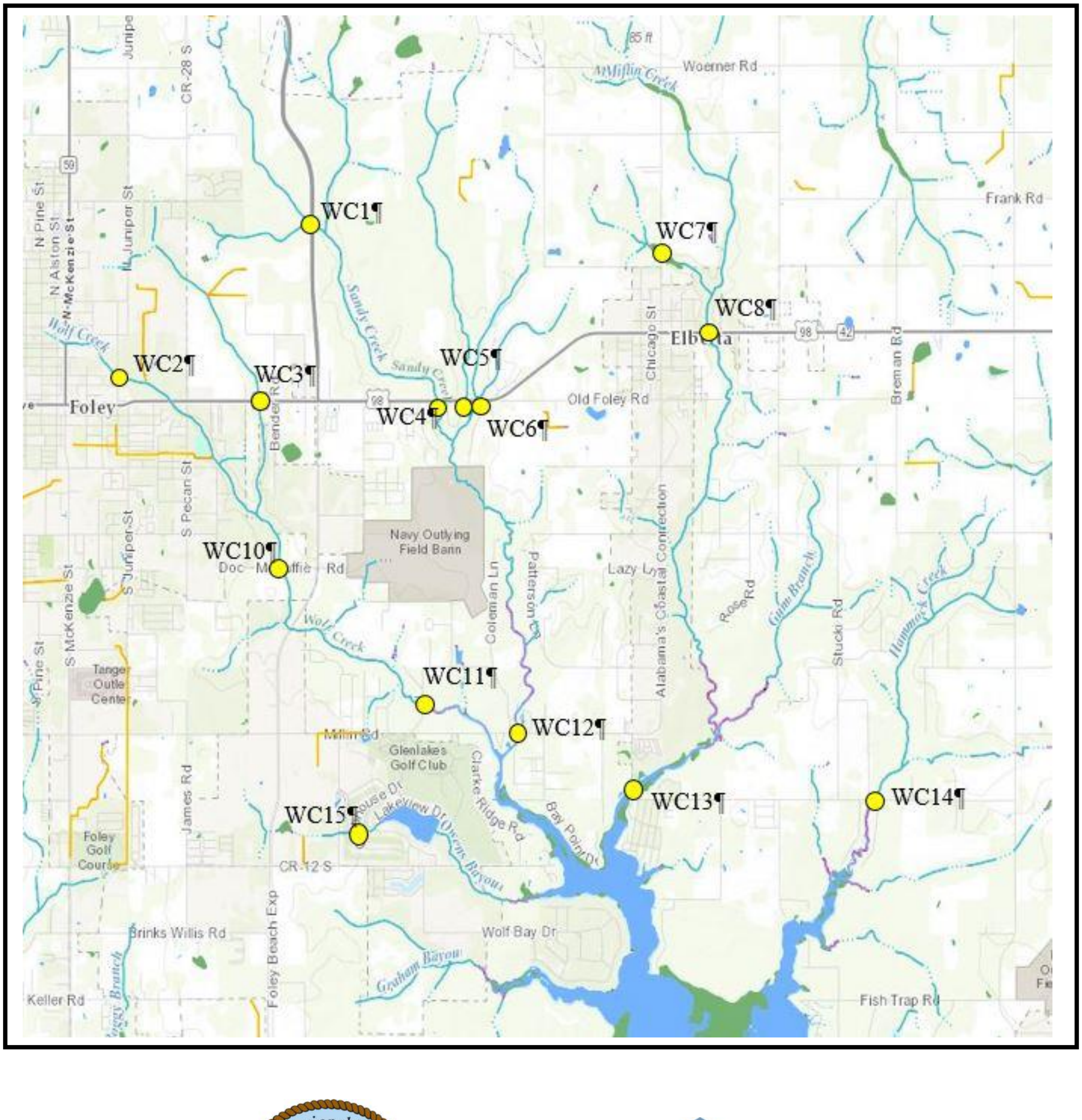
# PRE-RESTORATION ANALYSIS OF DISCHARGE, SEDIMENT TRANSPORT RATES, WATER QUALITY, AND LAND-USE IMPACTS INTHE WOLF BAY WATERSHED, BALDWIN COUNTY, ALABAMA



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By

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TABLE OF CONTENTS



ILLUSTRATIONS

TABLES

## INTRODUCTION

Baldwin County is among the fastest growing areas in Alabama with a 14.4 percent (%) population increase between 2010 and 2016, compared to a 1.7% growth rate for the rest of the state for the same period (US Census, 2016). However, with rapid growth comes quality of life issues, including traffic, increasing water demand, loss of natural landscapes, and watershed degradation. When activities related to population and economic growth are combined with highly erodible soils and 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 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 city of Foley is an example of Baldwin County rapid population growth with a 20.5% increase between 2010 and 2016 (US Census, 2016). The city is on a watershed divide, where runoff from the southern and western parts of the city drains into Bon Secour River, Bon Secour Bay, and Mobile Bay and the eastern part drains into Wolf Creek, Wolf Bay, Perdido Bay, and the Gulf of Mexico.

The purpose of this investigation is to assess general hydrogeologic and water quality conditions and to estimate nutrient loads and sediment transport rates for tributaries to Wolf Bay including Owens Bayou, Hammock Creek, Miflin Creek, Sandy Creek, and Wolf Creek and their tributaries (fig. 1). 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 Wolf Bay watershed.

## ACKNOWLEDGMENTS

Ms. Roberta Swann, Director; Mr. Tom Herder, Watershed Protection Coordinator, Mobile Bay National Estuary Program, provided administrative and coordination assistance for the project; Mr. Bruce Bradley, President, Polyengineering, Inc., provided administrative assistance; Ms. Leslie Gahagan, Environmental Manager,

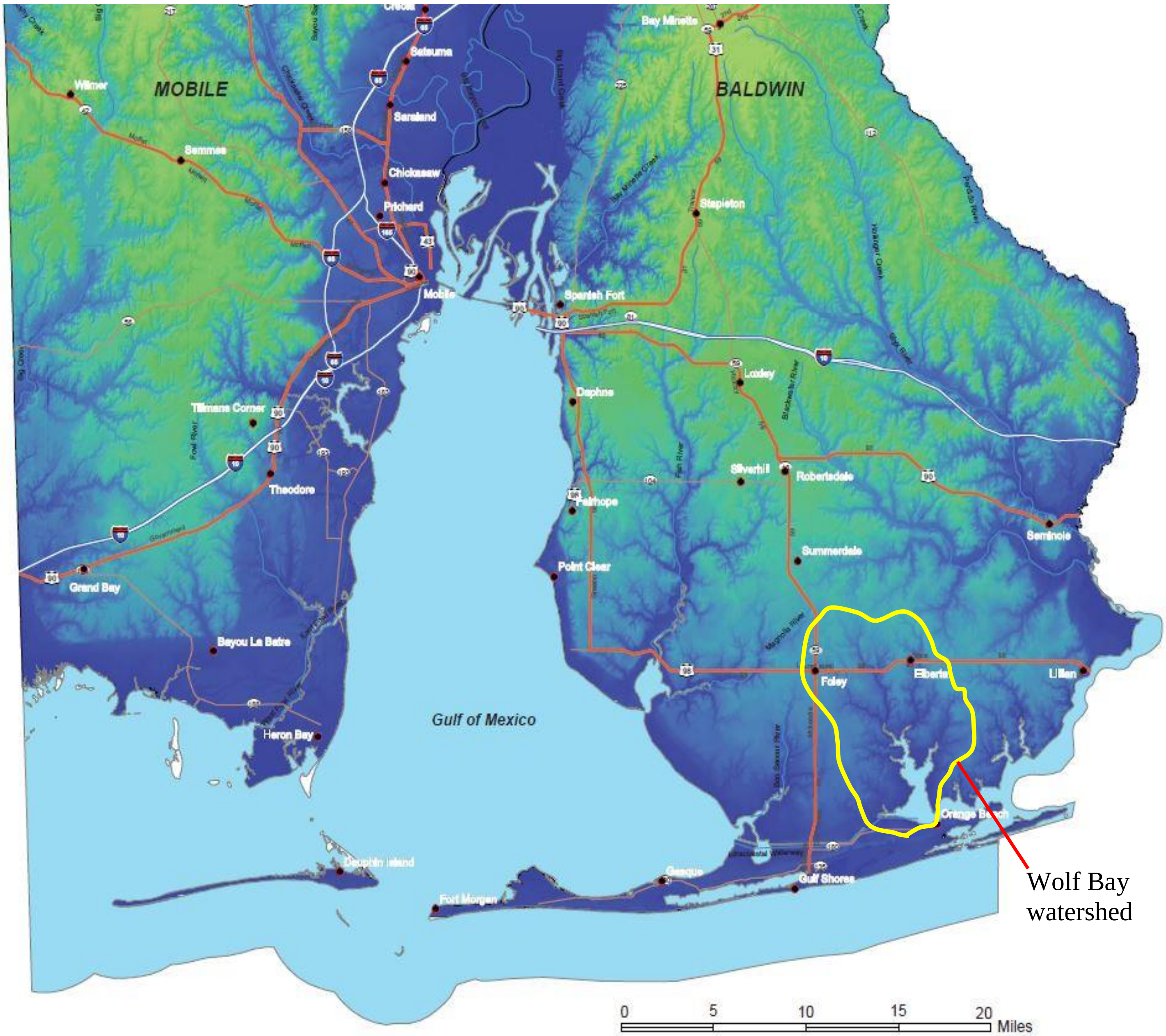


Figure 1.—Mobile and Baldwin Counties with the Wolf Bay watershed.

city of Foley, provided technical assistance; and Mr. Tony Darling, Riviera Utilities, provided bacterial analyses for the project.

## PROJECT AREA

The Wolf Bay watershed covers about 54 square miles ($mi^2$) (US Geological Survey (USGS), 2017) in two major tributary watersheds; Wolf Creek (44.4 $mi^2$) and Hammock Creek (9.7 $mi^2$). The project area has 14 monitoring sites on 10 streams, extending from headwaters north of US Highway 98 to brackish reaches along the norther margin of Wolf Bay (fig. 2). Elevations in the project area vary from about 85 feet above mean sea level (ft MSL) at the headwaters to sea level at the mouth. There are currently no streams in the Wolf Bay watershed that are on the Alabama Department of Environmental Management (ADEM) 303(d) list of impaired waters in Alabama (ADEM, 2017). In 2007 Wolf Bay was declared an Outstanding Alabama Water.

## PROJECT MONITORING STRATEGY AND SITE CHARACTERISTICS

The strategy employed for the Wolf Bay project was to select monitoring sites on as many tributaries as possible, based on accessibility and reach length. 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, salinity (where applicable), and dissolved oxygen. Laboratory analyses was performed for total suspended solids, nitrate+nitrite nitrogen, and total phosphorus. Bed sediment transport rates were measured and daily and annual loads were estimated for suspended and bed sediment, nitrogen, and phosphorus.

Site WC1 is on Sandy Creek at the Foley Beach Expressway, about 2.5 miles downstream from the headwaters (latitude (lat) 30.42614, longitude (long) -87.64850). The watershed upstream from site WC1 covers 1,408 acres (2.2 $mi^2$) (USGS, 2017) (fig. 2).

Site WC2 is on Wolf Creek at north Poplar Street, about 1 mile downstream from the headwaters (lat 30.40967, long -87.67639). The watershed upstream from site WC2 covers 634 acres (0.99 $mi^2$) (USGS, 2017) (fig. 2).

Site WC3 is on an unnamed tributary to Wolf Creek at US Highway 98 (lat 30.40690, long -87.65579). The watershed upstream from site WC3 covers 826 acres (1.3 $mi^2$) (USGS, 2017) (fig. 2).

Site WC4 is on Sandy Creek at US Highway 98, (lat 30.40684, long -87.63024).

The watershed upstream from site WC4 covers 3,776 acres (5.9 $mi^2$) (USGS, 2017) (fig. 2).

Site WC5 is on an unnamed tributary at US Highway 98 about 1,200 ft from the confluence with Sandy Creek, (lat 30.40667, long -87.62627). The watershed upstream from site WC5 covers 1,088 acres (1.7 $mi^2$) (USGS, 2017) (fig. 2).

Site WC6 is on an unnamed tributary to Sandy Creek at US Highway 98, (lat 30.40671, long -87.62481). The watershed upstream from site WC6 covers 1,114 acres (1.74 $mi^2$) (USGS, 2017) (fig. 2).

Site WC7 is on Elberta Creek at Baldwin County Road 83, (lat 30.42262, long -87.59837). The watershed upstream from site WC7 covers 704 acres (1.1 $mi^2$) (USGS, 2017) (fig. 2).

Site WC8 is on Miflin Creek at US Highway 98, about 3.2 mi from the headwaters (lat 30.41433, long -87.59159). The watershed upstream from site WC8 covers 2,368 acres (3.7 $mi^2$) (USGS, 2017) (fig. 2).

Site WC10 is on Wolf Creek at Doc McDuffie Road, (lat 30.38979, long -87.65302). The watershed upstream from site WC10 covers 3,136 acres (4.9 $mi^2$) (USGS, 2017) (fig. 2).

Site WC11 is on Wolf Creek at Swift Church Road, (lat 30.37350, long -87.63262). The watershed upstream from site WC11 covers 5,696 acres (8.9 $mi^2$) (USGS, 2017) (fig. 2).

Site WC12 is on Sandy Creek at Baldwin County Road 20, (lat 30.37041, long -87.61852). Sandy Creek at site WC12 is tidally influenced. The watershed upstream from site WC12 covers 8,512 acres (13.3 $mi^2$) (USGS, 2017) (fig. 2).

Site WC13 is on Miflin Creek at Baldwin County Road 20, (lat 30.36395, long -87.60249). Miflin Creek at site WC13 is tidally influenced. The watershed upstream from site WC13 covers 8,000 acres (12.5 $mi^2$) (USGS, 2017) (fig. 2).

Site WC14 is on Hammock Creek at Baldwin County Road 20, (lat 30.36303, long -87.56769). Hammock Creek at site WC12 is tidally influenced. The watershed upstream from site WC14 covers 2,432 acres (3.8 $mi^2$) (USGS, 2017) (fig. 2).

Site WC15 is on Owens Bayou at Lakeview Drive, 1.0 mi from the headwaters (lat 30.35980, long -87.63927). Site WC15 is 300 ft upstream from Lake Muriel. The watershed upstream from site WC15 covers 512 acres (0.8 $mi^2$) (USGS, 2017) (fig. 2).

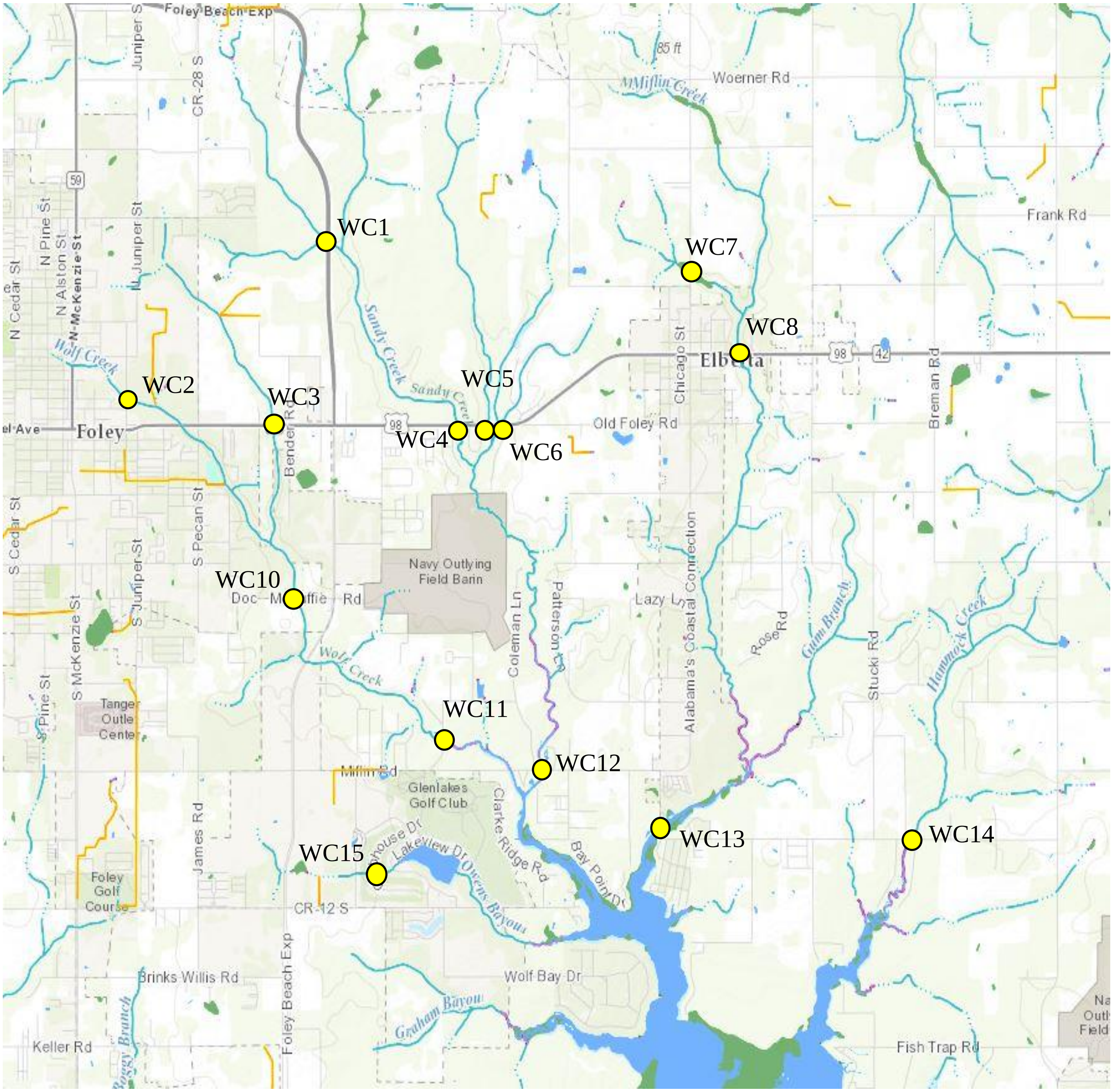


Figure 2.—Monitoring sites for streams in the Wolf Bay watershed.

