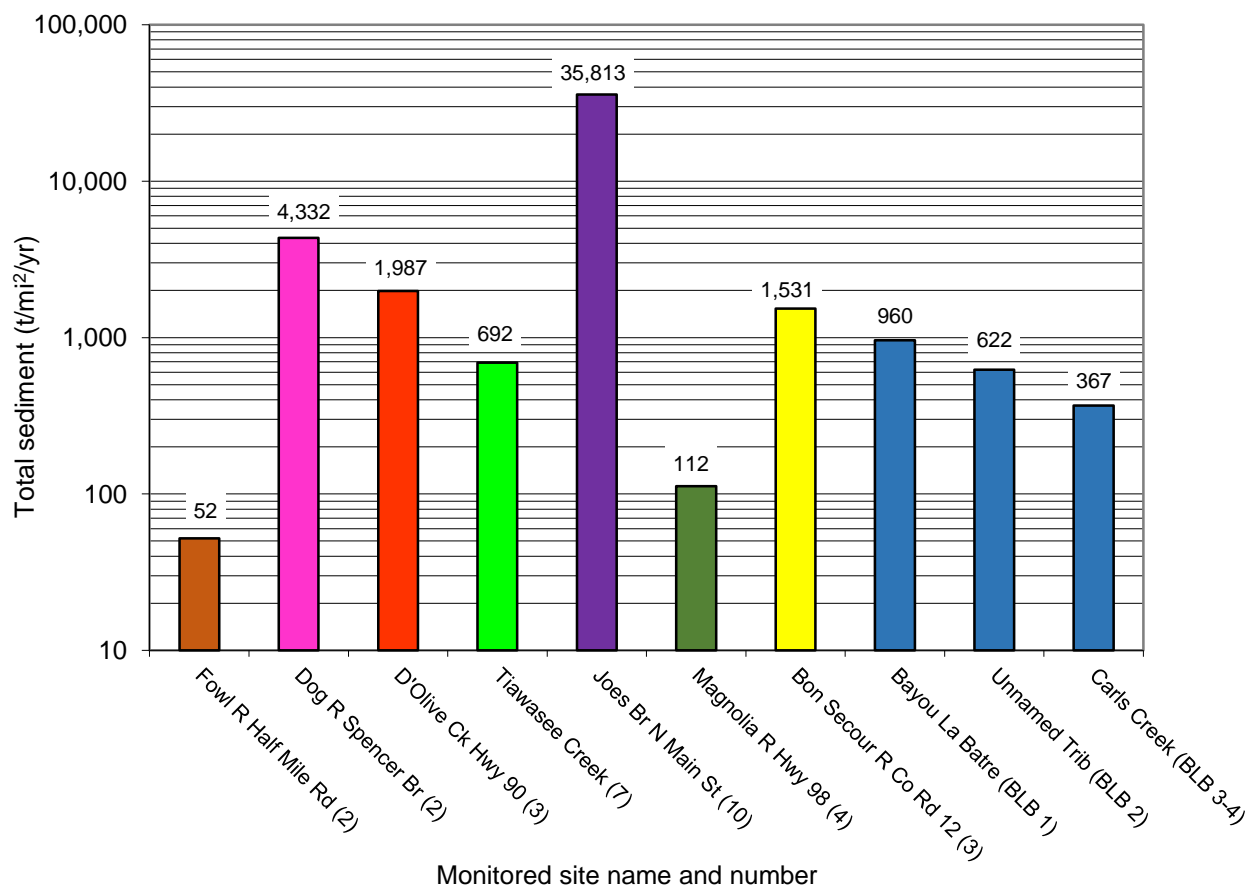


Figure 11.—Comparison of total sediment loads for streams in Baldwin and Mobile Counties.

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 eutrophic 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 ($\text{NO}_3\text{-N}$) and phosphorus (P-total).

