PRE-RESTORATION ANALYSIS OF DISCHARGE, SEDIMENT TRANSPORT RATES, WATER QUALITY, AND LAND-USE IMPACTS IN WATERSHEDS ALONG THE EASTERN SHORE OF MOBILE BAY, BALDWIN COUNTY, ALABAMA

Mobile Bay National Estuary Program

BARRY A. VITTOR AND ASSOCIATES

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By

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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 nutrient rich runoff, sediment transport, and loss of biological habitat in streams downstream from areas affected by rapid runoff and erosion. These deleterious impacts originate from land uses dominated by impervious surfaces, deforestation, and transition of land uses from vegetated and agriculture to commercial and residential. Other areas are virtually unimpacted by land-use change and are characterized by natural landscapes dominated by forests and wetlands. The Mobile Bay eastern shore fits into this categorization as an area with beautiful natural coastal landscapes and areas of rapidly expanding residential and commercial development. 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 nutrient loads and sediment transport rates for tributaries to Mobile Bay along the eastern shore, including Yancy Branch, Red Gully, Rock Creek, Fly Creek, Volanta Creek, Big Mouth Gully, Tatumville Gully, Point Clear Creek, Baily Creek, and four unnamed 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 watersheds along the eastern shore of Mobile Bay.

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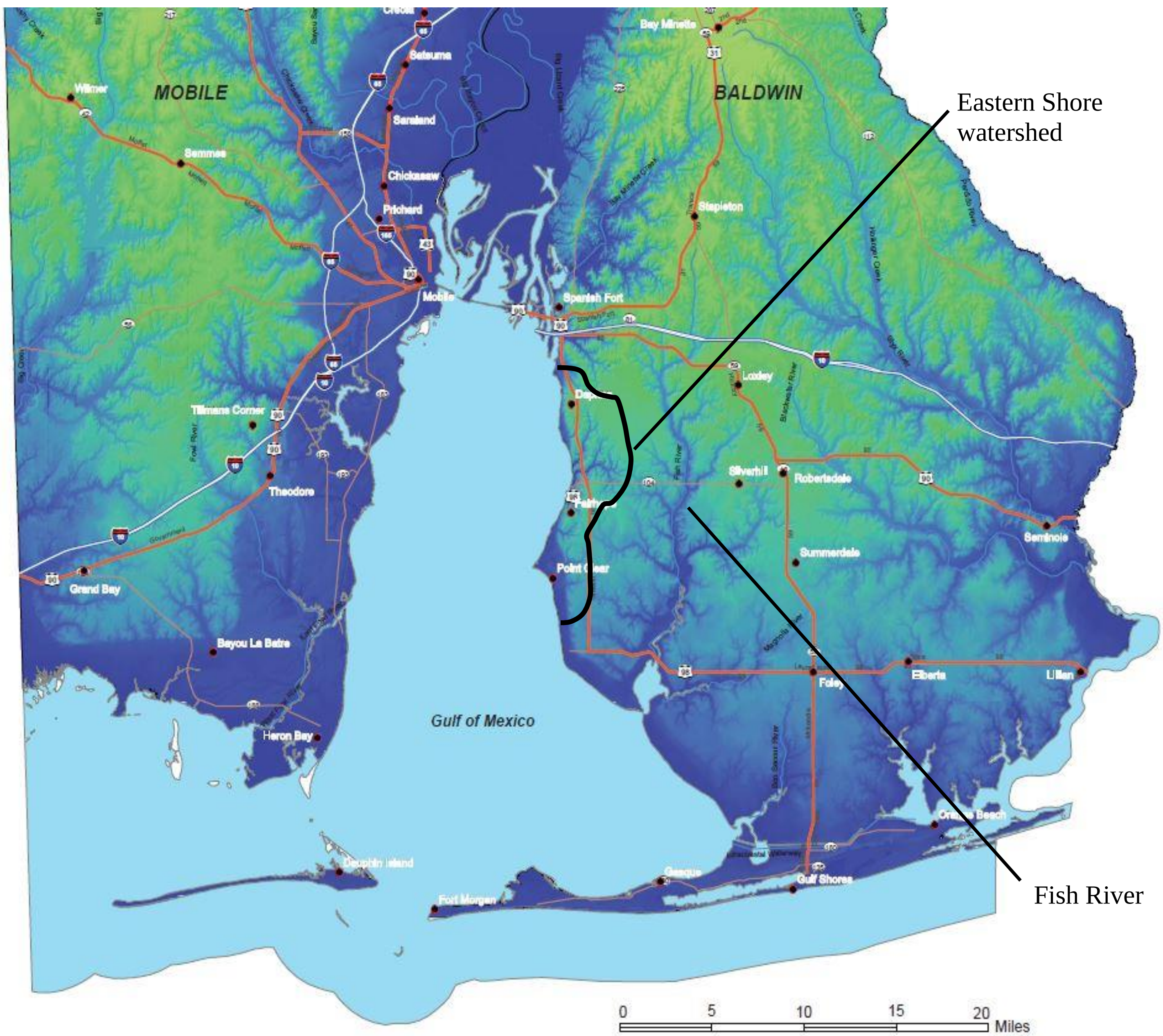

Figure 1.—Mobile and Baldwin Counties with the eastern Shore watershed and Fish River.