## 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 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).

The dominant land use/land cover category in the Wolf Bay watershed is forest, which includes forested wetlands (fig. 3). Most streams flow through forested floodplains or are anastomosing. 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. Agriculture is the second largest land use/land cover and dominates headwaters and areas of higher elevation. Crops consist of peanuts, soybeans, corn, cotton, pecans, and pasture and hay (fig. 3). Developed land is dominated by residences and commercial development, primarily along roadways, and residential development on land previously used for agriculture. Developed land covers about 16% of the watershed (USGS, 2017) (fig. 3). Land uses and their specific impacts are discussed in detail in the Conclusions and 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. Numerous streams in Baldwin County exhibit flashy discharge due to relatively high topographic relief and land-use change. Stream channels in the northern parts of the watershed, including the headwaters of Wolf, Sandy, and Miflin Creeks, are characterized by relatively high elevation (maximum 100 ft MSL), with topography that decreases in relief from north (upstream) to south (downstream) towards Wolf Bay. Monitored tributary floodplains are dominated by forest and wetlands, with channels that are in part, anastomosing, and

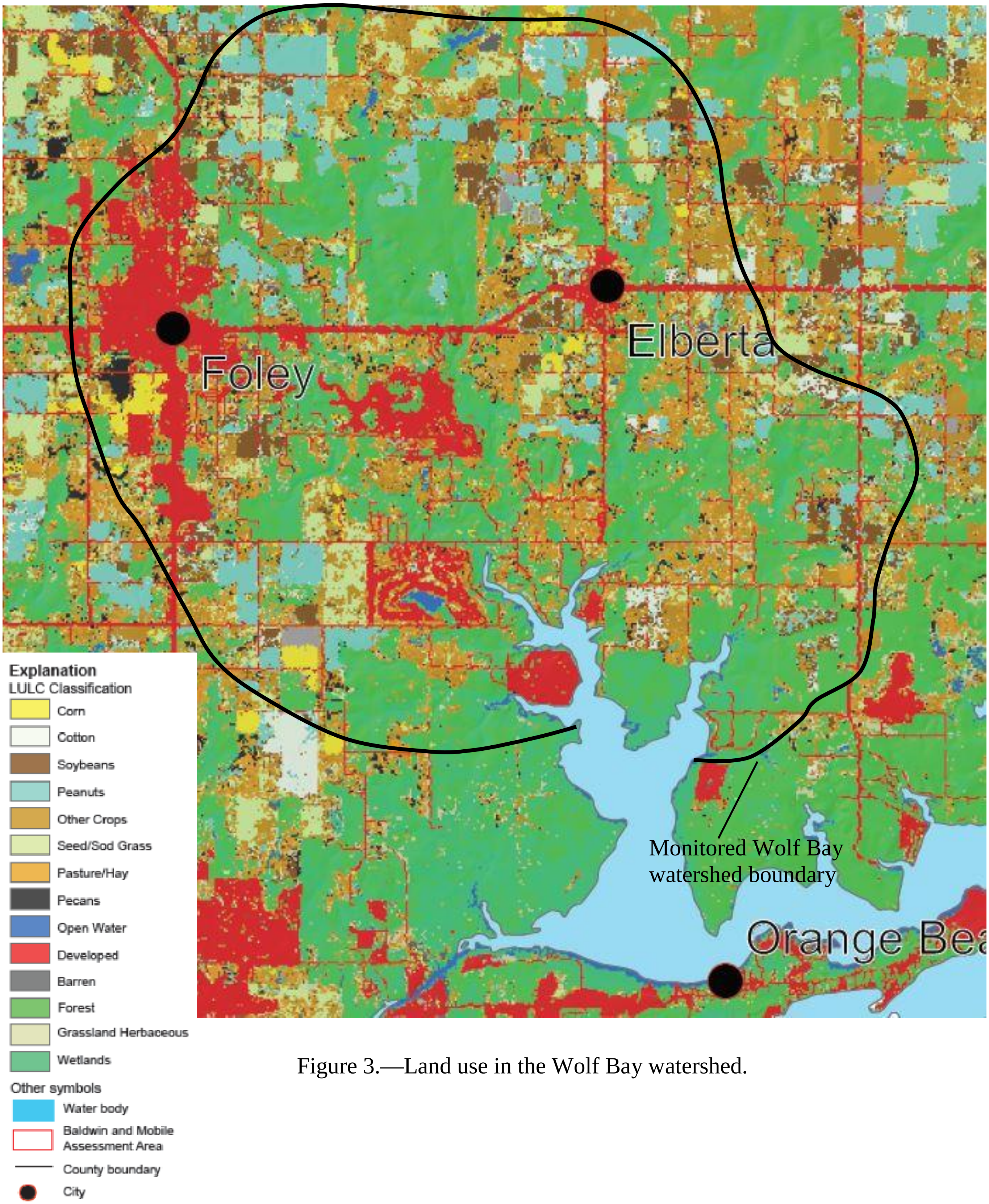


Figure 3.—Land use in the Wolf Bay watershed.

stream gradients that vary from 14.3ft/mi for Wolf Creek, 15.7 ft/mi for Sandy Creek, 16.1 ft/mi for Miflin Creek, and 26.5 ft/mi for Hammock Creek (table 1).

A wide range of discharge events are required to adequately evaluate hydrologic conditions and water quality in the Wolf Bay watershed. Table 1 shows that sampling occurred during discharge conditions from base flow to flood. For example, for the project period, minimum average daily discharge for Wolf Creek at Doc McDuffie Road (site WC10) was 6.8 cubic ft/second (cfs) (October 28, 2016) and the maximum was 149 cfs, on April 3, 2017. Average daily discharge for each monitored stream is required to adequately estimate constituent loading. Discharge data collected at the USGS stream gaging site 02378170, Wolf Creek below Foley, Alabama was used as a basis for average daily discharge calculation for each monitored stream.

Table 1.—Stream-flow characteristics for monitored sites in the Wolf Bay watershed.

| Monitored site | Average measured discharge (cfs) | Maximum measured discharge (cfs) | Minimum measured discharge (cfs) | Average discharge per unit area (cfs/mi$^2$) | Stream gradient (ft/mi) |
|---|---|---|---|---|---|
| WC1 | 22 | 44 | 5.1 | 10.0 | 21.0 |
| WC2 | 16 | 35 | 0.8 | 16.0 | 18.8 |
| WC3 | 44 | 180 | 1.0 | 34.0 | 18.6 |
| WC4 | 48 | 170 | 14.0 | 8.1 | 18.6 |
| WC5 | 9 | 29 | 0.7 | 5.3 | 22.9 |
| WC6 | 11 | 31 | 1.0 | 6.5 | 29.8 |
| WC7 | 22 | 63 | 2.7 | 20.0 | 27.3 |
| WC8 | 41 | 140 | 3.9 | 11.1 | 18.5 |
| WC10 | 55 | 149 | 6.8 | 11.3 | 18.5 |
| WC11 | 159 | 718 | 17.5 | 17.9 | 16.1 |
| WC12 | 398 | 940 | 151.0 | 29.9 | 12.5 |
| WC13 | N/A[1] | N/A | N/A | N/A | 12.7 |
| WC14 | 62 | 218 | 10.0 | 16.3 | 24.1 |
| WC15 | 25 | 60 | 2.7 | 31.6 | 15.0 |

[1]Discharge not measured due to tidal influence

## SPECIFIC CONDUCTANCE

Surface water in each project watershed is characterized by a unique specific conductance (SC) (microseimens/centimeter (µS/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, 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 or at times of large rainfall runoff volumes. Table 2 shows SC in monitored streams in the Wolf Bay watershed. Sites WC12 (Sandy Creek), WC13 (Miflin Creek), and WC14 (Hammock Creek) were influenced by tidal influx (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 Alabama Department of Environmental Management (ADEM) established reference sites on streams throughout Alabama to determine reference water-quality standards for selected level IV ecoregions. The ADEM reference median concentration for SC for ecoregion 65f, which includes the Wolf Bay watershed is 20.4 µS/cm (ADEM, 2010). Median measured SC for all Wolf Bay watershed sites exceeded the ADEM standard (table 2).

Table 2.—Measured specific conductance values for Wolf Bay watershed monitoring sites.

| Monitored site | Average SC (µS/cm) | Maximum SC (µS/cm) | Minimum SC (µS/cm) | ADEM median reference (µS/cm) | Median SC (µS/cm) |
|---|---|---|---|---|---|
| WC1 | 75 | 101 | 56 | 20.4 | 71 |
| WC2 | 98 | 140 | 41 | 20.4 | 92 |
| WC3 | 67 | 117 | 35 | 20.4 | 66 |
| WC4 | 99 | 302 | 39 | 20.4 | 54 |
| WC5 | 57 | 87 | 31 | 20.4 | 56 |
| WC6 | 61 | 82 | 47 | 20.4 | 62 |
| WC7 | 60 | 75 | 44 | 20.4 | 59 |
| WC8 | 68 | 94 | 33 | 20.4 | 64 |
| WC10 | 101 | 159 | 47 | 20.4 | 111 |
| WC11 | 109 | 269 | 41 | 20.4 | 77 |
| WC12 | 3,976 | 14,000 | 38 | 20.4 | 429 |
| WC13 | 12,673 | 16,200 | 3,640 | 20.4 | 14,450 |
| WC14 | 2,008 | 12,000 | 29 | 20.4 | 61 |
| WC15 | 65 | 104 | 34 | 20.4 | 56 |

## 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. Average measured turbidity shown in figure 4, illustrates that sites WC5 (unnamed tributary at US Highway 98), WC11 (Wolf Creek at Swift Church Rd), and WC6 (unnamed tributary at US Highway 98) have the highest turbidity (110, 77, and 75 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. Although there are a number of areas in the Wolf Bay watershed that are undergoing conversion from agriculture to commercial and residential development, the majority of human activity in the watershed continues to be agricultural. Wolf Creek sites WC2, WC10, and WC11 have the highest percentage of residential and commercial development related to the city of Foley (84.8 and 43.2, and 35.4 percent, respectively). Site WC15 (Owens Bayou at Lakeview Drive) has 22.0 percent urban development related to the Glenn Lakes subdivision and the city of Foley. agricultural land use. The ADEM reference concentration for turbidity is 9.7 NTU for ecoregion 65f ($90^{th}$ %ile). Average turbidity for all Wolf Bay watershed sites exceeded the ADEM standard by 3 to 24 times (fig. 4).

## 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

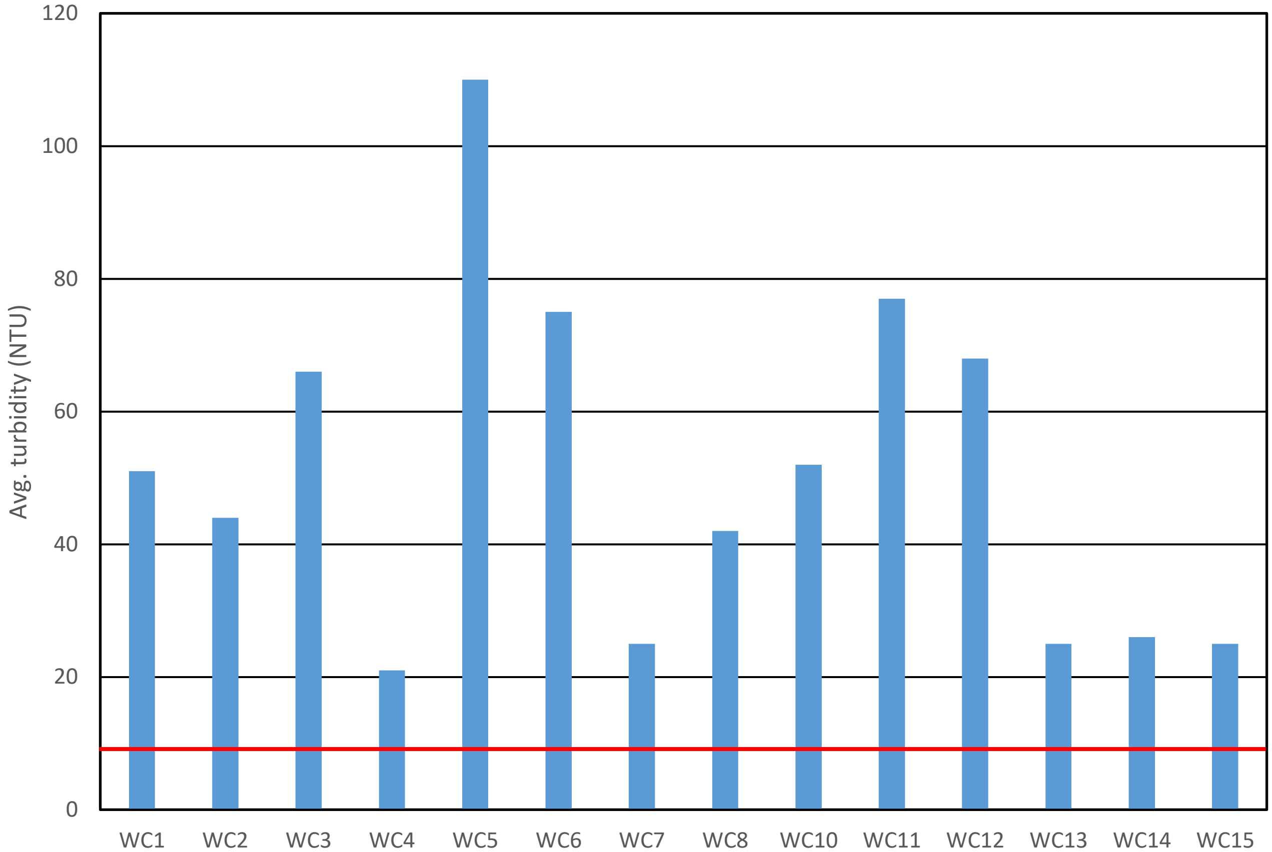


Figure 4.—Average turbidity for Wolf Bay watershed monitored sites with ADEM reference value.

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, soils, and land use are all important factors that influence sediment transport characteristics of streams. Sediment transport conditions in the Wolf Bay watershed were 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 in the downstream part of the watershed also play prominent roles in sediment transport and overall water quality in the Wolf Bay 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 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. Currently, except for the northwest margin of the watershed, dominated by the city of Foley, and a few large residential developments, the Wolf Bay watershed is characterized by a relatively rural setting, extensive row crop and turf agriculture, floodplains dominated by abundant wetlands, anastomosing stream channels, and forest. Anthropogenic impacts to stream flow, sediment transport, and water quality include erosion from agricultural fields, increased runoff and land disturbance related to residential development and commercial areas of Foley and Elberta.

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). Seven Wolf Bay watershed monitoring sites had measurable suspended and bed sediment loads. Only suspended sediment could be measured at six sites due to flow and channel conditions and one site (WC13, Miflin Creek at Baldwin County Road 20) had no measurable sediment loads due to tidal influx.

### *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 Wolf Bay watershed site. It shows an excellent correlation between turbidity and TSS. The ADEM reference concentration for TSS for ecoregion 65f, which includes the Wolf Bay watershed is 13.2 mg/L ($90^{th}$ %ile).

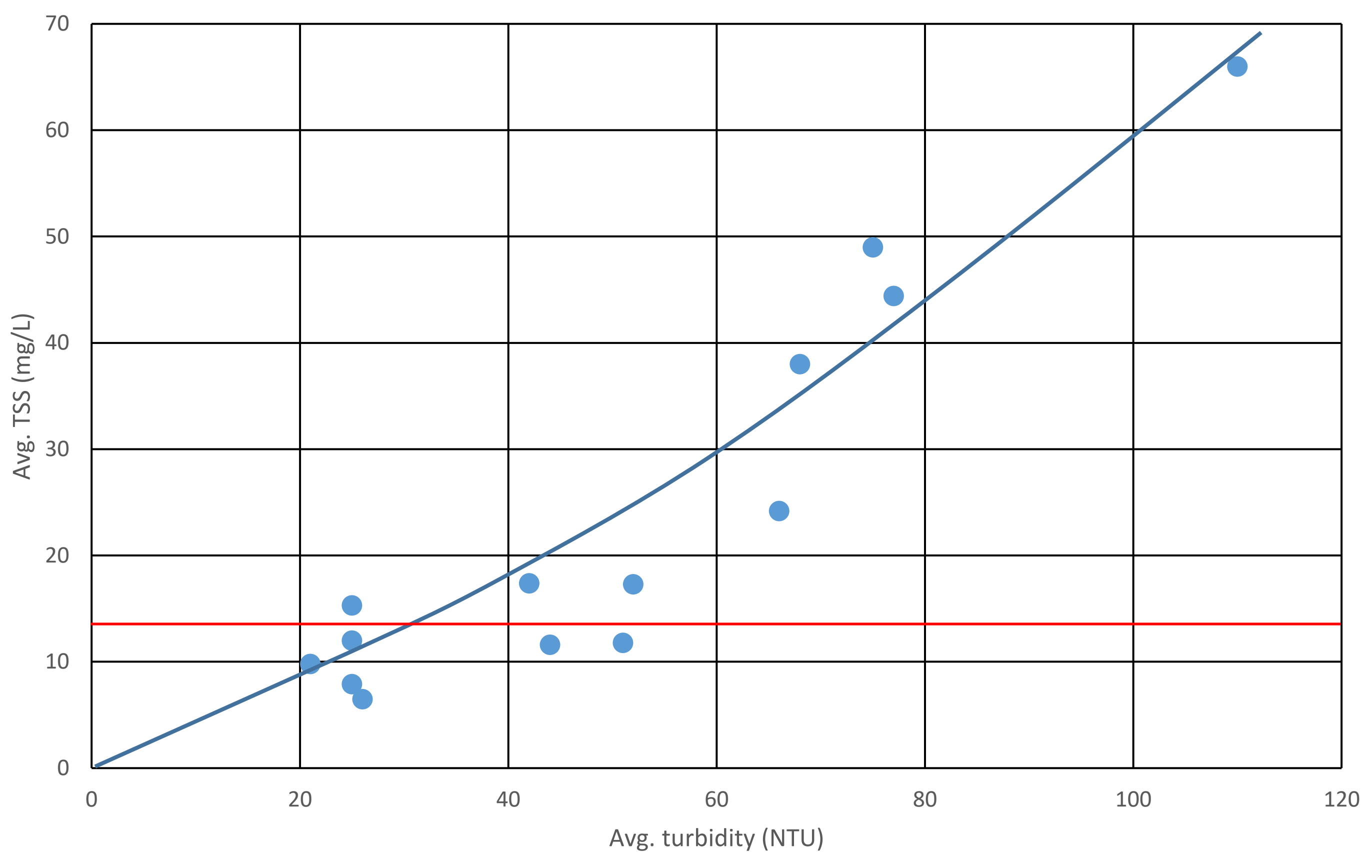


Figure 5.—Average turbidity and TSS for Wolf Bay watershed monitored sites with ADEM reference value (red).

Annual suspended sediment loads were estimated for Wolf Bay watershed monitored streams 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 site, 02378170, Wolf Creek below Foley, Alabama. This site is at the Doc McDuffie Road crossing of Wolf Creek, about 0.3 mi west of the Foley Beach Expressway.

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 (August 15, 2016 to August 14, 2017). Sandy Creek at Baldwin Co. Rd. 20 (WC12), Wolf Creek at Swift Church Rd. (WC11), Wolf Creek at Doc McDuffie Rd. (WC10), west unnamed tributary to Sandy Creek at US Highway 98 (WC5), east unnamed tributary to Sandy Creek at US Highway 98 (WC6), had the largest suspended sediment loads (929, 861, 460, 444, and 368 tons per year (t/yr), respectively (fig. 6, table 3).