NITRATE

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 January through May 2016 at Bayou La Batre monitoring sites for discharge events from base flow to bank full. Samples were analyzed for nitrate. The critical nitrate concentration in surface water for excessive algae growth is 0.5 mg/L (Maidment, 1993). All samples analyzed for nitrate at site BLB1 (Bayou La Batre at Wintzell Avenue) were below detection limit of 0.3 mg/L. All samples analyzed for nitrate from site BLB2 (unnamed tributary to Bayou La Batre at Little River Road) were below detection limit or below the 0.5 mg/L nitrate criterion. Forty-three percent of analytical results from samples collected at site BLB3 (man-made channel of Carls Creek at Arnette Street) were below the detection limit, 43 percent were below the 0.5 mg/L nitrate criterion, and 14 percent exceeded the 0.5 mg/L criterion. Analytical results for samples collected at site BLB4 (natural channel of Carls Creek at Arnette Street) indicate that 57 percent are below the detection limit and 29 percent are below the 0.5 mg/L

nitrate criterion, and 14 percent exceeded the 0.5 mg/L criterion. Lower concentrations of nitrate are common in most streams during high flows due to dilution, resulting in negative regressions when nitrate is plotted with discharge. However, nitrate and discharge are not well correlated for streams in the Bayou La Batre watershed. Extremely small nitrate concentrations at sites BLB1 (Bayou La Batre at Wintzell Avenue) and BLB2 (unnamed tributary to Bayou La Batre at Little River Road) are likely caused by dilution of runoff from the urban area of Bayou La Batre. Nitrate is poorly correlated with discharge at site BLB3 but is relatively well correlated with conductivity (fig. 12). Nitrate/conductivity correlations were the subject of an investigation by Iowa State University researchers (Gali and others, 2012). The Iowa State University researchers showed that in fresh water, conductivity and nitrate form positive regression correlations and in some cases, conductivity could be used as a surrogate for nitrate. Nitrate has a much better correlation with discharge at site BLB4, forming an expected negative regression (fig. 13). These relationships indicate that dilution is a primary control of nitrate concentrations in fresh-water streams.

Although concentrations are relatively small throughout the monitoring period, elevated concentrations of nitrate in Carls Creek are expected, due to row crop agriculture, cattle, and residential development in the headwaters of Bishop Manor Creek and Hammar Creek (tributaries to Carls Creek) (fig. 3).

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). Although no official water-quality criterion for

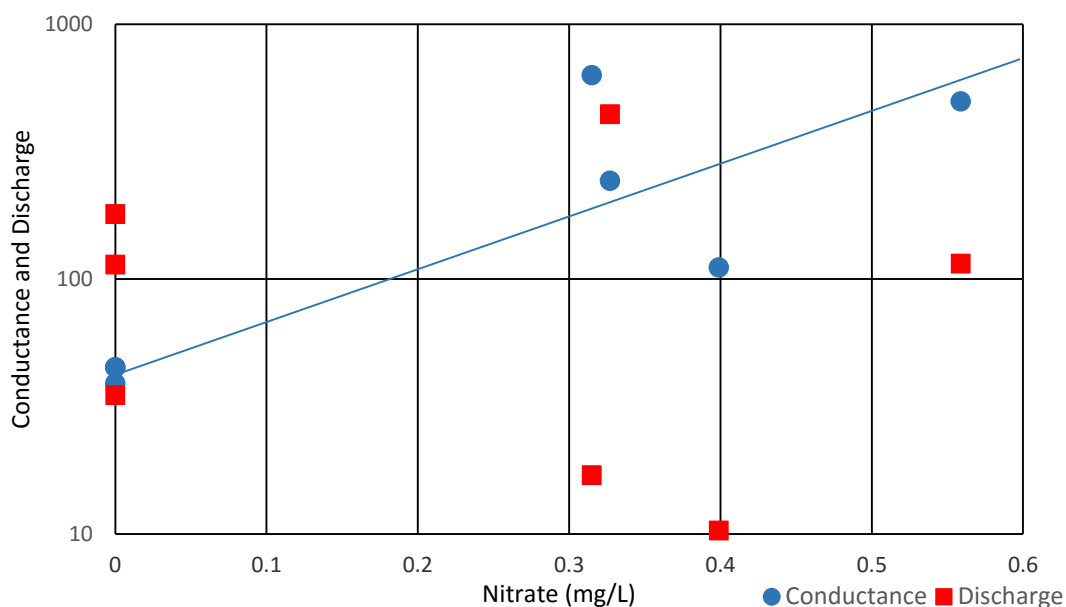


Figure 12.—Relationships of measured nitrate with measured conductance and discharge at site BLB3 (Carls Creek man-made channel at Arnette Street).