Manager, city of Daphne, Alabama and the city of Fairhope Environmental Advisory Board provided technical assistance.

PROJECT AREA

The eastern shore project area covers about 30 square miles (mi^2) and includes streams that flow westward into Mobile Bay from a drainage divide that separates the eastern shore watershed from the Fish River watershed (fig. 1). The project area has 15 monitoring sites on 14 streams, extending from Yancey Branch in Daphne, near I-10 to Bailey Creek, south of Point Clear (fig. 2). Elevations in the project area vary from sea level along the Mobile Bay shoreline to about 170 feet above mean sea level (ft MSL) at the headwaters of Yancey Branch. Fly Creek is the only eastern shore watershed stream on the Alabama Department of Environmental Management (ADEM) 303(d) list of impaired waters in Alabama (ADEM, 2020). It is listed for excessive pathogens (E. coli), caused by animal grazing in the watershed.

PROJECT MONITORING STRATEGY AND SITE CHARACTERISTICS

The strategy employed for the eastern shore project was to select monitoring sites on all accessible streams. Each stream reach was monitored over a wide range of measured discharge from base flow to high flow, including Hurricane Barry in July 2019. Water samples were collected for measurement of specific conductance, pH, temperature, turbidity, salinity (where applicable), and dissolved oxygen. Laboratory analyses were performed for total suspended solids, nitrate+nitrite nitrogen, and total phosphorus. Bed sediment transport rates were measured, where possible and daily and annual loads were estimated for suspended and bed sediment.

Site ES1 is on Yancey Branch near Harbor Place Drive, about 2.6 miles downstream from the headwaters (latitude (lat) 30.626982, longitude (long) -87.914488). The watershed upstream from site ES1 covers 1,088 acres (1.7 mi^2) (USGS, 2020) (fig. 2).

Site ES2 is on Red Gully at Bay Shore Drive, about 2 miles downstream from the headwaters (lat 30.578396, long -87.904789). The watershed upstream from site WC2 covers 512 acres (0.8 mi^2) (USGS, 2020) (fig. 2).

Site ES3 is on Rock Creek at US Highway 98 (lat 30.562950, long -87.894250). The watershed upstream from site ES3 covers 2,624 acres (4.1 mi^2) (USGS, 2020) (fig. 3).

Site ESFC4 is on an unnamed tributary at Headwaters Road, about 3,000 ft from the confluence with Fly Creek (lat 30.56470, long -87.88013). The watershed upstream from site ESFC4 covers 832 acres (1.3 mi^2) (USGS, 2020) (fig. 3).

Site ESFC5 is on an unnamed tributary to Fly Creek at Woodland Drive about 700 ft from the confluence with Fly Creek, (lat 30.55160, long -87.88832). The watershed upstream from site ESFC5 covers 192 acres (0.3 mi^2) (USGS, 2020) (fig. 3).

Site ESFC6 is on Fly Creek at Scenic US Highway 98, (lat 30.55122, long -87.89874). The watershed upstream from site ESFC6 covers 4,608 acres (7.2 mi^2) (USGS, 2020) (fig. 3).

Site ESFC7 is on Fly Creek at Alabama Highway 13, (lat 30.55456, long -87.86995). The watershed upstream from site ESFC7 covers 2,496 acres (3.9 mi^2) (USGS, 2020) (fig. 3).

Site ESFC8 is on an unnamed tributary to Fly Creek at AL Highway 104, about 1.1 mi from the headwaters (lat 30.54537, long -87.86796). The watershed upstream from site ESFC8 covers 2,368 acres (3.7 mi^2) (USGS, 2020) (fig. 3).

Site ESFC9 is on an unnamed tributary to Fly Creek at AL Highway 104, about 0.9 mi from the headwaters (lat 30.54530, long -87.86497). The watershed upstream from site ESFC9 covers 256 acres (0.4 mi^2) (USGS, 2020) (fig. 3).