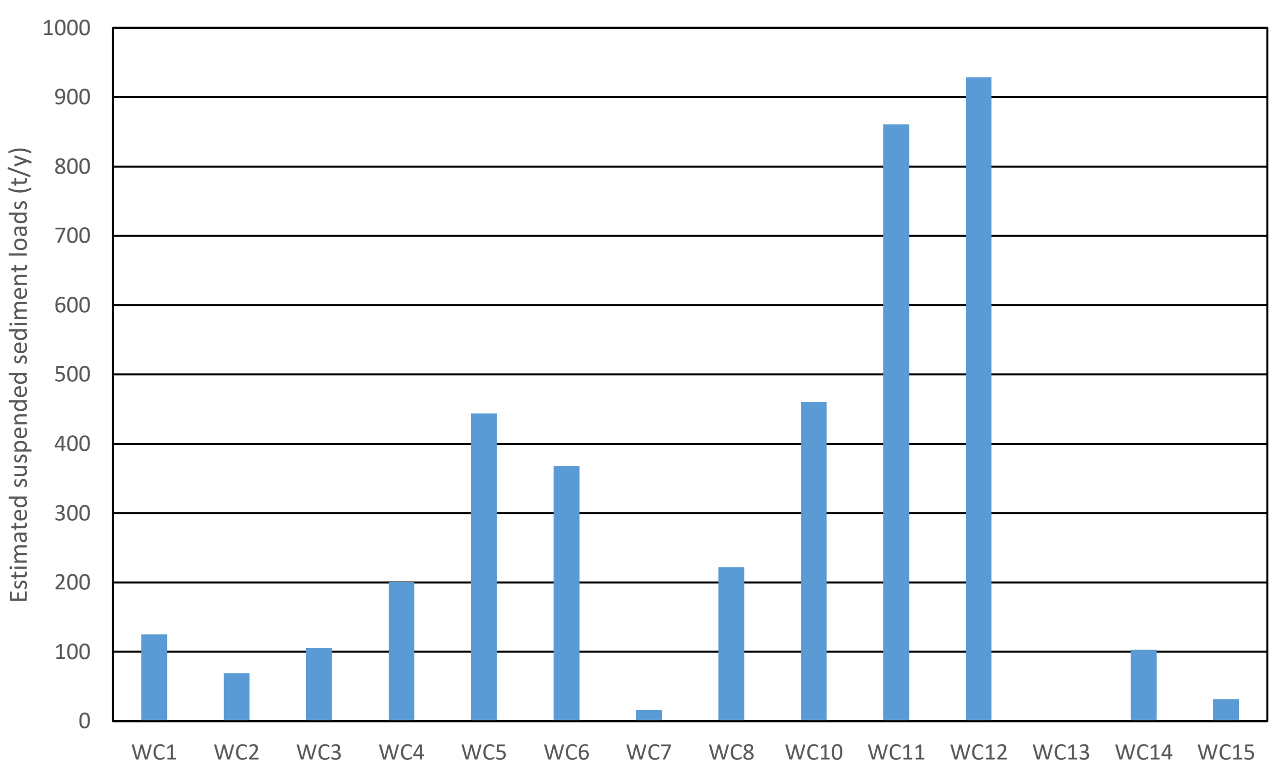


Figure 6.—Estimated annual suspended sediment loads for Wolf Bay watershed monitored sites.

Table 3.—Measured discharge, turbidity, TSS, and estimated suspended sediment loads in monitored streams in the Wolf Bay watershed.

| 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) |
|---|---|---|---|---|---|---|---|---|
| WC1 | 7.7 | 51 | 115 | 12 | 13.2 | 24 | 125 | 57 |
| WC2 | 3.4 | 44 | 144 | 12 | 13.2 | 30 | 69 | 70 |
| WC3 | 4.6 | 66 | 127 | 24 | 13.2 | 61 | 106 | 81 |
| WC4 | 21 | 21 | 63 | 10 | 13.2 | 36 | 201 | 34 |
| WC5 | 6.0 | 110 | 365 | 365 | 13.2 | 275 | 66 | 261 |
| WC6 | 6.0 | 75 | 260 | 49 | 13.2 | 216 | 368 | 217 |
| WC7 | 3.9 | 25 | 55 | 8 | 13.2 | 22 | 16 | 15 |
| WC8 | 13 | 42 | 141 | 17 | 13.2 | 52 | 222 | 60 |
| WC10 | 17 | 52 | 174 | 17 | 13.2 | 74 | 460 | 94 |
| WC11 | 31 | 77 | 237 | 44 | 13.2 | 139 | 861 | 94 |
| WC12 | 46 | 75 | 198 | 38 | 13.2 | 128 | 929 | 70 |
| WC13 | N/A | 25 | 56 | 15 | 13.2 | 24 | N/A[1] | N/A |
| WC14 | 13 | 26 | 96 | 7 | 13.2 | 15 | 103 | 27 |
| WC15 | 2.7 | 25 | 36 | 12 | 13.2 | 19 | 32 | 40 |

[1]Suspended sediment loading not estimated due to tidal influence

Suspended sediment loads generally increase from upstream to downstream due to increasing volumes of sediment in stream channels and increased flow velocity that transports larger sediment volumes. Although site WC11 is downstream from site WC10 the suspended sediment load at site WC10 is 8.7 times larger. This is due to the proximity of site WC11 to the reach of Wolf Creek with tidal influence. At times of high discharge and especially when the tide is rising, water backs up past site WC11, causing relatively low velocity flow and corresponding small volume of suspended sediment transport (fig. 2).

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 monitored sites in the Wolf Bay watershed are portrayed on figure 7, which shows the largest normalized suspended sediment loads at west unnamed tributary to Sandy Creek at US Highway 98 (WC5) (261 t/mi$^2$/yr), east unnamed tributary to Sandy Creek at US Highway 98 (WC6) (217 t/mi$^2$/yr), Wolf Creek at Doc McDuffie Rd. (WC10) (94 t/mi$^2$/yr), and Wolf Creek at Swift Church Rd. (WC11) (94 t/mi$^2$/yr) (table 3).

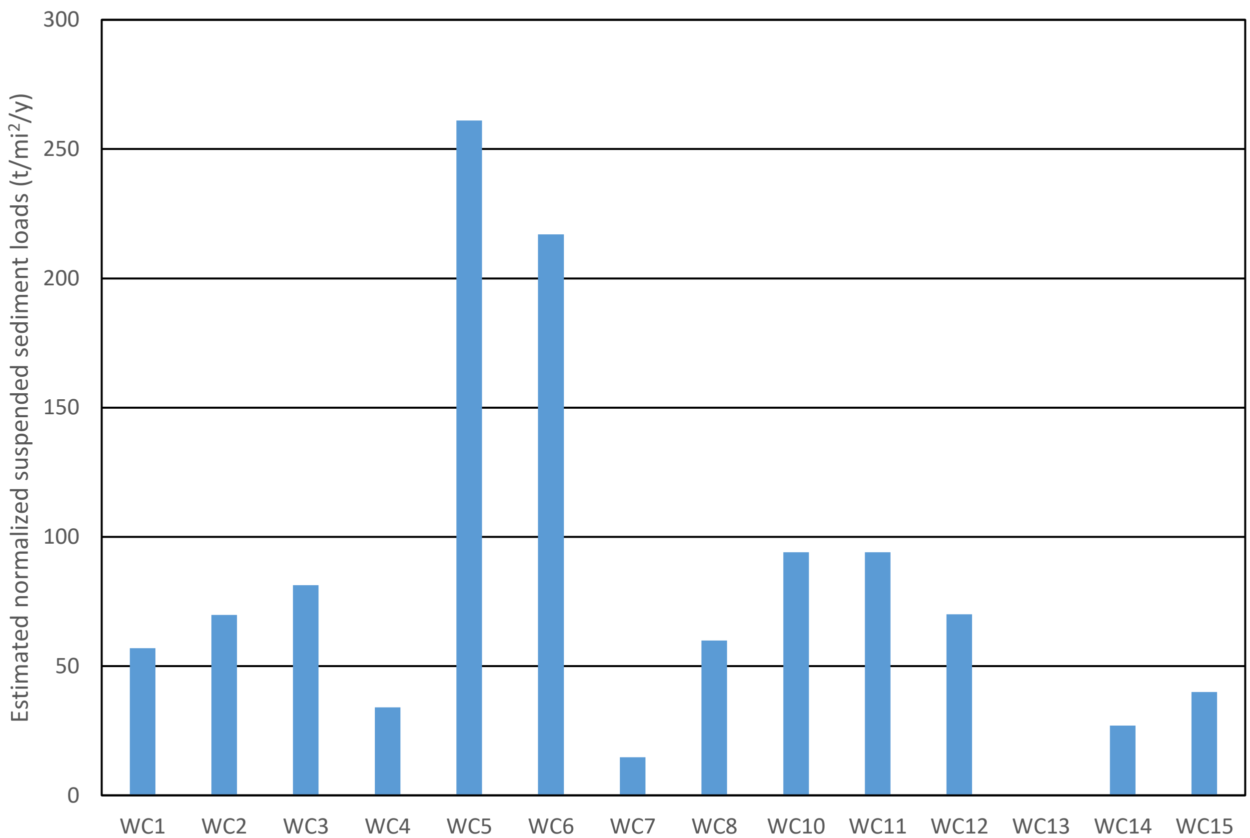


Figure 7.—Estimated normalized suspended sediment loads for Wolf Bay watershed monitored sites.

### *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 sediment loads are 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.

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 six Wolf Bay watershed sites (WC1, WC2, WC5, WC6, WC8, and WC10). 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 estimated annual bed sediment loads for sites with measurable bed sediment. Figure 9 shows estimated annual bed sediment loads normalized with respect to watershed drainage area. 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. Sites WC10 (Wolf Creek at Doc McDuffie Rd) and WC5 (west unnamed tributary to Sandy Creek at US Highway 98), and WC6 (east unnamed tributary to Sandy Creek at US Highway 98) had the largest bed sediment loads with 10,471, 1,551 and 1,347 t/yr, respectively. After normalization of bed sediment loads relative to drainage area, sites WC10 (Wolf Creek at Doc McDuffie Rd), WC5 (west unnamed tributary to Sandy Creek at US Highway 98), and WC6 (east unnamed tributary to Sandy Creek at US Highway 98) had the largest loads with 2,137, 912, and 792 tons/mi$^2$/yr, respectively. Table 4 shows that discharge and bed sediment loads do not correlate well in streams in the Wolf Bay watershed. This is particularly true for site WC5 and WC6 where excessive upstream erosion contributes an disproportionately large amount of bed sediment. Bed sediment loading could not be estimated for site WC11, where transport rates could not be measured during rising or high tide conditions, which caused backwater impacts.

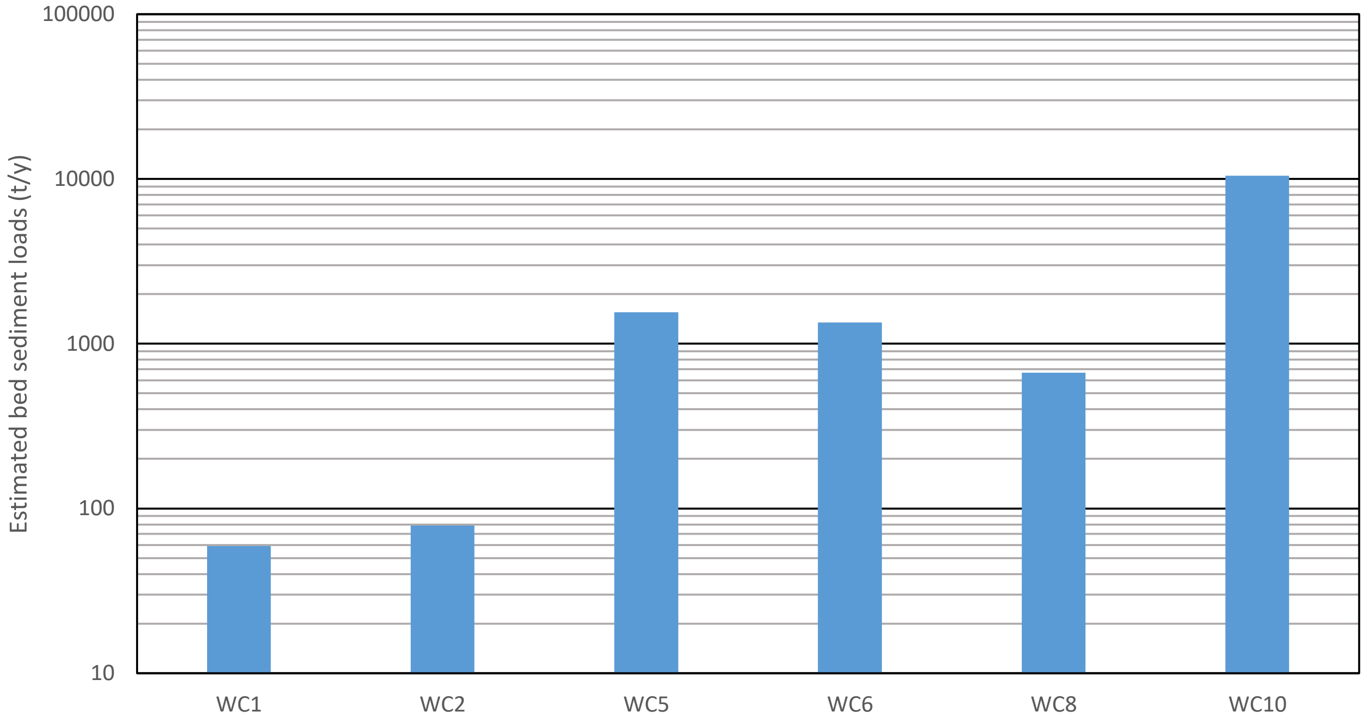


Figure 8.—Estimated bed sediment loads for Wolf Bay watershed monitoring sites with measurable bed sediment.

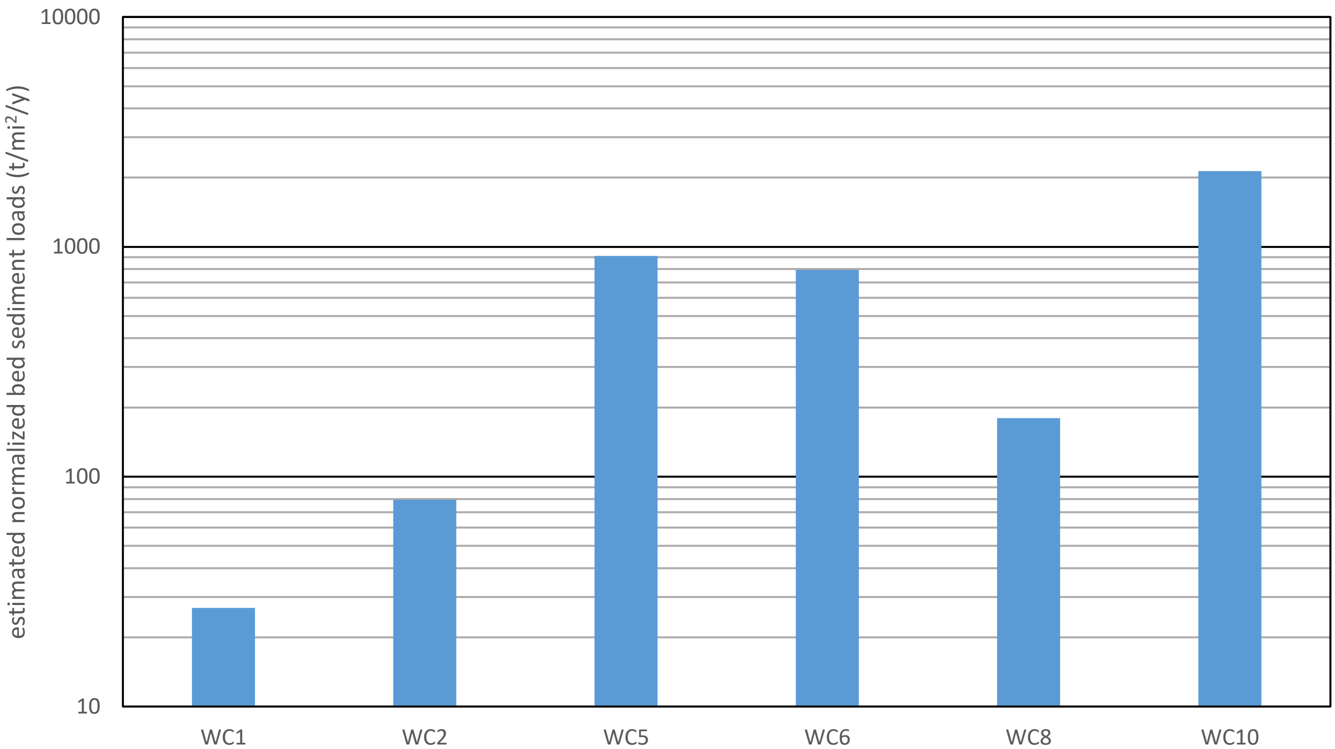


Figure 9.—Estimated normalized bed sediment loads for Wolf Bay watershed sites with measurable bed sediment.

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 discharge (cfs) | Estimated annual bed sediment loads (tons/yr) | Estimated normalized annual bed sediment loads (tons/mi $^2$/yr) |
|---|---|---|---|
| WC1 | 22 | 59 | 27 |
| WC2 | 16 | 79 | 80 |
| WC5 | 9 | 1,551 | 912 |
| WC6 | 11 | 1,347 | 792 |
| WC8 | 41 | 668 | 180 |
| WC10 | 55 | 10,471 | 2,137 |

**BED SEDIMENT GRAIN SIZE ANALYSES**

Sedimentation processes, including erosion, transport, deposition, and consolidation and sorting, are critical considerations in evaluating stream stability and developing restoration designs. The form of a channel is a consequence of the magnitude, timing, and frequency of both runoff and sediment yield from the watershed. The composition of streambed and banks is an important facet of stream character, which influences channel form and hydraulics, erosion rates, sediment supply, and other parameters. Sediment characteristics that may be important in executing stream restoration projects include the sediment size, shape, specific weight, fall velocity, and parent geology (Fischenich and Little, 2007).

The composition of streambed and banks is an important facet of stream character, which influences channel form and hydraulics, erosion rates, sediment supply, and other parameters. Particle-size data are usually reported in terms of di, where i represents some percentile of the distribution, and di for a particle grain size, usually expressed in millimeters, where i percent of the total sample by weight is finer. For example, 84 percent of the total sample would be finer than the d84 particle size (Fischenich and Little, 2007).

Bed sediment samples were collected at three Wolf Bay watershed monitoring sites with measurable bed sediment. One cubic ft of wet sediment was weighed on site and a representative subsample was placed in a one gallon plastic bag for transport. Samples were dried and sieved and data were analyzed according to procedures developed by the North Carolina Stream Restoration Institute at North Carolina State University (Doll and others, 2003). Samples were-sieved, using a sieve set that retains material with the following sizes in millimeters: >4, 2-4, 2-0.5, 0.5-0.25, 0.25-.11, a bottom pan for silt and clay. Retained material on each sieve was weighed and the weights (less tare weight) were recorded by size class. The percentage of each size class relative to the total weight was determined. The percentage of finer material to each class was also determined. The percentages are represented for sites WC6, WC8, and WC10 on graphs in figure 10.