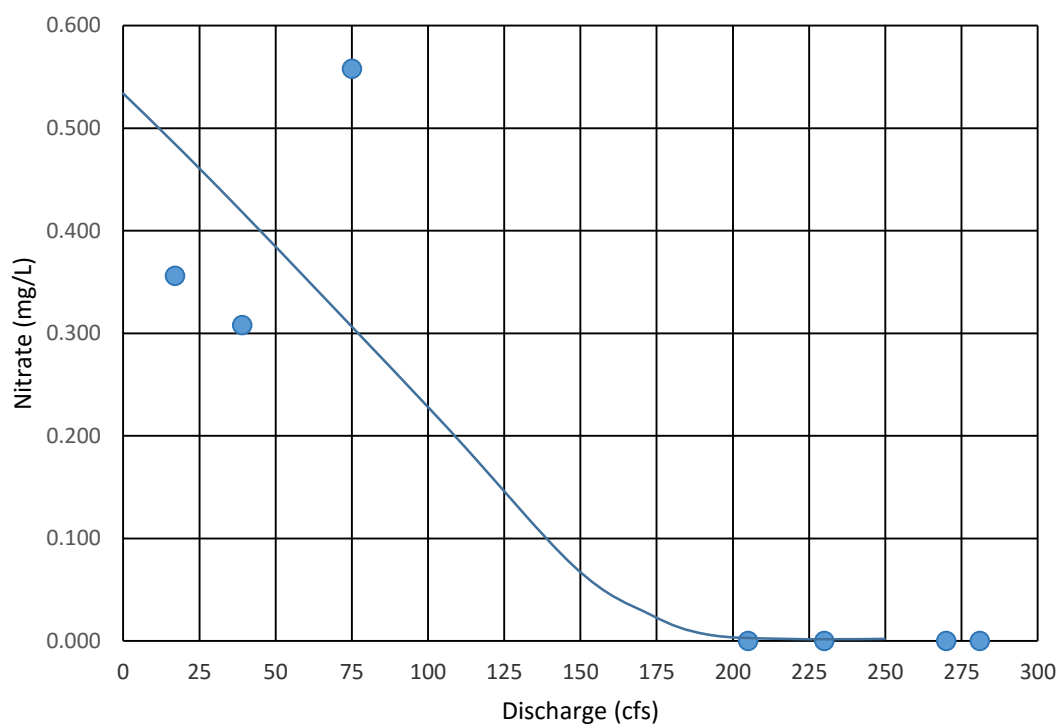


Figure 13.—Relationship of nitrate and discharge at site BLB4 (Carls Creek natural channel at Arnette Street).

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). In many streams phosphorus is

the primary nutrient that influences excessive biological activity. These streams are termed “phosphorus limited.” All samples analyzed for total phosphorus at site BLB1 (Bayou La Batre at Wintzell Avenue) were below detection limit of 0.05 mg/L. All samples but one analyzed for total phosphorus from site BLB2 (unnamed tributary to Bayou La Batre at Little River Road) were below detection limit. One saline water sample collected in April 2016 had a total phosphorus concentration of 0.063 mg/L. All samples but one analyzed for total phosphorus from site BLB3 (man-made channel of Carls Creek at Arnette Street) were below detection limit. The sample collected during the largest discharge event for the monitoring period had a total phosphorus concentration of 0.398, which exceeded the 0.05 mg/L criterion. All samples analyzed for total phosphorus at site BLB4 (natural channel of Carls Creek at Arnette Street) were below detection limit of 0.05 mg/L.