Site ESFC10 is on an unnamed tributary to Fly Creek at AL Highway 104, about 0.6 mi from the headwaters (lat 30.54548, long -87.86023). The watershed upstream from site ESFC10 covers 128 acres (0.2 mi^2) (USGS, 2020) (fig. 3).

Site ES11 is on Volanta Gully at Scenic Highway 98, about 1.2 mi from the headwaters (lat 30.53677, long -87.90037). The watershed upstream from site ES11 covers 320 acres (0.5 mi^2) (USGS, 2020) (fig. 3).

Site ES12 is on Big Mouth Gully at North Bancroft Street, about 1.0 mi from the headwaters (lat 30.52857, long -87.90176). The watershed upstream from site ES12 covers 384 acres (0.6 mi^2) (USGS, 2020) (fig. 3).

Site ES13 is on Tatumville Gully at South Section Street, about 0.8 mi from the headwaters (lat 30.50954, long -87.90276). The watershed upstream from site ES13 covers 256 acres (0.4 mi^2) (USGS, 2020) (fig. 3). *This site was unusable due to vegetation and stream channel characteristics and was abandoned.

Site ES14 is on Tatumville Gully at Scenic Highway 98, about 1.9 mi from the

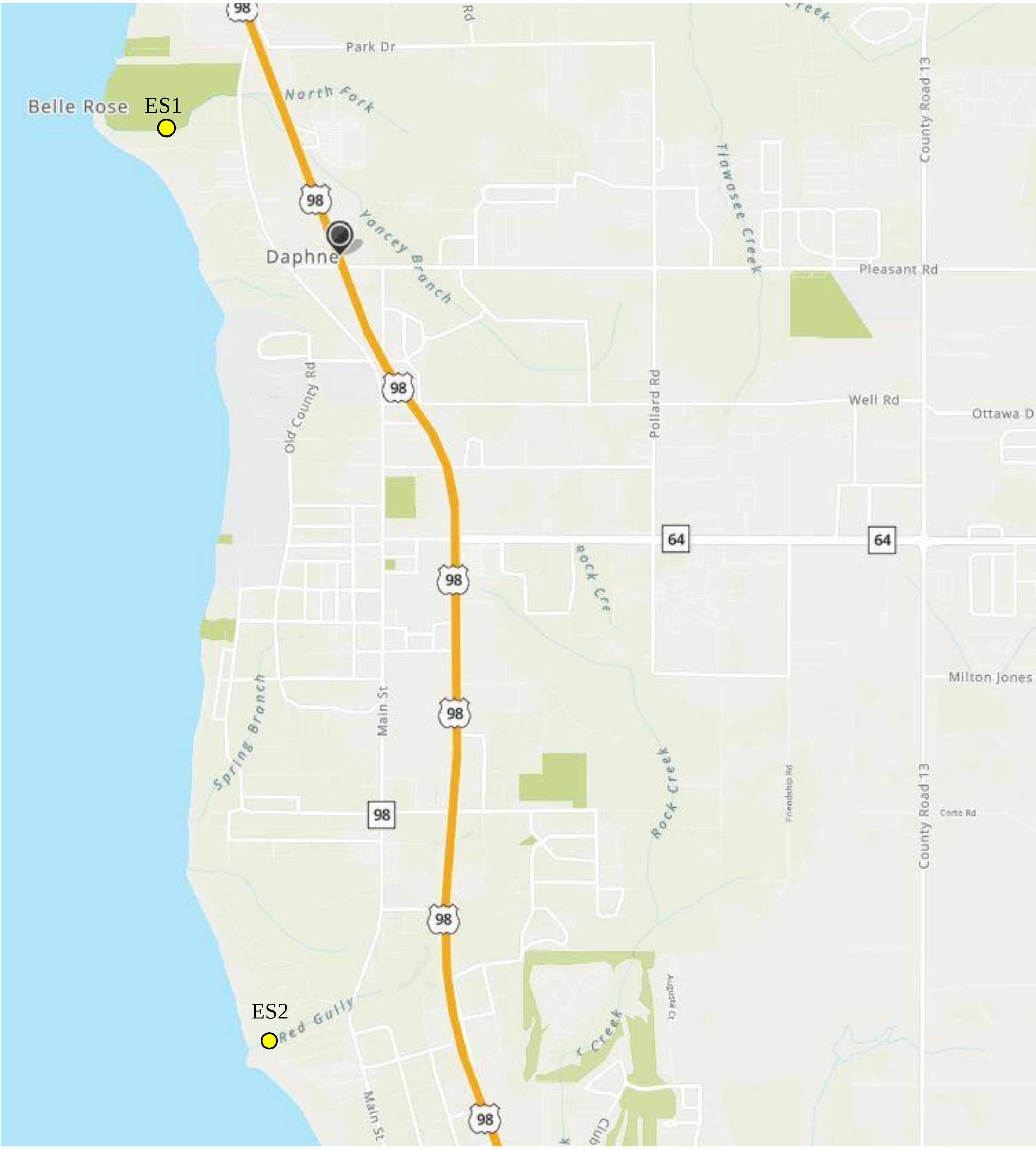

Figure 2.—Northern part of the monitored eastern shore watershed with monitoring sites.