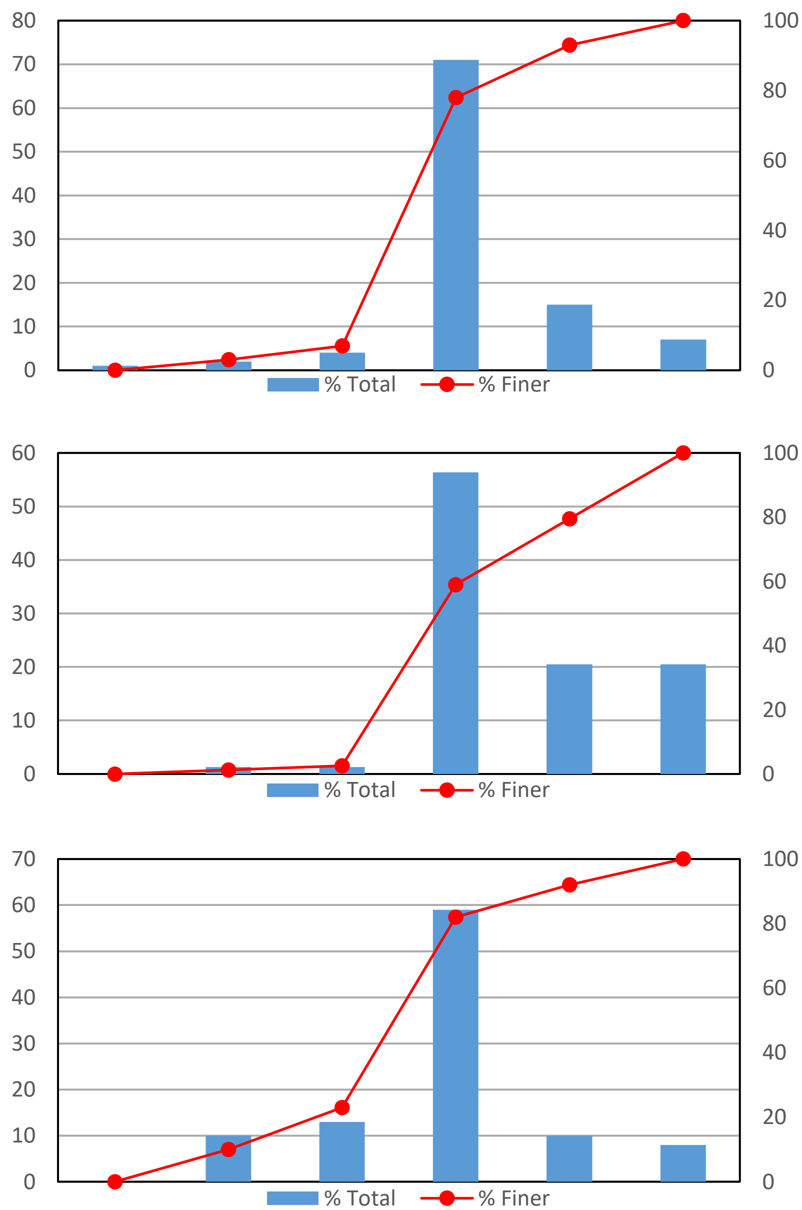


Figure 10.—Results of sieve analysis for Wolf Bay watershed sites WC6 (top), WC8 (center), and WC10 (bottom).

*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 72% of the total sediment loads for streams with measurable suspended and bed sediment. Table 5 and figures 11 and 12 show total sediment loads for monitored reaches in the Wolf Bay watershed. Wolf Creek at Doc McDuffie Road (WC10), west unnamed tributary to Sandy Creek at US Highway 98 (WC5), east unnamed tributary to Sandy Creek at US Highway 98 (WC6), and Wolf Creek at Swift Church Road (WC11) had the largest total sediment loads (10,931, 1,995, 1,715, and 1,257 tons per year (t/yr), respectively (fig. 11, table 5).

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 annual daily discharge (cfs) | Estimated annual total sediment loads (tons/yr) | Estimated normalized annual total sediment loads ($tons/mi^2/yr$) |
|---|---|---|---|---|
| WC1 | 2.2 | 7.7 | 184 | 84 |
| WC2 | 1.0 | 3.4 | 148 | 149 |
| WC3 | 1.3 | 4.6 | 106 | 81 |
| WC4 | 5.9 | 21 | 201 | 34 |
| WC5 | 1.7 | 6.0 | 1,995 | 1,173 |
| WC6 | 1.7 | 6.0 | 1,715 | 1,009 |
| WC7 | 1.1 | 3.9 | 16 | 15 |
| WC8 | 3.7 | 13 | 890 | 240 |
| WC10 | 4.9 | 17 | 10,931 | 2,231 |
| WC11 | 8.9 | 31 | 1,257 | 139 |
| WC12 | 13.3 | 46 | 929 | 70 |
| WC13 | 12.5 | N/A | | |
| WC14 | 3.8 | 13 | 103 | 27 |
| WC15 | 0.8 | 2.7 | 32 | 40 |

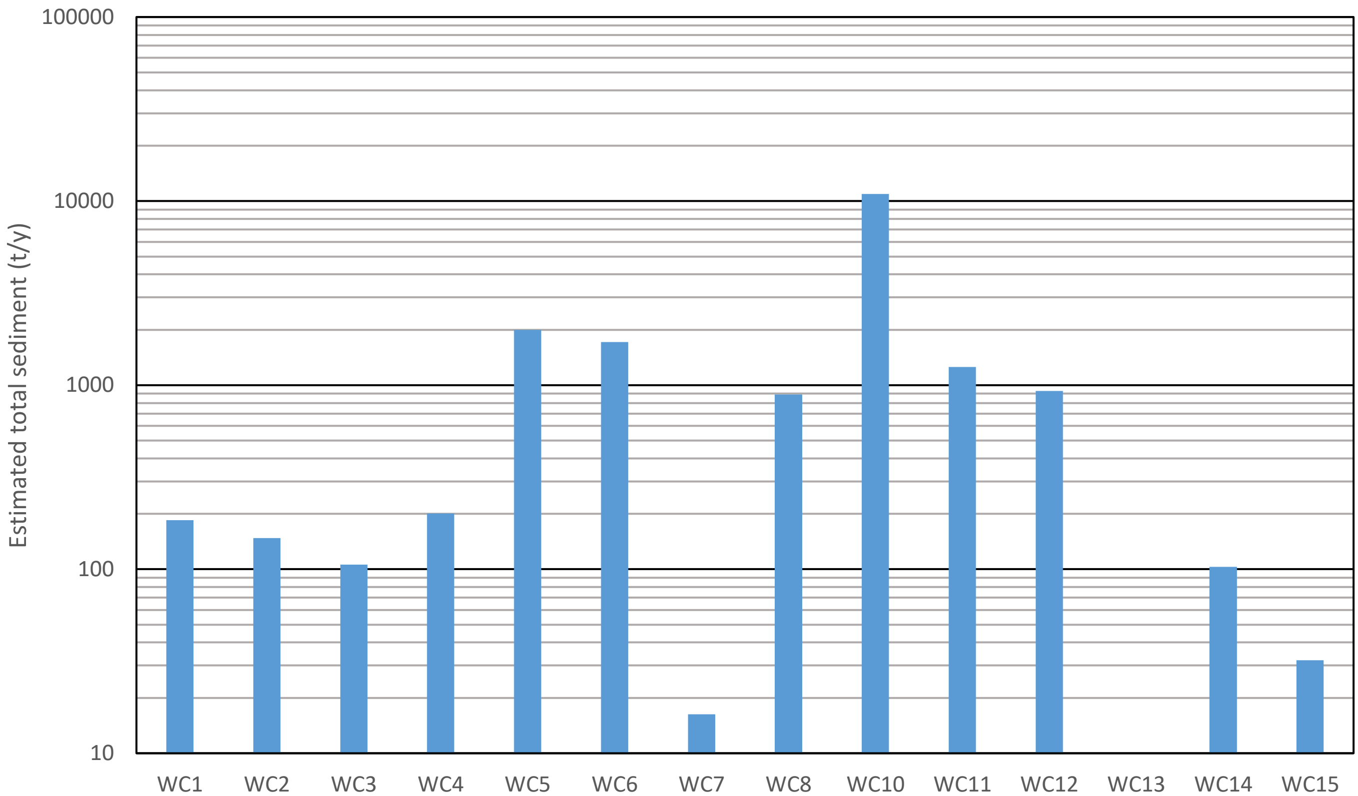

Figure11.—Estimated total sediment loads for Wolf Bay watershed monitored sites.

Normalizing sediment loads to unit watershed area permits comparison of monitored watersheds and negates the influence of drainage area size and discharge on sediment loads. Normalized total sediment loads for monitored sites in the Wolf Bay watershed are portrayed on figure 12, which shows the largest normalized total sediment loads at Wolf Creek at Doc McDuffie Road (WC10) (2,231 t/mi$^2$/yr), west unnamed tributary to Sandy Creek at US Highway 98 (WC5) (1,173 t/mi$^2$/yr), east unnamed tributary to Sandy Creek at US Highway 98 (WC6) (1,009 t/mi$^2$/yr), and Miflin Creek at US 98 (WC8) (240 t/mi$^2$/yr).

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 9 of 13 monitored watersheds were from 1.1 to 34.9 times greater than the geologic erosion rate (fig. 12). Sites WC4 (Sandy Creek at US Highway 98), WC7 (Elberta Creek), and WC14 (Hammock Creek), and WC15 (Owens Bayou) were at or below the geologic erosion rate (fig. 12). Sediment loads generally increase from upstream to downstream due to increasing volumes of sediment in stream channels and increased flow velocity that

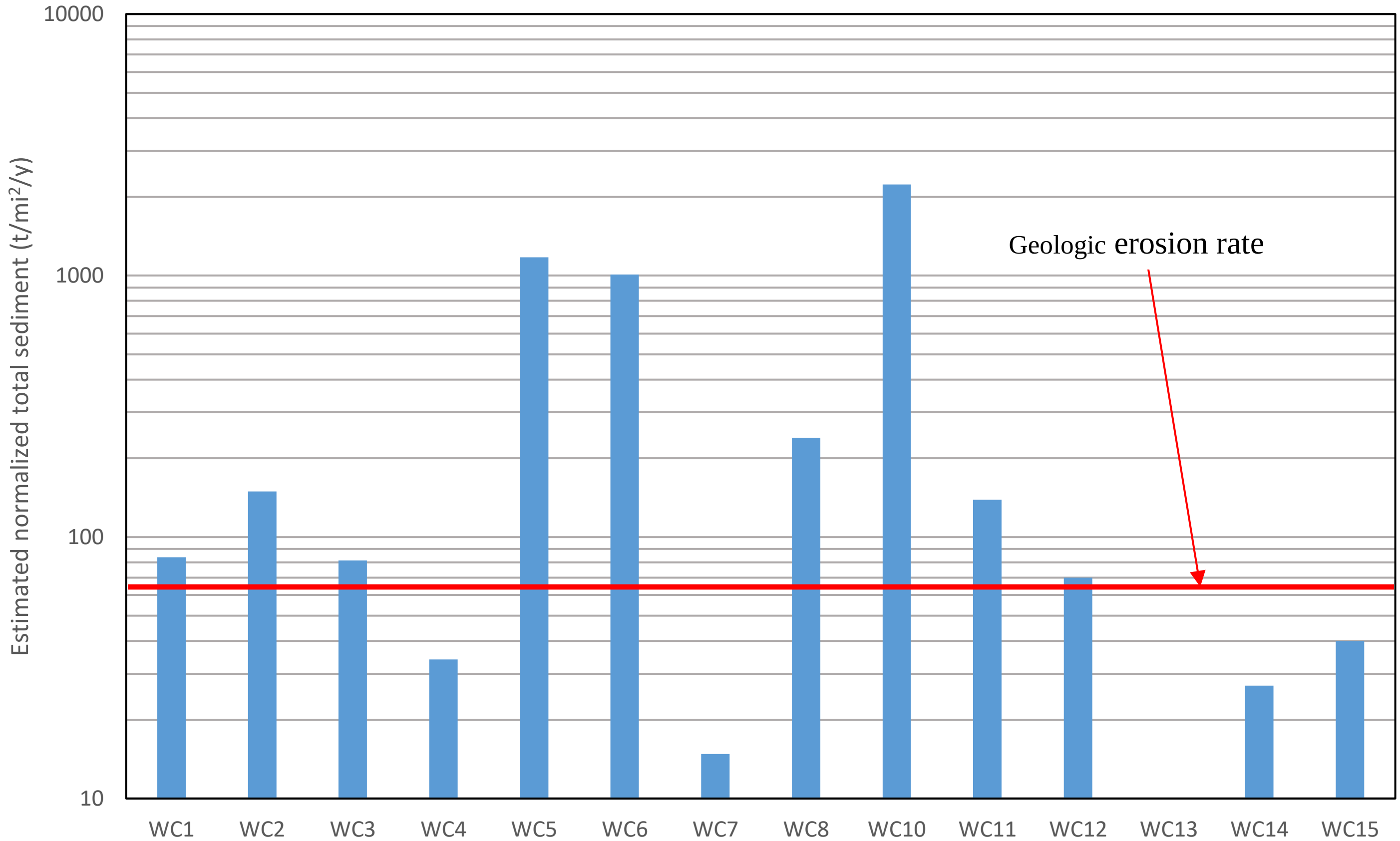

Figure 12.—Estimated normalized total sediment loads for Wolf Bay monitored sites.

transports larger sediment volumes. This is illustrated in Sandy Creek, where increasing sediment loads occur at sites WC1 (upstream), WC4 (mid reach), and WC12 (downstream) (fig. 11).

Comparisons of sediment loads from other watersheds 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 Wolf Bay watershed sites WC5, WC6, and WC10 with sites in six previously monitored watersheds in Mobile and Baldwin Counties, including Dog River tributary, Spencer Branch site DR2 (at Cottage Hill Road in the city of Mobile) (Cook, 2012), Fowl River site FR2 (at Half-Mile Road) (Cook, 2015), D'Olive Creek site DC3 (at U.S. Highway 90 in Daphne) (Cook, 2008), D'Olive Creek tributary Joes Branch site JB7 (at North Main Street in Daphne) (Cook, 2008), Magnolia River site MR4 (at U.S. Highway 98) (Cook, 2009), and Bon Secour River site BSR3 (County Road 12 in Foley) (Cook, 2013) (fig. 13).

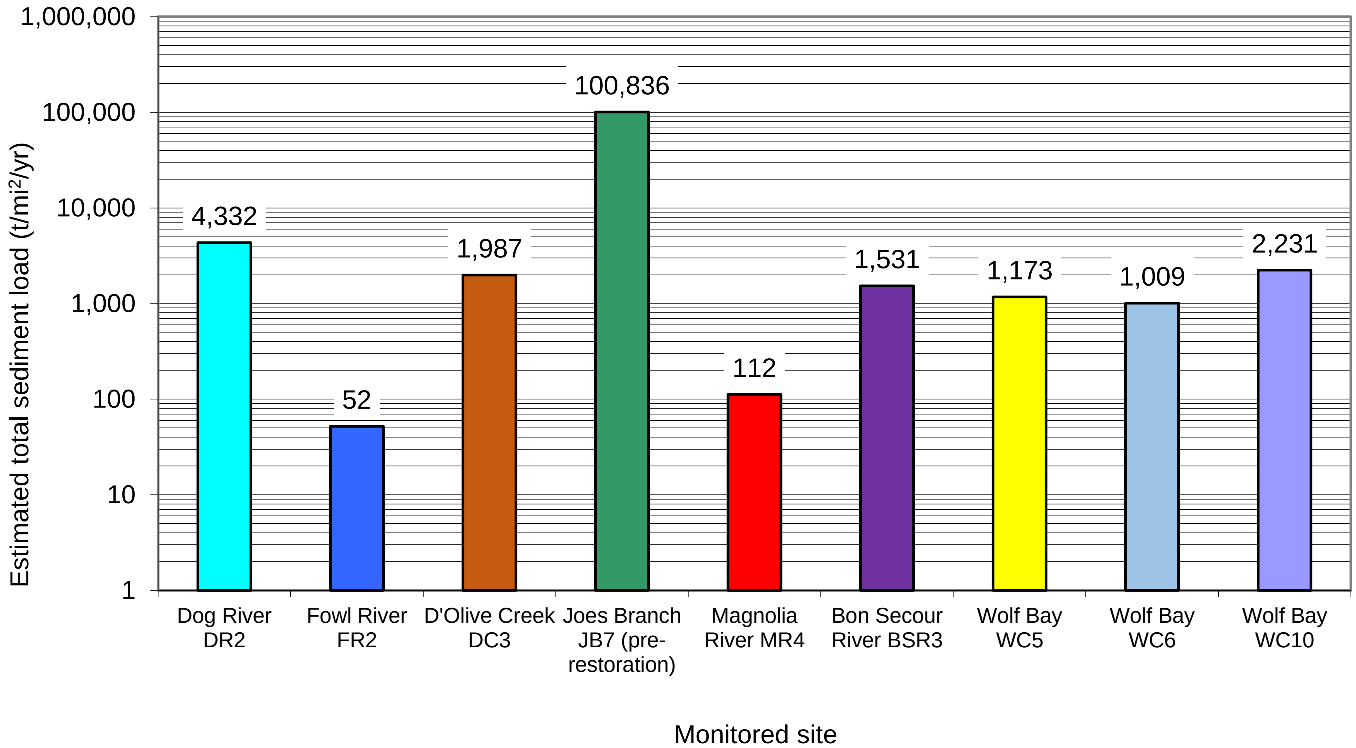


Figure 13.—Comparisons of estimated normalized total sediment loads for sites in previously monitored watersheds with Wolf Bay watershed sites WC5, WC6, and WC10.

Land use is a major factor in the magnitude of erosion and stream sediment loading. Figure 14 shows total sediment loads and urban development as a percentage of total monitored watershed area. Three major urban development/sediment load relationships are identified on the graph. First are watersheds with relatively large urban development (>20%) and corresponding, relatively large sediment loads, which includes Wolf Creek sites WC10 and WC11 (fig. 14). The second are watersheds with relatively large urban development (>20%) and relatively small sediment loads, which includes Wolf Creek site WC2 and Owens Bayou site WC15 (fig. 14). Site WC2 is near the headwaters of Wolf Creek near downtown Foley and is immediately downstream from a restored reach that has significantly slowed urban runoff and has successfully limited erosion and sediment transport upstream from the monitoring site. Site WC15 is in Glenn Lakes subdivision, immediately upstream from Lake Muriel and near the headwaters of Owen Bayou. The reach upstream from the site has row crop agriculture and fallow fields along the drainage divide that separates Owens Bayou from the Bon Secour watershed, but further downstream land use is residential development, where the stream channel has significant armoring with limestone riprap. The third is watersheds with relatively small urban development (<20%) and relatively large sediment loads, which includes unnamed tributaries to Sandy Creek at US Highway 98 (WC5 and WC6) and Miflin Creek at US Highway 98 (WC8) (fig. 14). These watersheds are dominated by forested floodplains and row crop agricultural land use at higher elevations.