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. The effects of an impoundment on DO in the impounded waters and in the downstream release from the impoundment must be carefully considered in the planning and design stage of a reservoir project. The equilibrium concentration of DO in water that is in contact with air is primarily related to water temperature and barometric pressure and secondarily related to concentrations of other solutes (Hem, 1985). Equilibrium DO in water at 10° C and 25° C is 11.27 mg/L and 8.24 mg/L, respectively. DO concentrations in the project watersheds are significantly affected by water temperature, stream discharge, concentrations of organic material in the water, and oxygen-consuming pollutants. These factors are represented in table 4 where observed DO is compared to the 100 percent dissolved oxygen saturation for the observed stream temperature for each of the monitoring periods. Additional DO measurements were made on August 3, 2016 in Carls Creek tributaries, dominated by wetlands and anastomosing stream channels. Hammar Creek at 3 Mile Road and Bishop Manor Creek at Argyle Road had DO concentrations of 4.7 and 5.2 mg/L, respectively.

Table 4.—Dissolved oxygen measured in monitored streams in the Bayou La Batre watershed.

Site	Dissolved oxygen (mg/L)			Average DO saturation (% atmospheric saturation)
	Maximum	Minimum	Average	
BLB1	8.3	6.9	7.5	84
BLB2	8.2	6.4	7.3	83
BLB3	9.8	6.4	7.4	80
BLB4	8.3	7.1	7.6	84

CONCLUSIONS AND SOURCES OF WATER-QUALITY IMPACTS

Evaluations of sediment loads, water-quality analyses, land-use data, and aerial imagery led to conclusions of probable sources of water quality and habitat impairments in the Bayou La Batre watershed. Stream flow conditions are an important factor that influences erosion, sediment transport, and attenuation of nutrients and other contaminants that impact water quality in a watershed. Streams in the Bayou La Batre watershed are characterized by relatively low gradients, anastomosing channels, forested flood plains, extensive wetlands, and tidal impacts in the downstream part of the watershed. The topography of the watershed can be divided into two zones; an upland headwaters zone and a downstream coastal zone. The upland headwaters zone has elevations of about 140 ft MSL, 80 ft of relief, and three percent slopes. The average stream gradient in the upland zone is about 20 ft/mi. The downstream coastal zone part of the watershed is in the Alabama Coastal Zone and is characterized by extensive wetlands and marsh, maximum elevation of 25 ft MSL, and an average stream gradient of 7 ft/mi.

Carls Creek splits into two channels just south of Padgett Switch Road (fig. 14). Site BLB3 is on the man-made relief channel of Carls Creek at Arnette Street. This site had the highest average turbidity (47 NTUs) and the highest turbidity to discharge ratio (0.4 NTU/cfs).

Site BLB1 (Bayou La Batre at Wintzell Avenue), had a suspended sediment load of 22,277 tons per year (t/yr). Site BLB2 (unnamed tributary at Little River Road) and the combined load for sites BLB3 and BLB4 (Carls Creek at Arnette Street) had suspended sediment loads of 2,921 and 7,604 t/yr, respectively. Sediment loads normalized to unit drainage area in the Bayou La Batre watershed are 960 t/mi²/yr for Bayou La Batre site