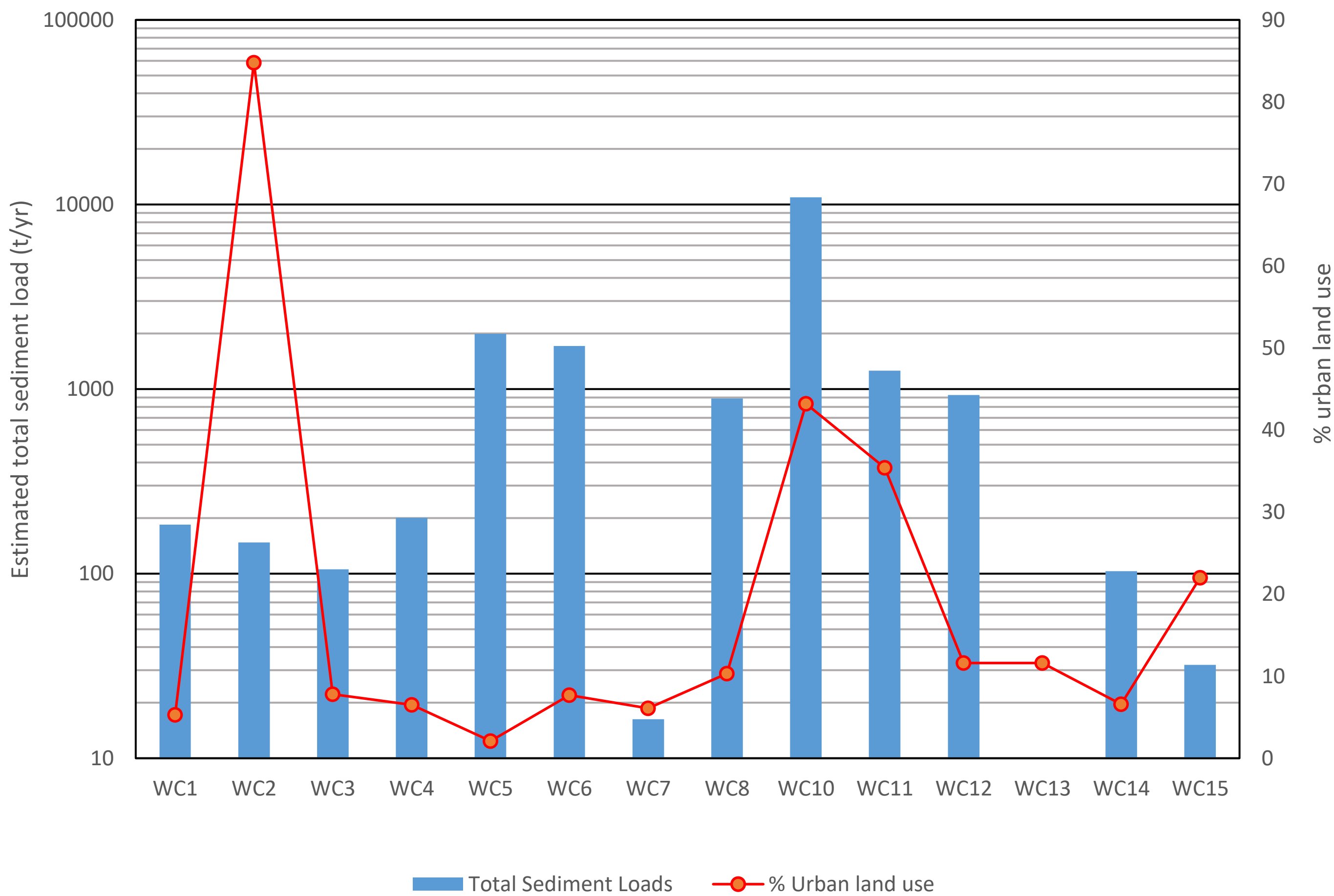


Figure 14.—Estimated total sediment loads and % urban land use in Wolf Bay watershed monitored sites.

## 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 ($NO_3$-nitrite) 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 August 2015 through August 2016 at Wolf Bay watershed monitoring sites for discharge events from base flow to bank full. In order to compare Wolf Bay watershed samples to the ADEM reference concentration (0.3258 mg/L nitrate+nitrite nitrogen = 90$^{th}$ %ile) for Ecoregion 65f, samples were analyzed for nitrate+nitrite nitrogen.

Nitrogen concentrations are highly variable for each monitoring site, due to temporal variations in the sources of nitrate and highly variable stream discharge. Nitrogen and discharge commonly form negative regressions, indicating that increased discharge results in decreased concentrations of nitrogen. Nitrate+nitrite nitrogen loads were estimated using regressions generated from measured nitrate concentrations and discharge. The largest nitrate+nitrite nitrogen loads were at sites WC8 (Miflin Creek), WC4 (Sandy Creek at US Highway 90), WC12 (Sandy Creek at Baldwin Co Rd 20), and WC11 (Wolf Creek) with 64.4, 56.7, 43.2, and 42.3 t/yr, respectively (table 6, fig. 15). The largest normalized nitrate+nitrite nitrogen loads were at sites WC8, WC5 (unnamed tributary to Sandy Creek at US Highway 90), WC4, and WC1 (Sandy Creek at Foley Beach Expressway), with 17.4, 14.7, 9.6, and 7.3 t/mi$^2$/yr (table 6, fig. 16).

Table 6.—Measured nitrate+nitrite nitrogen concentrations and estimated loads in monitored streams in the Wolf Bay watershed.

| Monitored site | Average nitrate+nitrite (mg/L) | Maximum nitrate+nitrite (mg/L) | Minimum Nitrate+nitrite (mg/L) (% samples BDL[1]) | % samples above 0.3258 mg/L ADEM reference concentration | Estimated Nitrate+nitrite load (t/yr) | Estimated normalized Nitrate+nitrite load (t/mi$^2$/yr) |
|---|---|---|---|---|---|---|
| WC1 | 1.3 | 2.1 | 0.7 (0) | 100 | 16.0 | 7.3 |
| WC2 | 0.5 | 1.0 | 0.2 (0) | 86 | 5.7 | 5.8 |
| WC3 | 0.4 | 0.8 | 0.2 (0) | 57 | 3.6 | 2.8 |
| WC4 | 1.2 | 1.6 | 0.7 (0) | 100 | 56.7 | 9.6 |
| WC5 | 2.7 | 5.8 | 0.5 (0) | 100 | 25.0 | 14.7 |
| WC6 | 1.5 | 2.3 | 0.6 (0) | 100 | 8.5 | 5.0 |
| WC7 | 0.4 | 0.6 | 0.2 (0) | 86 | 1.6 | 1.4 |
| WC8 | 1.5 | 3.5 | 0.1 (0) | 89 | 64.4 | 17.4 |
| WC10- | 1.0 | 1.4 | 0.3 (0) | 100 | 20.6 | 4.2 |
| WC11 | 1.1 | 1.8 | 0.5 (0) | 100 | 42.3 | 4.8 |
| WC12 | 0.6 | 0.9 | 0.2 (0) | 71 | 43.2 | 3.3 |
| WC13 | 0.1 | 0.6 | BDL (67) | 17 | N/A[2] | N/A |
| WC14 | 0.6 | 0.9 | 0.2 (0) | 83 | 7.9 | 2.1 |
| WC15 | 0.4 | 0.4 | 0..3 (0) | 66 | 1.1 | 1.4 |

[1] Below detection limit
[2] Insufficient data for load estimation

## ***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

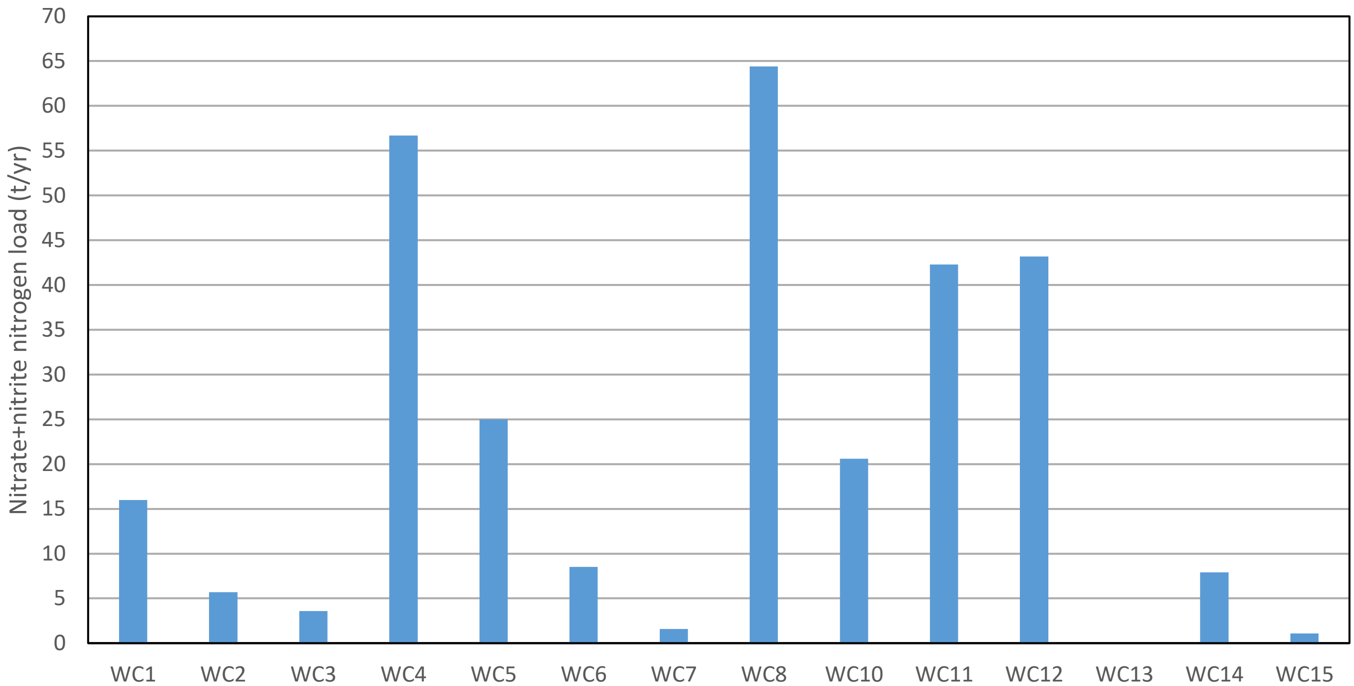


Figure 15.—Estimated nitrate+nitrite nitrogen loads for Wolf Bay watershed monitored streams.

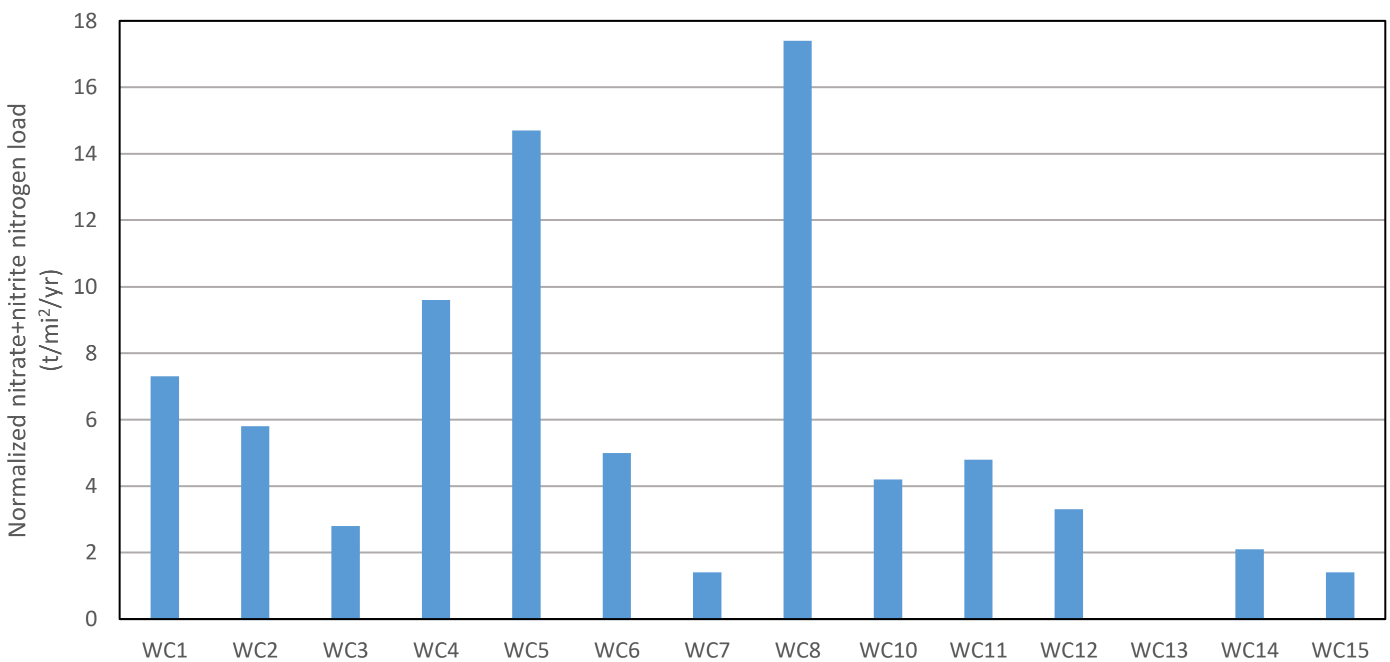


Figure 16.—Estimated normalized nitrate+nitrite nitrogen loads for Wolf Bay monitored streams.

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 for total phosphorus for level IV ecoregion 65f (including the Wolf Bay watershed) of 0.04 mg/L (90th %ile). In many streams phosphorus is the primary nutrient that influences excessive biological activity. These streams are termed “phosphorus limited.”

Ten of 14 Wolf Bay watershed monitoring sites had average phosphorus concentrations above the 0.04 mg/L reference criterion (table 7). Wolf Creek sites WC10 and WC11 have the largest average phosphorus concentrations, 0.69 and 0.39 mg/L, respectively. Ten of 14 sites had sufficient phosphorus data to estimate annual loads. The largest phosphorus loads were at sites WC11 (Wolf Creek) and WC5 (unnamed tributary to Sandy Creek), with 17.8 and 9.1 t/yr, respectively (table 7, fig. 17). When loads are normalized with respect to drainage area, Wolf Creek sites WC11 and WC10 had the largest loads with 2.0 and 0.9 $t/mi^2/yr$ (table 7, fig. 18).

Table 7.—Measured total phosphorus concentrations and estimated loads in monitored streams in the Wolf Bay 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 (%) | Estimated total phosphorus load (t/yr) | Estimated normalized total phosphorus load ($t/mi^2/yr$) |
|---|---|---|---|---|---|---|
| WC1 | 0.08 | 0.16 | BDL (38) | 63 | 0.68 | 0.31 |
| WC2 | 0.08 | 0.13 | BDL (25) | 75 | 0.27 | 0.30 |
| WC3 | 0.19 | 0.30 | 0.08 (0) | 100 | 0.63 | 0.48 |
| WC4 | BDL | BDL | BDL (100) | 0 | N/A | N/A |
| WC5 | 0.07 | 0.18 | BDL (50) | 100 | 9.10 | 0.21 |
| WC6 | 0.04 | 0.10 | BDL (86) | 14 | N/A | N/A |
| WC7 | 0.06 | 0.10 | BDL (29) | 71 | 0.17 | 0.15 |
| WC8 | 0.06 | 0.12 | BDL (33) | 67 | 0.90 | 0.23 |
| WC10- | 0.69 | 1.64 | 0.19 (0) | 100 | 4.30 | 0.90 |
| WC11 | 0.39 | 0.73 | 0.18 (0) | 100 | 17.80 | 2.0 |
| WC12 | 0.09 | 0.15 | BDL (29) | 71 | 3.20 | 0.24 |
| WC13 | BDL | BDL | BDL (100) | 0 | N/A | N/A |
| WC14 | 0.03 | 0.08 | BDL (17) | 17 | N/A | N/A |
| WC15 | 0.19 | 0.25 | 0.14 (0) | 100 | 0.53 | 0.66 |

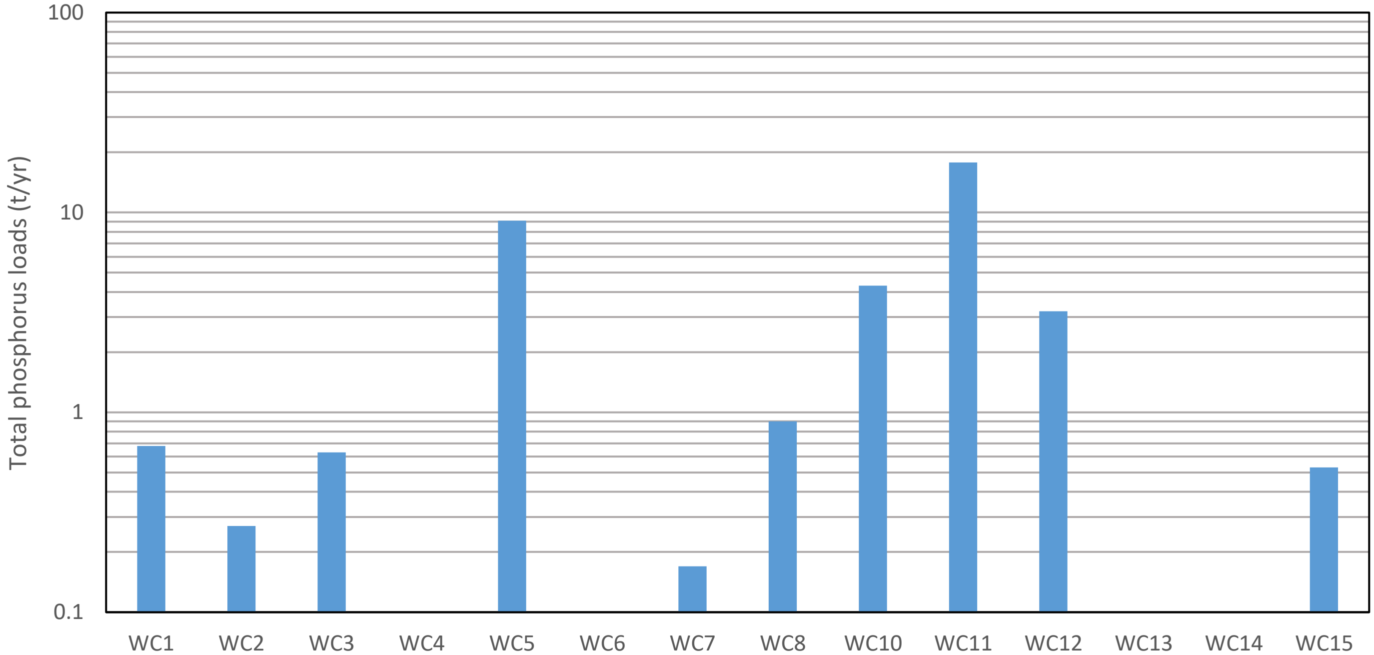

Figure 17.—Estimated total phosphorus loads for Wolf Bay monitored streams.