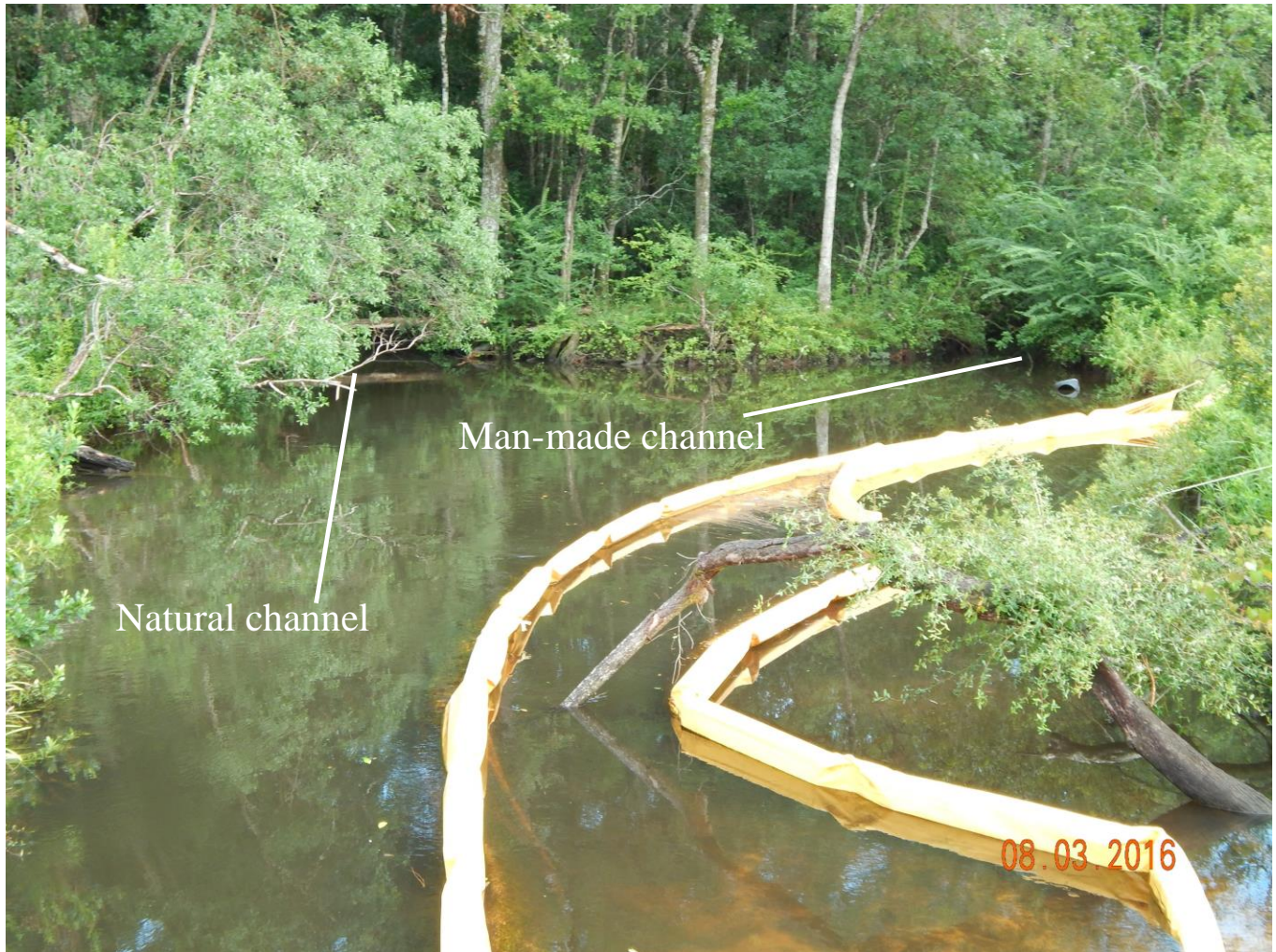


Figure 14.—Carls Creek channel bifurcation just south of Padgett Switch Road.

BLB1, 622 t/mi²/yr for site BLB2, and 367 t/mi²/yr for combined sites BLB3 and BLB4.

When the Carls Creek load is subtracted from the load at Bayou La Batre site BLB1, the remaining load for Bayou La Batre upstream from site BLB1 is 14,673 t/yr (5,869 t/mi²/yr). Field reconnaissance and research review led to the conclusion that this surprisingly large suspended sediment load results from three primary sources. The first, as discussed previously, are estuary streams with tidal influence that have constantly elevated turbidity and suspended sediment due to movement of water upstream and downstream in response to tidal cyclicity that mobilizes fine-grained sediment that settled out in the low gradient estuary zone. Secondly, part of the town of Bayou La Batre storm water runoff enters Bayou La Batre immediately upstream from the BLB1 site. The third

source is from three upstream, unnamed tributaries to Bayou La Batre that have relatively severe bank erosion (fig. 15).

Comparisons of sediment transport rates and water-quality data in watersheds in Baldwin and Mobile Counties indicate that streams in the Bayou La Batre watershed have moderate-sized sediment loads and generally good water quality. This is attributed to the relatively rural setting, extensive wetlands and forests, and use of winter cover crops on agricultural fields. However, water quality and habitats could be improved and protected for the future by employing best management practices that prevent destruction of wetlands, prevent erosion and sediment transport from areas of timber harvesting and row crop agriculture, and control runoff from urban areas including construction sites and areas with significant bare and impervious surfaces. Sources of sediment in the Bayou La Batre watershed include runoff from headwaters row crop agriculture, sand mining operations, and runoff from urban areas in the town of Bayou La Batre (fig. 15). Observations recorded during monitoring included at least seven fields used for row crop agriculture in the headwaters of Bishop Manor and Hammar Creeks have streams or drainage ditches running through them with no vegetative buffer or sediment detention (Google Earth, 2016) (fig. 15). One of these streams (unnamed tributary to Hammar Creek at Tom Waller Road, site BLB8), had the highest turbidity (375 NTU) recorded during during a storm event in early August 2016 (figs. 15, 16). Other potential sediment sources are two sand mining operations (fig. 15).

Water samples collected from January through May 2016 at Bayou La Batre monitoring sites were analyzed for nitrate. The critical nitrate concentration in surface water for excessive algae growth is 0.5 mg/L. All samples analyzed for nitrate at site BLB1 (Bayou La Batre at Wintzell Avenue) were below detection limit of 0.3 mg/L. All samples analyzed for nitrate from site BLB2 (unnamed tributary to Bayou La Batre at Little River Road) were below detection limit or below the 0.5 mg/L nitrate criterion. Forty-three percent of analytical results from samples collected at site BLB3 (man-made channel of Carls Creek at Arnette Street) were below the detection limit, 43 percent were below the 0.5 mg/L nitrate criterion, and 14 percent exceeded the 0.5 mg/L criterion. Analytical results for samples collected at site BLB4 (natural channel of Carls Creek at Arnette Street) indicate that 57 percent are below the detection limit and 29 percent are below the 0.5 mg/L nitrate criterion, and 14 percent exceeded the 0.5 mg/L criterion.