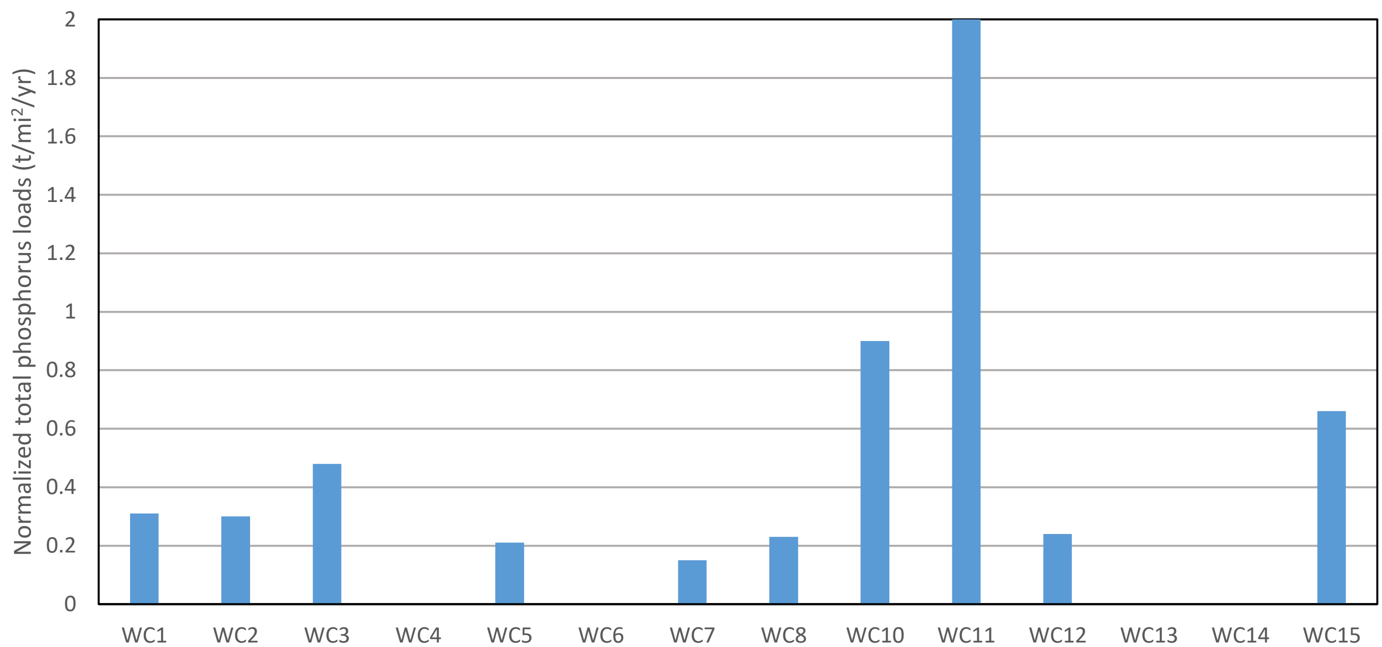

Figure 18.—Estimated normalized total phosphorus loads for Wolf Bay monitored streams.

## 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 (including the Wolf Bay watershed), which is 6.94 mg/L.

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 8 where observed DO is compared to the 100 percent dissolved oxygen saturation for the observed stream temperature for each of the monitoring periods.

Dissolved oxygen was measured at Wolf Bay watershed monitoring sites from December 2016 through August 2017. Stream water temperatures during the monitoring period varied from 16.4 to 26.3°C. Site WC7 (Elberta Creek at Baldwin Co Rd 83) had the lowest average DO (6.3 mg/L) and site WC5 (unnamed tributary to Sandy Creek at US Highway 90) had the highest average DO (8.6 mg/L). Values lower than the ADEM Fish and Wildlife standard (5.0 mg/L) were measured at sites WC2, WC3, WC7, WC12, WC13, WC14, and WC15 (fig. 16). Twelve of 14 sites had measured DO values less than the ADEM reference standard (6.94 mg/L) (table 8). Average DO and water temperature values were compared with atmospheric DO saturation (table 8). Sites WC7 and WC14 (Hammock Creek at Baldwin Co Rd 20) had the lowest percentage of atmospheric saturation and site WC5 had the highest percentage (table 8).

Table 8.—Dissolved oxygen measured in monitored streams in the Wolf Bay watershed.

| Site | Dissolved oxygen (mg/L) | | | Average DO saturation (% atmospheric saturation) |
|---|---|---|---|---|
| | Maximum | Minimum | Average | |
| WC1 | 9.5 | 6.1 | 7.8 | 89 |
| WC2 | 8.5 | 4.9 | 7.5 | 88 |
| WC3 | 8.4 | 3.8 | 6.6 | 76 |
| WC4 | 9.6 | 6.6 | 8.2 | 94 |
| WC5 | 9.6 | 7.9 | 8.6 | 97 |
| WC6 | 9.3 | 7.0 | 7.9 | 89 |
| WC7 | 7.9 | 4.5 | 6.3 | 71 |
| WC8 | 8.2 | 5.5 | 6.9 | 77 |
| WC10- | 8.4 | 5.2 | 6.9 | 77 |
| WC11 | 9.1 | 5.4 | 7.6 | 85 |
| WC12 | 8.3 | 4.5 | 6.9 | 77 |
| WC13 | 9.1 | 4.8 | 7.2 | 81 |
| WC14 | 8.3 | 4.2 | 6.6 | 74 |
| WC15 | N/A[1] | N/A | N/A | N/A |

[1] Insufficient number of samples collected.

## PATHOGENS

In 1986 the US Environmental Protection Agency (EPA) recommended Escherichia coli (E. coli) as the bacterial indicator to assess concentrations of bacteria in fresh water. On December 11, 2009, ADEM adopted the E. coli criteria as the bacterial indicator for Alabama freshwater bodies. Criterion for acceptable bacteria levels for the Fish &Wildlife use classification (fresh water) is described in ADEM Admin. Code R. 335-6-10-.09(5)(e)7(i) and (ii) as follows:

*7. Bacteria:*

*(i) In non-coastal waters, bacteria of the E. coli group shall not exceed a geometric mean of 548 colonies/100 ml; nor exceed a maximum of 2,507 colonies/100 ml in any sample.*

During this assessment samples were collected during a low discharge event on August 3, 2017. Samples were analyzed for E. coli by personnel from the Riviera

Utilities Wolf Creek wastewater treatment plant, using the IDEXX Quanti Tray 2000 method. Experience shows that bacteria concentrations in streams at low flow are more likely to represent point sources, including municipal and industrial waste-water discharge and sewer line leaks, where impacts of runoff are minimized.

The IDEXX Quanti Tray 2000 method results in a most probable number (mpn) of E. coli colonies in a 100-ml sample. The ADEM single sample criterion maximum is 2,507 mpn. Sites WC2, WC3, WC4, WC7, WC8, WC10, and WC11 were sampled during the low discharge event. Sites WC12, WC13, and WC14 were not sampled due to tidal influence. Sites WC11 (Wolf Creek at Swift Church Road), WC10 (Wolf Creek at Doc McDuffie Road, and WC7 (Elberta Creek at Baldwin Co Rd 83) had the highest mpn for the low discharge event with 313, 186, and 186 colonies, respectively (fig. 19). These numbers are relatively low for surface water and most likely do not represent any particular pathogen point source. E-coli was evaluated against stream discharge and watershed area. Discharge did not correlate well, however figure 19 shows a good correlation between watershed area and E-coli, accept at site WC7, where bacteria counts are relatively high and may represent a source of pathogens above background levels.

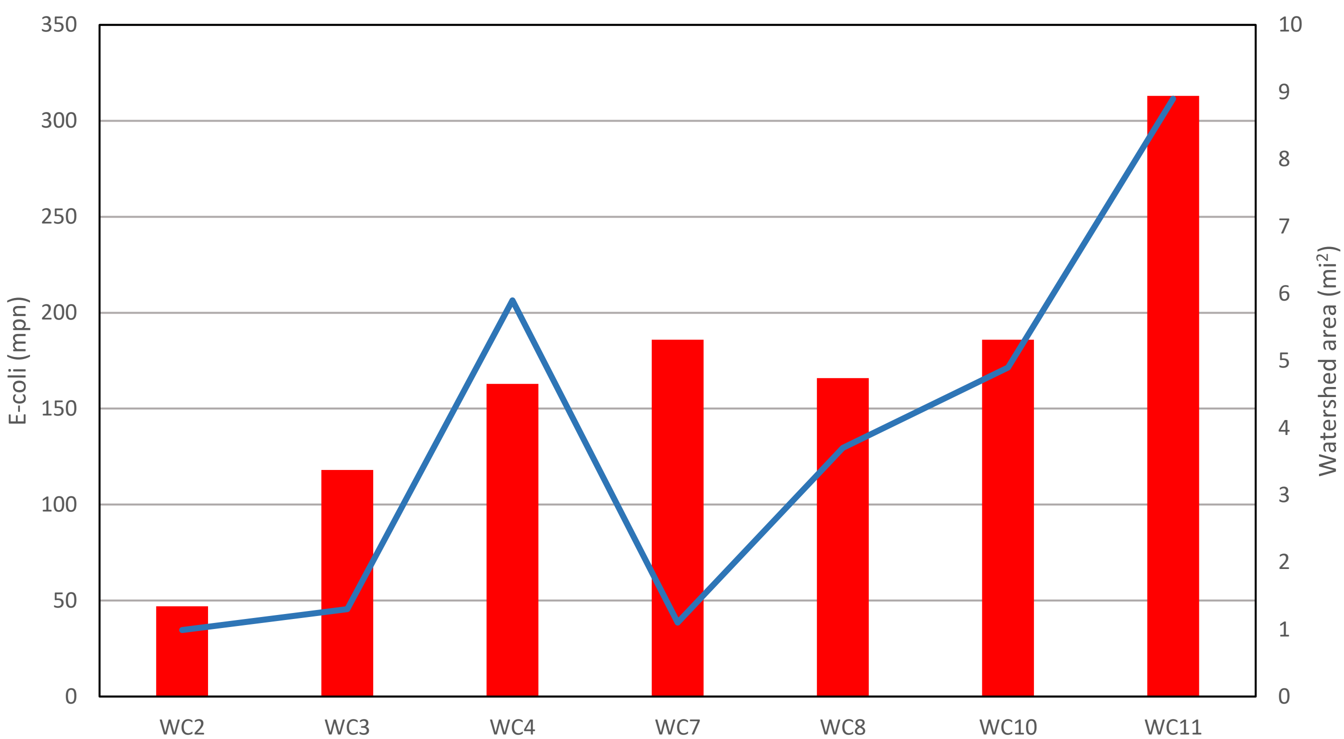


Figure 19.—E. coli mpn for a low discharge event and watershed area at selected Wolf Bay watershed monitoring sites.

## 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 Wolf Bay watershed. 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 and hydrologically, the Wolf Bay watershed can be divided into two regions; non-tidally influenced streams with uplands dominated by agriculture and commercial and residentially development, north of Miflin Road (Baldwin Co Rd 20) (fig. 20);and downstream, tidally influenced estuaries south of Miflin Road and east of Foley Beach Expressway, dominated by wetlands and coastal marsh with upland areas dominated by residential development with limited agriculture (fig. 20). These are most likely drown stream channels that formed during the previous low stand in sea level (fig. 20). The watershed is primarily rural but impacted by land-use conversion from agriculture to commercial and residential. Urban impacts to tributaries come from the towns of Foley and Elberta (fig. 20).

No streams in the Wolf Bay watershed are currently on the ADEM 303-D list of impaired waters. However, results of this assessment show that several stream reaches are impacted by excessive erosion and sedimentation. The largest suspended sediment loads in the Wolf Bay watershed occur in Sandy Creek upstream from Baldwin Co. Rd. 20 (WC12), in Wolf Creek upstream from Swift Church Rd. (WC11) and upstream from Doc McDuffie Rd. (WC10), in the west unnamed tributary to Sandy Creek upstream from US Highway 98 (WC5), and the east unnamed tributary to Sandy Creek upstream from US Highway 98 (site WC6). The mass of suspended sediment estimated at these sites were 929, 861, 460, 444, and 368 tons per year (t/yr), respectively. When normalized relative to drainage area, the largest suspended sediment loads were in the west unnamed tributary to Sandy Creek at US Highway 98 (WC5) (261 t/mi$^2$/yr), east unnamed tributary to Sandy Creek at US Highway 98 (WC6) (217 t/mi$^2$/yr), Wolf Creek at Doc McDuffie Rd. (WC10) (94 t/mi$^2$/yr), and Wolf Creek at Swift Church Rd. (WC11) (94 t/mi$^2$/yr).

Six sites (WC1, WC2, WC5, WC6, WC8, and WC10) had measurable bed sediment. Sites WC10 (Wolf Creek at Doc McDuffie Rd) and WC5 (west unnamed tributary to Sandy Creek at US Highway 98), and WC6 (east unnamed tributary to Sandy

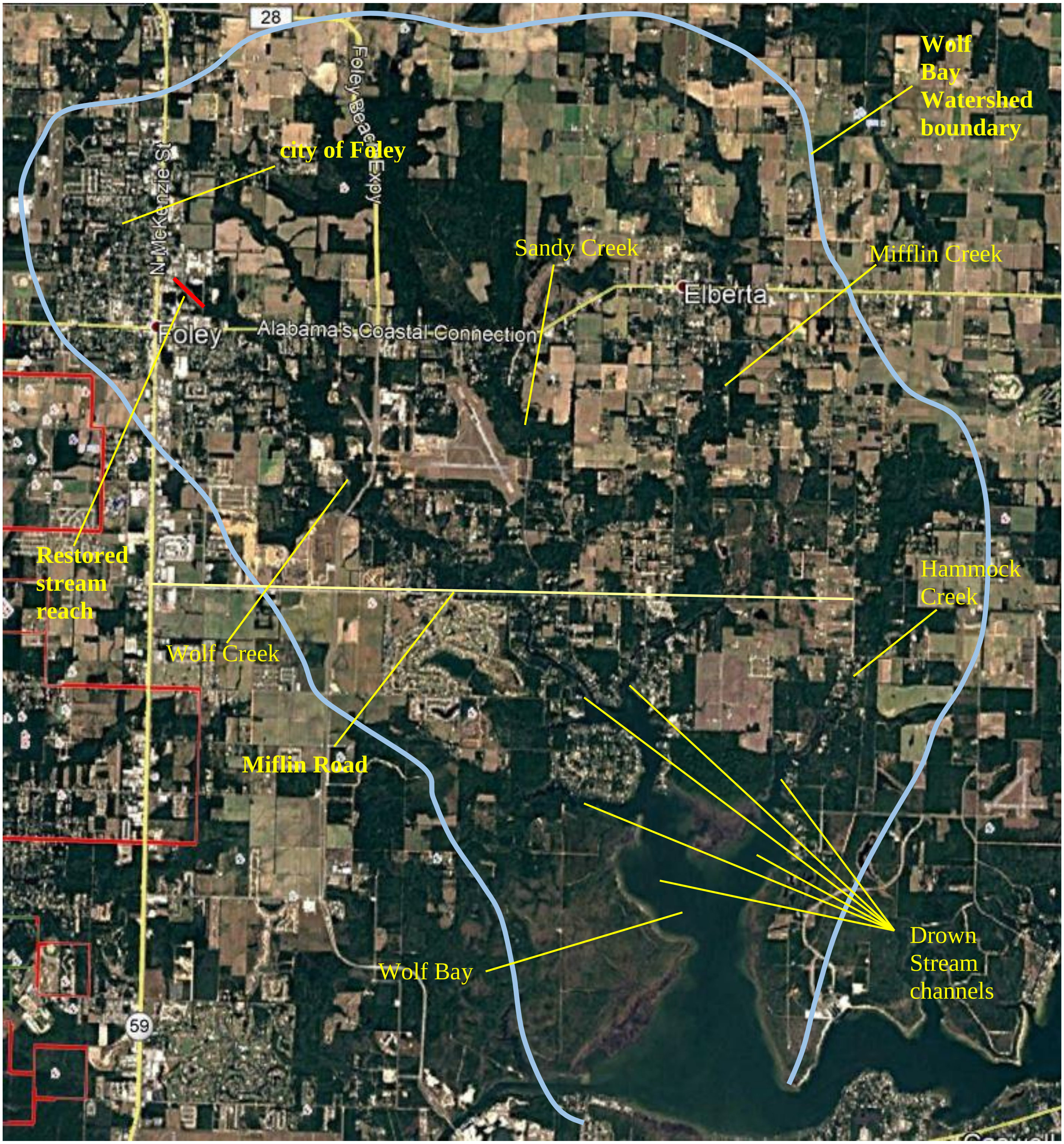


Figure 20. Image of the Wolf Bay watershed (Google Earth, 2017).

Creek at US Highway 98) had the largest bed sediment loads with 10,471, 1,551 and 1,347 t/yr, respectively. After normalization of bed sediment loads relative to drainage area, sites WC10 (Wolf Creek at Doc McDuffie Rd), WC5 (west unnamed tributary to

Sandy Creek at US Highway 98), and WC6 (east unnamed tributary to Sandy Creek at US Highway 98) had the largest loads with 2,137, 912, and 792 tons/mi$^2$/yr, respectively.

Wolf Creek at Doc McDuffie Road (WC10), west unnamed tributary to Sandy Creek at US Highway 98 (WC5), east unnamed tributary to Sandy Creek at US Highway 98 (WC6), and Wolf Creek at Swift Church Road (WC11) had the largest total sediment loads (10,931, 1,995, 1,715, and 1,257 tons per year (t/yr), respectively. The largest normalized total sediment loads occurred at Wolf Creek at Doc McDuffie Road (WC10) (2,231 t/mi$^2$/yr), west unnamed tributary to Sandy Creek at US Highway 98 (WC5) (1,173 t/mi$^2$/yr), east unnamed tributary to Sandy Creek at US Highway 98 (WC6) (1,009 t/mi$^2$/yr), and Miflin Creek at US 98 (WC8) (240 t/mi$^2$/yr). On average, bed sediment makes up 69% of total sediment loads for streams with measurable bed sediment.

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 9 of 13 monitored watersheds were from 1.1 to 34.9 times greater than the geologic erosion rate (fig. 12). Sites WC4 (Sandy Creek at US Highway 98), WC7 (Elberta Creek), and WC14 (Hammock Creek), and WC15 (Owens Bayou) were at or below the geologic erosion rate.

Site WC10 (Wolf Creek at Doc McDuffie Road) had the largest normalized estimated sediment loads in the Wolf Bay watershed. An evaluation of aerial imagery (Google Earth, January 2013 and February 2017) indicates that the watershed upstream from the monitoring site has three primary land uses that contribute to erosion and sediment that is being transported by Wolf Creek (fig. 20). The central and western headwaters area (upstream from Foley Beach Expressway) is in the city of Foley where urban runoff is characterized by flashy high velocity flows (fig. 20). One positive feature in this area is a 2,200 ft long channelized reach of Wolf Creek upstream from North Poplar Street that was restored in 2014 and includes meanders and natural vegetation that reduces streamflow velocities and limits erosion downstream. Figure 21 shows before and after imagery of the restored reach.