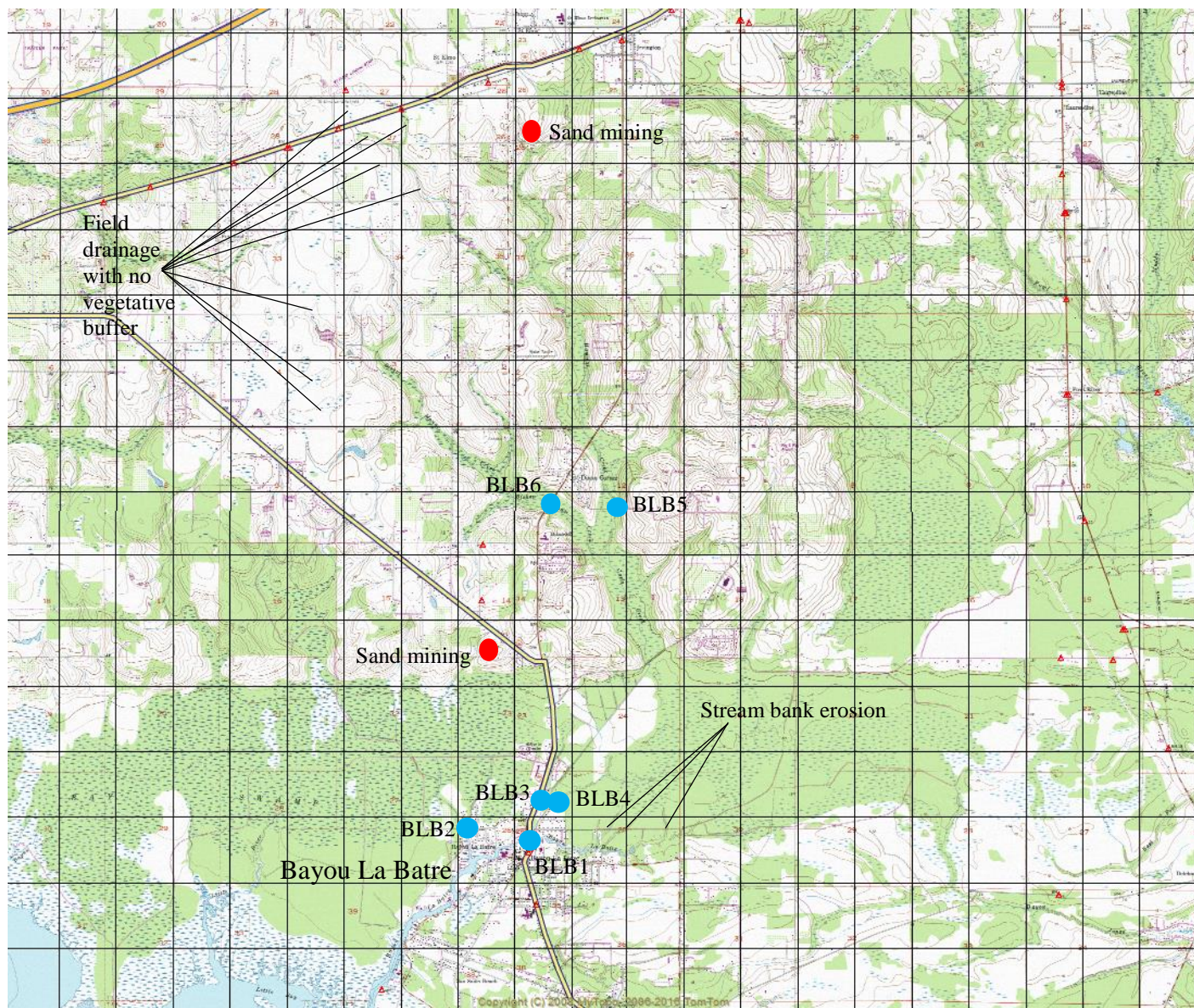


Figure 15.—Sources of water quality impacts identified by field observations.



Figure 16.—Turbid runoff from row-crop fields in unnamed tributary to Hammar Creek at Tom Waller Road immediately after a rain event.

Water samples collected at Bayou La Batre monitoring sites were also analyzed for total phosphorus. All samples collected at site BLB1 (Bayou La Batre at Wintzell Avenue) were below detection limit of 0.05 mg/L. All samples but one analyzed for total phosphorus from site BLB2 (unnamed tributary to Bayou La Batre at Little River Road) were below detection limit. One saline water sample collected in April 2016 had a total phosphorus concentration of 0.063 mg/L. All samples but one analyzed for total phosphorus from site BLB3 (man-made channel of Carls Creek at Arnette Street) were below detection limit. The sample collected during the largest discharge event for the monitoring period had a total phosphorus concentration of 0.398, which exceeded the 0.05 mg/L criterion. All samples analyzed for total phosphorus at site BLB4 (natural channel of Carls Creek at Arnette Street) were below detection limit of 0.05 mg/L.

This assessment indicates that the water quality in the Bayou La Batre watershed is relatively good, due primarily to the rural character of the watershed and land cover dominated by forest and wetlands. However, sediment loads are significantly larger than the geologic erosion rate. Therefore, steps should be taken to correct current impairments and to protect the watershed from future negative impacts that are common in streams in Alabama's coastal region, including urban expansion, timber cutting, poorly maintained agricultural fields, and conversion of agricultural and forest land to residential development. One of the primary targets of watershed protection should be preservation of wetlands and marsh in the Bayou La Batre watershed.

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APPENDIX A

FIELD AND ANALYTICAL DATA

Bayou La Batre at North Wintzel Avenue

Drainage area=23.2 square miles

Site	Date	Time	Discharge	Temp	Conductance	Turbidity	pH	DO	Salinity	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L		mg/L	mg/L	mg/L
BLB1	01/13/16	9:05	439		22,100	8	6.4		13.2	10.4	<0.3	<.05
BLB1	01/21/16	22:40	668		16,700	15	6.0		10	22.0	<0.3	<.05
BLB1	02/15/16	20:45	1,031	15.1	20,800	21	7.3	8.3	12.4	12.0	<0.3	<.05
BLB1	03/11/16	14:10	1,937	19.7	2,650	58	6.9	7.1	1.4	31.2	<0.3	<.05
BLB1	03/28/16	11:15	1,362	21.0	101	25	5.9	7.5	0	6.0	<0.3	<.05
BLB1	04/01/16	14:45	1,473	21.2	709	44	6.5	6.9	0.3	13.6	<0.3	<.05
BLB1	05/31/16	18:10	1,008	28.1	20,100	14	6.9	7.8	12.0	14.0	<0.3	<.05

Unnamed Tributary to Bayou La Batre at Little River Road

Drainage area=4.7 square miles

Site	Date	Time	Discharge	Temp	Conductance	Turbidity	pH	DO	Salinity	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L		mg/L	mg/L	mg/L
BLB2	01/13/16	8:45	130		18,300	8	6.0		11	10.0	<.3	<.05
BLB2	01/21/16	22:55	198		11,000	16	6.0		6.6	13.6	0.424	<.05
BLB2	02/15/16	21:00	230	15.1	21,700	35	7.0	8.2	13.0	16.8	<.3	<.05
BLB2	03/11/16	14:25	189	19.2	79	30	5.3	7.4	0.0	11.6	<.3	<.05
BLB2	03/28/16	11:30	110	20.9	42	13	4.6	7.5	0.0	7.0	<.3	<.05
BLB2	04/01/16	14:55	150	20.8	52	22	5.5	6.4	0.0	8.4	<.3	<.05
BLB2	05/31/16	18:30	129	29.1	18,700	16	6.7	7.0	11.1	15.2	<.3	0.063

Carls Creek at Arnette Street (man-made channel)

Drainage area=17.8

Site	Date	Time	Discharge	Temp	Conductance	Turbidity	pH	DO	Salinity	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L		mg/L	mg/L	mg/L
BLB3	01/13/16	8:20	10.3		111	16	5.5		0.07	2	0.399	<.05
BLB3	01/21/16	23:10	444		243	122	6.8		0.1	100.0	0.327	0.398
BLB3	02/15/16	21:15	115	14.9	498	44	6.4	7.4	0.2	18.8	0.559	<.05
BLB3	03/11/16	14:30	180	19.3	39	67	6.4	7.1	0	46.0	<.3	<.05
BLB3	03/28/16	11:40	35	21.0	45	21	6.0	9.8	0	6.0	<.3	<.05
BLB3	04/01/16	15:05	114	20.8	45	48	6.3	6.5	0	18.8	<.3	<.05
BLB3	05/31/16	18:45	17	25.6	630	10	4.3	6.4	0.2	2.0	0.315	<.05

Unnamed Tributary to Bayou La Batre at Arnette Street (natural channel)

Drainage area=2.9 square miles

Site	Date	Time	Discharge	Temp	Conductance	Turbidity	pH	DO	Salinity	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L		mg/L	mg/L	mg/L
BLB4	01/13/16	8:30	17		112	6	5.6		0.07	2	0.356	<.05
BLB4	01/21/16	23:20	281		1,690	10	5.6		1	6.4	<.3	<.05
BLB4	02/15/16	21:20	75	14.7	110	20	6.4	7.5	0.1	5.6	0.558	<.05
BLB4	03/11/16	14:35	270	19.2	37	42	6.1	7.3	0	26.4	<.3	<.05
BLB4	03/28/16	11:50	205	20.9	42	32	6.3	7.6	0	8.4	<.3	<.05
BLB4	04/01/16	15:15	230	20.9	45	35	6.4	7.1	0	10.8	<.3	<.05
BLB4	05/31/16	18:55	39	25.2	680	5	4.6	8.3	0.3	2.0	0.308	<.05

BLB 5 Hammar Creek at 3 mile road

Site	Date	Time	Discharge	Temp	Conductance	Turbidity	pH	DO	Salinity	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L		mg/L	mg/L	mg/L
BLB5	8/3/2016	1630	55	25.1	79	44	5.6	4.7	0	24.0	0.509	<.05

Bishop Manor Creek at Argyle Road

Site	Date	Time	Discharge	Temp	Conductance	Turbidity	pH	DO	Salinity	TSS	Nitrate	Total Phosphorus
			cfs	°C	mS/cm	NTU		mg/L		mg/L	mg/L	mg/L
BLB6	8/3/2016	1650	28	25.2	46	114	6.0	5.2	0	50.0	<.3	0.116

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