The western part of the headwaters area including the unnamed tributary upstream from site WC3 (north of US Highway 98) is dominated by row crop agriculture (fig. 20). Land use in the downstream part of the watershed is characterized by a mix of forested residential areas, row crop agriculture and industrial and construction sites, including the

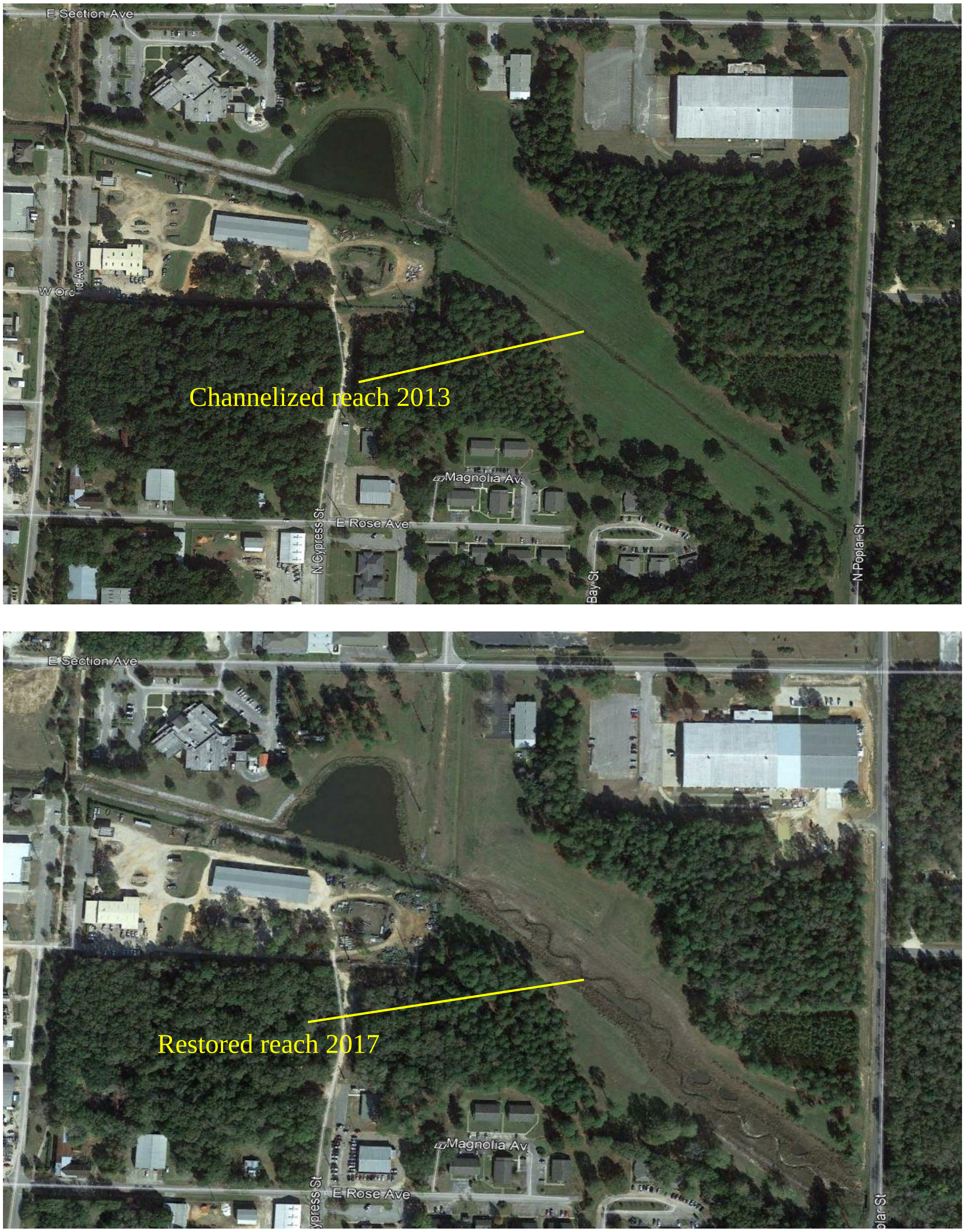


Figure 21.—Before and after restoration of a channelized reach of Wolf Creek in Foley (Google Earth, 2013 and 2017).

OWA amusement park construction site (figs. 20). Construction on the OWA site (at the intersection of Baldwin County Road 20 and Foley Beach Expressway) began in late 2014 after aerial image 1 in figure 22 was acquired in January 2013. Figure 22 shows the progression of the site preparation from pre-construction in January 2013 to partial site preparation in February 2015 to the beginning stages of construction in February 2017.

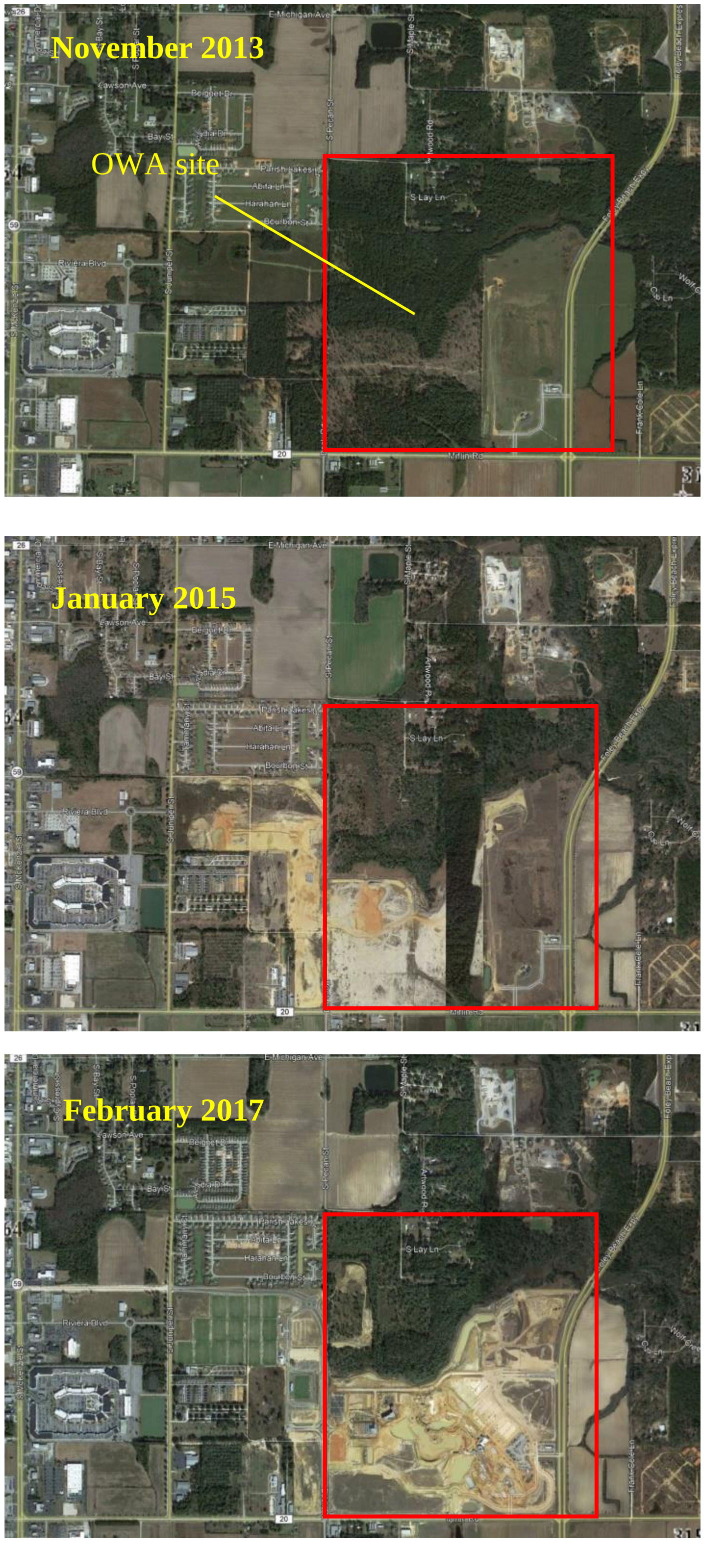


Figure 22.—Progression of site preparation from 2013 to 2017 for the OWA amusement park (Google Earth, 2013, 2015, 2017).

Impacts of OWA construction on Wolf Creek were monitored throughout the major construction period in 2017 using upstream site WC10 and downstream site WC11. Normalization of turbidity, TSS, and suspended sediment loads data from sites WC10 and WC11 indicate little or no impact from sediment contributed to Wolf Creek from the OWA site. Contractors and the city of Foley are commended for limiting erosion and retaining sediment on site during this major construction project. Although a single dominant source of sediment could not be determined from evaluation of aerial photography, all of the land uses listed above play a role in sediment loads estimated for Wolf Creek.

Sites WC5 (west unnamed tributary to Sandy Creek at US Highway 98), WC6 (east unnamed tributary to Sandy Creek at US Highway 98), and WC8 (Miflin Creek at US 98) had excessive sediment loads and are all in the same general geographic area near the town of Elberta along US Highway 98. Land use in all three watersheds is dominated by row crop and turf agriculture. The upland row crop fields are drained by a series of ditches that form headwaters of streams and are incised, in part, contributing excessive amounts of sediment during large rain events.

Bed sediment samples were collected at sites WC6 (east unnamed tributary at US Highway 98), WC8 (Miflin Creek at US Highway 98), and WC10 (Wolf Creek at Doc McDuffie Road). Wet samples were weighed to determine the mass in pounds per cubic ft (lbs/ft$^3$), which was 90, 105, and 118 lbs/ft$^3$, respectively. Samples were sieved to determine sediment grain sizes. Grain size classes were dominated by medium-grained sands, which are sourced from erosion of the Citronelle Formation.

Water samples were collected from December 2016 through August 2017 at Wolf Bay watershed monitoring sites for discharge events from base flow to bank full. Samples were analyzed for nitrate+nitrite nitrogen and total phosphorus. Analytical results were compared with reference concentrations for nitrate+nitrite nitrogen (0.3258 mg/L) and total phosphorus (0.04 mg/L) established by ADEM for Ecoregion 65f, which includes the Wolf Bay watershed. The ADEM reference concentration for nitrate+nitrite nitrogen was exceeded in 83% of samples collected. The largest nitrate+nitrite nitrogen loads were at sites WC8 (Miflin Creek), WC4 (Sandy Creek at US Highway 90), WC12 (Sandy Creek at Baldwin Co Rd 20), and WC11 (Wolf Creek) with 64.4, 56.7, 43.2, and 42.3 t/yr, respectively. The largest normalized nitrate+nitrite nitrogen loads were at sites WC8, WC5 (unnamed tributary to Sandy Creek at US Highway 90), WC4, and WC1 (Sandy Creek at Foley Beach Expressway), with 17.4, 14.7, 9.6, and 7.3 t/mi$^2$/yr. These watersheds are all dominated by row crop and turf agricultural land use.

The ADEM reference concentration for total phosphorus was exceeded in 63% of samples collected from Wolf Bay monitoring sites. The largest phosphorus loads were at sites WC11 (Wolf Creek) and WC5 (unnamed tributary to Sandy Creek), with 17.8 and 9.1 t/yr, respectively. When loads are normalized with respect to drainage area, Wolf Creek sites WC11 and WC10 had the largest loads with 2.0 and 0.9 t/mi$^2$/yr, respectively. The watershed upstream from site WC5 is dominated by row crop agriculture and land use upstream from sites WC10 and WC11 is dominated by urban development. Relatively large average concentrations and loadings of nitrogen and phosphorus in most of the monitored Wolf Bay watershed streams originate from sources related to unban, residential, and agricultural land use that dominate specific parts of the watershed.

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 (including the Wolf Bay watershed), which is 6.94 mg/L.

Dissolved oxygen was measured at Wolf Bay watershed monitoring sites from December 2016 through August 2017. Stream water temperatures during the monitoring period varied from 16.4 to 26.3°C. Site WC7 (Elberta Creek at Baldwin Co Rd 83) had the lowest average DO (6.3 mg/L) and site WC5 (unnamed tributary to Sandy Creek at US Highway 90) had the highest average DO (8.6 mg/L). Land use in the upland areas along the margins of the Elberta Creek watershed upstream from site WC7 is primarily row crop agriculture. However, the floodplain of the creek is a large wooded wetland with a small beaver pond immediately upstream from Baldwin County Road 83.Values lower than the ADEM Fish and Wildlife standard (5.0 mg/L) were measured at sites WC2, WC3, WC7, WC12, WC13, WC14, and WC15. Twelve of 14 sites had measured DO values less than the ADEM reference standard (6.94 mg/L)

When all assessed constituents are considered with respect to water quality and potential remediation and restoration, watersheds upstream from Wolf Creek sites WC10 and WC11, and unnamed tributaries to Sandy Creek upstream from sites WC5 and WC6 have the highest degree of impairment and should be considered primary targets for various types of remediation and restoration.

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## APPENDIX A

## FIELD AND ANALYTICAL DATA

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sandy Creek | | | | | 30.42614 | | | Area | | | | |
| at Foley Beach Expressway | | | | | 87.6485 | | | 2.2 $mi^2$ | | | | |
| Site | Date | Time | Dis | Temp | Cond | Turb | pH | DO | TSS | Bed Sed | Nitrate + Nitrite | Total P |
| | | | cfs | °C | mS/cm | NTU | | mg/L | mg/L | T/d | mg/L | mg/L |
| WC1 | 12/07/16 | 1630 | 5.1 | 17.6 | 65 | 13 | 6.1 | 8.3 | 3 | 0.08 | 1.9 | <.05 |
| WC1 | 12/14/16 | 915 | 17.3 | 18.1 | 56 | 42 | 5.9 | 7.5 | 6.0 | 0.46 | 0.689 | <.05 |
| WC1 | 01/21/17 | 1120 | 24.0 | 20.0 | 57 | 43 | 5.8 | 7.7 | 18.5 | 0.81 | 0.803 | 0.095 |
| WC1 | 02/08/17 | 1645 | 13.8 | 20.6 | 101 | 48 | 6.1 | 6.1 | 9.6 | 0.42 | 1.32 | 0.162 |
| WC1 | 02/21/17 | 1825 | 28.0 | 18.2 | 78 | 43 | 5.1 | 9.5 | 9.6 | 1 | 1.38 | 0.061 |
| WC1 | 03/30/17 | 1750 | 5.3 | 20.6 | 88 | 21 | 6.1 | 6.9 | 5.2 | 0.04 | 2.1 | <.05 |
| WC1 | 04/03/17 | 1620 | 38.0 | 22.3 | 92 | 115 | 5.2 | 8.3 | 24.0 | 1.35 | 0.941 | 0.112 |
| WC1 | 05/04/17 | 1025 | 44.0 | 20.3 | 64 | 84 | 5.1 | 8.4 | 18.4 | 1.55 | 0.84 | 0.108 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wolf Creek | | | | | 30.40967 | | | Area | | | | |
| at N. Poplar St. | | | | | 87.67639 | | | 0.99 $mi^2$ | | | | |
| Site | Date | Time | Dis | Temp | Cond | Turb | pH | DO | TSS | Bed Sed | Nitrate + Nitrite | Total P |
| | | | cfs | °C | mS/cm | NTU | | mg/L | mg/L | T/d | mg/L | mg/L |
| WC2 | 12/07/16 | 1515 | 0.8 | 18.0 | 89 | 19 | 6.1 | 7.8 | 6 | 0.003 | | <.05 |
| WC2 | 12/14/16 | 800 | 1.4 | 19.2 | 76 | 31 | 6.6 | 8.0 | 7.2 | 0.01 | 0.397 | 0.097 |
| WC2 | 01/21/17 | 1000 | 52 | 18.7 | 113 | 144 | 5.7 | 7.8 | 30 | 2.9 | <0.3 | 0.101 |
| WC2 | 03/30/17 | 1650 | 5.3 | 21.6 | 139 | 43 | 6.1 | 7.5 | 16.0 | 0.35 | 0.498 | 0.057 |
| WC2 | 04/03/17 | 1710 | 33 | 22.7 | 52 | 40 | 6.6 | 7.9 | 13.2 | 1.8 | 0.404 | 0.133 |
| WC2 | 04/30/17 | 2020 | 2.2 | 24.1 | 140 | 9 | 6.4 | 8.5 | 2.4 | 0.2 | 0.968 | <.05 |
| WC2 | 05/04/17 | 1055 | 9.7 | 21.3 | 41 | 26 | 6.4 | 8.3 | 6.4 | 0.45 | 0.288 | 0.105 |
| WC2 | 05/12/17 | 1515 | 35 | 22.1 | 138 | 70 | 6.4 | 6.4 | 20.0 | 1.9 | 0.569 | 0.064 |
| WC2 | 08/03/17 | 1440 | 2.8 | 26.3 | 92 | 16 | 6.5 | 4.9 | 3.0 | 0.25 | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unnamed tributary | | | | | 30.4069 | | | Area | | | | |
| at US Hwy 98 crossing | | | | | 87.65579 | | | 1.3 $mi^2$ | | | | |
| Site | Date | Time | Dis | Temp | Cond | Turb | pH | DO | TSS | | Nitrate + Nitrite | Total P |
| | | | cfs | °C | mS/cm | NTU | | mg/L | mg/L | | mg/L | mg/L |
| WC3 | 12/07/16 | 1600 | 2.0 | 17.8 | 67 | 19 | 6.0 | 7.6 | 6 | | | |
| WC3 | 12/14/16 | 840 | 10.6 | 18.4 | 54 | 25 | 6.3 | 5.8 | 5.6 | | 0.503 | 0.219 |
| WC3 | 01/21/17 | 1050 | 30.0 | 18.5 | 50 | 127 | 6.0 | 8.1 | 60.7 | | <0.3 | 0.180 |
| WC3 | 03/30/17 | 2055 | 1.5 | 19.0 | 78 | 94 | 5.9 | 5.6 | 31.6 | | 0.361 | 0.138 |
| WC3 | 04/03/17 | 1645 | 180.0 | 21.7 | 37 | 121 | 6.1 | 8.3 | 31.2 | | 0.772 | 0.216 |
| WC3 | 04/30/17 | 2030 | 0.8 | 23.3 | 117 | 39 | 6.2 | 4.9 | 18.8 | | <0.3 | <.05 |
| WC3 | 05/04/17 | 1145 | 170.0 | 20.2 | 35 | 68 | 6.3 | 8.4 | 16.8 | | 0.444 | 0.223 |
| WC3 | 05/12/17 | 1530 | 3.0 | 22.8 | 66 | 59 | 6.6 | 7.0 | 35.3 | | 0.15 | 0.080 |
| WC3 | 08/03/17 | 1420 | 1.0 | 23.9 | 99 | 38 | 6.0 | 3.8 | 12.0 | | | |

| Sandy Creek | | | | | 30.40682 | | | Area | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| at US Highway 98 crossing | | | | | 87.63024 | | | 5.9 $mi^2$ | | | | |
| Site | Date | Time | Dis | Temp | Cond | Turb | pH | DO | TSS | | Nitrate + Nitrite | Total P |
| | | | cfs | °C | mS/cm | NTU | | mg/L | mg/L | | mg/L | mg/L |
| WC4 | 12/13/16 | 1400 | 14.9 | 21.1 | 138 | 2 | 5.5 | 6.6 | 2 | | 1.570 | <.05 |
| WC4 | 01/19/17 | 830 | 17.8 | 20.8 | 65 | 7 | 6.0 | 8.3 | 3.0 | | | |
| WC4 | 01/21/17 | 1150 | 51.1 | 20.0 | 49 | 32 | 5.8 | 7.9 | 11.6 | | 0.752 | <.05 |
| WC4 | 02/21/17 | 2115 | 65.5 | 18.0 | 49 | 33 | 6.0 | 9.5 | 15.6 | | 0.875 | <.05 |
| WC4 | 03/30/17 | 2000 | 28 | 19.7 | 53 | 16 | 6.1 | 7.6 | 6.0 | | 1.41 | <.05 |
| WC4 | 04/03/17 | 1820 | 170 | 20.9 | 39 | 63 | 5.9 | 9.6 | 36.4 | | 0.986 | <.05 |
| WC4 | 04/30/17 | 2230 | 14.3 | 23.0 | 302 | 6 | 6.4 | 9.0 | 2 | | 1.52 | <.05 |
| WC4 | 05/04/17 | 1510 | 92 | 20.7 | 189 | 43 | 5.6 | 9.3 | 17.6 | | 0.733 | <.05 |
| WC4 | 05/12/17 | 1550 | 14 | 21.1 | 52 | 7 | 6.2 | 7.7 | 2 | | 1.580 | <.05 |
| WC4 | 08/03/17 | 1340 | 16.3 | 22.7 | 54 | 5 | 6.1 | 6.7 | 2.0 | | | |

| West unnamed tributary | | | | | 30.40667 | | | Area | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| at US Highway 98 | | | | | 87.62627 | | | 1.7 $mi^2$ | | | | |
| Site | Date | Time | Dis | Temp | Cond | Turb | pH | DO | TSS | Bed Sed | Nitrate + Nitrite | Total P |
| | | | cfs | °C | mS/cm | NTU | | mg/L | mg/L | T/d | mg/L | mg/L |
| WC5 | 12/13/16 | 1415 | 0.74 | 21.2 | 87 | 2 | 5.7 | 7.9 | 2 | 0.62 | 5.800 | <.05 |
| WC5 | 12/14/16 | 1030 | 3.3 | 19.0 | 56 | 26 | 5.7 | 8.1 | 5.6 | 2.6 | 1.850 | <.05 |
| WC5 | 01/19/17 | 900 | 2.7 | 20.9 | 70 | 12 | 5.8 | 8.1 | 10 | 0.18 | | |
| WC5 | 01/21/17 | 1215 | 17.9 | 20.8 | 42 | 355 | 5.4 | 9.6 | 248.0 | 7.8 | 0.451 | 0.072 |
| WC5 | 02/22/17 | 915 | 7.5 | 17.8 | 47 | 71 | 6.1 | 8.7 | 29.2 | 12.7 | 1.660 | 0.095 |
| WC5 | 04/03/17 | 1840 | 29 | 20.9 | 31 | 270 | 5.9 | 9.6 | 147.0 | 26.7 | 1.580 | 0.176 |
| WC5 | 05/12/17 | 1605 | 3 | 20.8 | 69 | 31 | 5.8 | 8.0 | 18.0 | 2.0 | 4.660 | <.05 |

| East unnamed tributary | | | | | 30.40671 | | | Area | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| at US Highway 98 | | | | | 87.62481 | | | 1.7 $mi^2$ | | | | |
| Site | Date | Time | Dis | Temp | Cond | Turb | pH | DO | TSS | Bed Sed | Nitrate + Nitrite | Total P |
| | | | cfs | °C | mS/cm | NTU | | mg/L | mg/L | T/d | mg/L | mg/L |
| WC6 | 12/13/2016 | 1445 | 1.9 | 21.6 | 74 | 5 | 6.1 | 7.9 | 3.33 | 0.14 | 2.26 | <.05 |
| WC6 | 12/14/2016 | 1100 | 4.8 | 19.3 | 63 | 17 | 6.2 | 7.9 | 8.8 | 0.5 | 1.23 | <.05 |
| WC6 | 1/19/2017 | 915 | 1.5 | 21.9 | 63 | 18 | 6.1 | 7.6 | 15 | 2.3 | | |
| WC6 | 1/21/2017 | 1300 | 30.6 | 20.8 | 47 | 61 | 6.0 | 8.6 | 31.2 | 18.7 | 0.570 | <.05 |
| WC6 | 2/22/2017 | 1000 | 5.4 | 19.2 | 60 | 22 | 6.1 | 9.3 | 29.2 | 3.3 | 1.660 | 0.095 |
| WC6 | 4/3/2017 | 1915 | 20.9 | 21.7 | 49 | 260 | 6.1 | 8.1 | 216 | 12.8 | 1.360 | <.05 |
| WC6 | 5/1/2017 | 115 | 1 | 24.2 | 82 | 27 | 6.1 | 7.0 | 12 | 0.5 | 1.950 | <.05 |
| WC6 | 5/12/2017 | 1615 | 22 | 22.8 | 48 | 192 | 6.1 | 7.0 | 77.5 | 13 | 1.320 | <.05 |

| Elberta Creek | | | | | 30.42262 | | | Area | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| at Baldwin Co Road 83 | | | | | 87.59837 | | | 1.1 mi$^2$ | | | | |
| Site | Date | Time | Dis | Temp | Cond | Turb | pH | DO | TSS | | Nitrate + Nitrite | Total P |
| | | | cfs | °C | mS/cm | NTU | | mg/L | mg/L | | mg/L | mg/L |
| WC7 | 12/14/16 | 1140 | 15.0 | 18.5 | 64 | 11 | 5.7 | 5.3 | 3.2 | | 0.150 | 0.051 |
| WC7 | 02/09/17 | 1050 | 11.2 | 17.2 | 62 | 11 | 6.1 | 7.2 | 2 | | 0.417 | 0.088 |
| WC7 | 02/21/17 | 2150 | 63.0 | 17.1 | 56 | 19 | 6.0 | 7.1 | 4.8 | | 0.631 | 0.068 |
| WC7 | 03/30/17 | 2040 | 53.0 | 19.5 | 56 | 35 | 5.9 | 6.6 | 10 | | 0.486 | <.05 |
| WC7 | 04/03/17 | 1950 | 23.0 | 20.4 | 44 | 39 | 5.9 | 7.2 | 10 | | 0.559 | 0.057 |
| WC7 | 04/30/17 | 2250 | 2.7 | 22.9 | 75 | 19 | 5.9 | 4.5 | 8 | | 0.343 | <.05 |
| WC7 | 05/12/17 | 1630 | 2.9 | 21.2 | 55 | 55 | 5.9 | 7.9 | 21.5 | | 0.403 | 0.097 |
| WC7 | 08/03/17 | 1405 | 3.2 | 23.9 | 64 | 13 | 6.0 | 4.5 | 4.0 | | | |

| Miflin Creek | | | | | 30.41433 | | | Area | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| at US Highway 98 | | | | | 87.59159 | | | 3.7 mi$^2$ | | | | |
| Site | Date | Time | Dis | Temp | Cond | Turb | pH | DO | TSS | Bed Sed | Nitrate + Nitrite | Total P |
| | | | cfs | °C | mS/cm | NTU | | mg/L | mg/L | T/d | mg/L | mg/L |
| WC8 | 12/14/16 | 1210 | 14.9 | 18.8 | 62 | 32 | 6.1 | 6.7 | 12.0 | 2 | 0.572 | 0.057 |
| WC8 | 02/09/17 | 1110 | 14.0 | 17.5 | 62 | 12 | 6.2 | 5.5 | 2.0 | 1.8 | 0.122 | 0.052 |
| WC8 | 02/21/17 | 2130 | 38.9 | 17.5 | 53 | 32 | 6.1 | 7.1 | 9.2 | 5 | 0.831 | 0.061 |
| WC8 | 03/30/17 | 2020 | 45.0 | 20.2 | 64 | 44 | 6.3 | 6.9 | 24.0 | 5.5 | 0.916 | 0.088 |
| WC8 | 04/03/17 | 1940 | 70.0 | 20.6 | 43 | 74 | 6.1 | 8.0 | 35.6 | 7.5 | 0.880 | 0.060 |
| WC8 | 04/30/17 | 2310 | 13.0 | 23.0 | 94 | 13 | 6.0 | 5.6 | 2.8 | 1.7 | 3.140 | <.05 |
| WC8 | 05/12/17 | 1640 | 12.0 | 21.2 | 86 | 12 | 6.0 | 6.5 | 4.8 | 1.6 | 3.450 | <.05 |
| WC8 | 08/03/17 | 1355 | 3.9 | 23.2 | 85 | 9 | 6.1 | 7.4 | 4.0 | 0.24 | 3.300 | <.05 |
| WC8 | 08/04/17 | 950 | 140.0 | 23.5 | 65 | 141 | 6.5 | 8.2 | 52.0 | 10 | 0.400 | 0.115 |
| WC8 | 08/29/17 | 2100 | 55.0 | 185.5 | 614 | 55 | | 61.9 | 28.0 | 6.4 | | |

| Wolf Creek | | | | | 30.38979 | | | Area | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| at Doc McDuffie Road crossing | | | | | 87.65302 | | | 4.9 mi$^2$ | | | | |
| Site | Date | Time | Dis | Temp | Cond | Turb | pH | DO | TSS | Bed Sed | Nitrate + Nitrite | Total P |
| | | | cfs | °C | mS/cm | NTU | | mg/L | mg/L | T/d | mg/L | mg/L |
| WC10 | 10/28/16 | 930 | 6.8 | | | | | | 2 | 0.14 | | |
| WC10 | 01/18/17 | 1600 | 12.4 | 21.2 | 159 | 10 | 6.4 | 6.3 | 2 | 1.1 | 1.420 | 1.580 |
| WC10 | 01/21/17 | 1410 | 129 | 20 | 56 | 96 | 6.4 | 8.4 | 46.7 | 65 | 0.332 | 0.256 |
| WC10 | 02/09/17 | 1000 | 12.3 | 17.6 | 111 | 11 | 6.4 | 5.2 | 2 | 0.22 | 1.300 | 0.411 |
| WC10 | 02/21/17 | 1940 | 63.7 | 18.7 | 74 | 63 | 6.3 | 7 | 15.6 | 52 | 0.682 | 0.703 |
| WC10 | 03/30/17 | 1820 | 15.8 | 21.1 | 145 | 23 | 6.4 | 6.5 | 12.4 | 6.8 | 1.360 | 1.640 |
| WC10 | 04/03/17 | 1800 | 149 | 20.9 | 49 | 174 | 6.5 | 8.2 | 63.0 | 70 | 0.790 | 0.226 |
| WC10 | 04/30/17 | 2045 | 11 | 23.9 | 147 | 8 | 6.4 | 6.3 | 2.0 | 0.8 | 1.180 | 0.533 |
| WC10 | 05/04/17 | 1230 | 140 | 21 | 47 | 67 | 6.5 | 7.8 | 23.6 | 68 | 0.528 | 0.187 |
| WC10 | 8/3/2017 | 1310 | 13.4 | 23.4 | 118 | 12 | 6.3 | 6.3 | 4.0 | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wolf Creek | | | | | 30.3735 | | | Area | | | | |
| at Swift Church Road | | | | | 87.63262 | | | 8.9 $mi^2$ | | | | |
| Site | Date | Time | Dis | Temp | Cond | Turb | pH | DO | TSS | | Nitrate + Nitrite | Total P |
| | | | cfs | °C | mS/cm | NTU | | mg/L | mg/L | | mg/L | mg/L |
| WC11 | 01/18/17 | 1400 | 17.5 | 23.3 | 195 | 11 | 6.1 | 8.8 | 2 | | 1.640 | 0.733 |
| WC11 | 01/21/17 | 1500 | 214.0 | 20.1 | 70 | 237 | 6.4 | 9.1 | 139 | | 0.510 | 0.388 |
| WC11 | 02/09/17 | 855 | 30.0 | 17.2 | 269 | 17 | 6.6 | 6.0 | 8 | | 1.550 | 0.249 |
| WC11 | 02/21/17 | 2000 | 113.0 | 18.7 | 74 | 63 | 6.3 | 7.0 | 35.2 | | 0.707 | 0.443 |
| WC11 | 02/22/17 | 815 | 42.9 | 17.9 | 80 | 42 | 6.5 | 8.7 | 13.6 | | 1.070 | 0.442 |
| WC11 | 03/30/17 | 1900 | 22.5 | 20.8 | 98 | 13 | 6.4 | 7.3 | 2.4 | | 1.750 | 0.588 |
| WC11 | 04/03/17 | 1740 | 277.0 | 21.3 | 47 | 147 | 6.6 | 8.4 | 81.5 | | 0.615 | 0.180 |
| WC11 | 04/30/17 | 2105 | 20.0 | 23.2 | 99 | 8 | 6.4 | 7.0 | 9.2 | | 1.640 | 0.259 |
| WC11 | 05/04/17 | 1220 | 265.0 | 20.5 | 43 | 121 | 6.5 | 8.4 | 56.0 | | 0.521 | 0.190 |
| WC11 | 08/03/17 | 1300 | 24.0 | 23.2 | 180 | 11 | 5.5 | 7.0 | 9.0 | | | |
| WC11 | 08/30/17 | 900 | 718.0 | 24.6 | 41 | 180 | 6.4 | 5.4 | | | | |
| | | | | | | | | | | | | |
| Sandy Creek | | | | | 30.37041 | | | Area | | | | |
| at Baldwin Co Road 20 | | | | | 87.61852 | | | 13.3 $mi^2$ | | | | |
| Site | Date | Time | Dis | Temp | Cond | Turb | pH | DO | TSS | | Nitrate + Nitrite | Total P |
| | | | cfs | °C | mS/cm | NTU | | mg/L | mg/L | | mg/L | mg/L |
| WC12 | 01/18/17 | 1525 | | 21.0 | 3,300 | 22 | 6.3 | 7.1 | 8.4 | | 0.15 | 0.245 |
| WC12 | 01/21/17 | 1430 | 348 | 20.3 | 184 | 27 | 6.2 | 8.2 | 8.4 | | 0.824 | 0.061 |
| WC12 | 02/09/17 | 825 | | 16.4 | 14,000 | 26 | 6.8 | 5.1 | 18.4 | | 0.15 | 0.025 |
| WC12 | 02/21/17 | 2050 | 156 | 18.5 | 437 | 630 | 6.3 | 7.3 | 128 | | 0.940 | 0.146 |
| WC12 | 04/03/17 | 2200 | 151 | 20.0 | 420 | 145 | 6.1 | 8.3 | 52.4 | | 0.872 | 0.093 |
| WC12 | 04/30/17 | 2330 | | 23.5 | 1,330 | 9 | 6.1 | 6.6 | 2 | | 0.688 | 0.025 |
| WC12 | 05/04/17 | 1210 | 397 | 21.1 | 172 | 95 | 6.2 | 7.8 | 31.2 | | 0.587 | 0.059 |
| WC12 | 08/30/17 | 840 | 940 | 24.4 | 38 | 198 | 6.0 | 4.5 | 55.0 | | | |
| | | | | | | | | | | | | |
| Miflin Creek | | | | | 30.36395 | | | Area | | | | |
| at Baldwin Co Road 20 | | | | | 87.60249 | | | 12.5 $mi^2$ | | | | |
| Site | Date | Time | | Temp | Cond | Turb | pH | DO | TSS | | Nitrate + Nitrite | Total P |
| | | | | °C | mS/cm | NTU | | mg/L | mg/L | | mg/L | mg/L |
| WC13 | 01/18/17 | 1515 | | 21.1 | 13,900 | 15 | 6.6 | 4.9 | 8.8 | | <.3 | <.05 |
| WC13 | 02/09/17 | 810 | | 17.5 | 16,200 | 14 | 6.7 | 4.8 | 13.2 | | <.3 | <.05 |
| WC13 | 02/21/17 | 2030 | | 20.0 | 15,400 | 18 | 6.6 | 8.2 | 18.0 | | <.3 | <.05 |
| WC13 | 04/03/17 | 2140 | | 20.4 | 3,640 | 56 | 6.3 | 8.2 | 24.0 | | 0.545 | <.05 |
| WC13 | 04/30/17 | 2140 | | 25.6 | 15,000 | 18 | 7.0 | 7.7 | 12.8 | | <.3 | <.05 |
| WC13 | 05/04/17 | 1450 | | 23.8 | 11,900 | 31 | 6.8 | 9.1 | 15.2 | | 0.222 | <.05 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hammock Creek | | | | | 30.36303 | | | Area | | | | |
| at Baldwin Co Road 20 | | | | | 87.56769 | | | 3.8 $mi^2$ | | | | |
| Site | Date | Time | Dis | Temp | Cond | Turb | pH | DO | TSS | | Nitrate + Nitrite | Total P |
| | | | cfs | °C | mS/cm | NTU | | mg/L | mg/L | | mg/L | mg/L |
| WC14 | 01/18/17 | 1500 | 16.2 | 22.1 | 1580 | 4 | 5.6 | 7.0 | 2 | | 0.447 | 0.081 |
| WC14 | 02/09/17 | 755 | 10.0 | 17.5 | 61 | 8 | 5.1 | 5.9 | 2 | | 0.914 | <.05 |
| WC14 | 02/21/17 | 2015 | 81.0 | 17.8 | 46 | 22 | 5.7 | 8.2 | 5.2 | | 0.595 | <.05 |
| WC14 | 04/03/17 | 2120 | 85.0 | 20.0 | 43 | 31 | 5.3 | 7.7 | 8.4 | | 0.724 | <.05 |
| WC14 | 04/30/17 | 2130 | 15.0 | 24.6 | 12000 | 4 | 6.2 | 4.2 | 5.2 | | 0.2 | <.05 |
| WC14 | 05/04/17 | 1435 | 10.0 | 21.4 | 297 | 18 | 5.8 | 8.3 | 7.6 | | 0.512 | <.05 |
| WC14 | 08/30/14 | 820 | 218.0 | 24.2 | 29 | 96 | 5.8 | 4.6 | 15.0 | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Owens Bayou | | | | | 30.3598 | | | Area | | | | |
| at Glen Lakes Lakeview Drive | | | | | 87.63927 | | | 0.8 $mi^2$ | | | | |
| Site | Date | Time | Dis | Temp | Cond | Turb | pH | DO | TSS | | Nitrate + Nitrite | Total P |
| | | | cfs | °C | mS/cm | NTU | | mg/L | mg/L | | mg/L | mg/L |
| WC15 | 08/29/17 | 2015 | 2.7 | 26.3 | 104 | 10 | 6.7 | 5.6 | 2 | | 0.418 | 0.135 |
| WC15 | 08/29/17 | 2150 | 13.3 | 25.9 | 56 | 28 | 6.8 | 3.7 | 19.2 | | 0.319 | 0.175 |
| WC15 | 08/30/17 | 750 | 60.0 | 24.8 | 34 | 36 | 6.8 | 5.4 | 14.8 | | 0.390 | 0.245 |