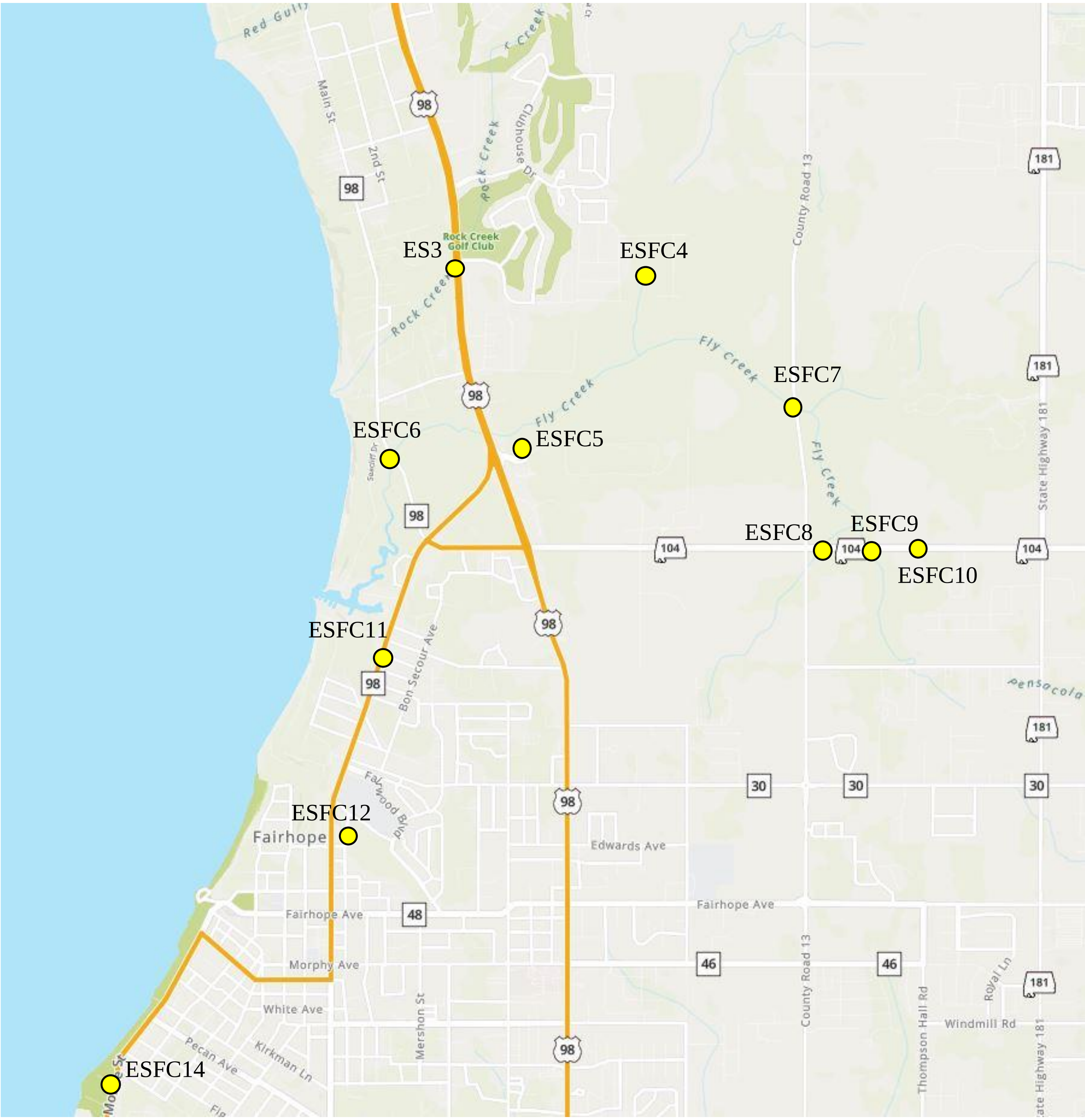

Figure 3.—Central part of the monitored eastern shore watershed with monitoring sites.

headwaters (lat 30.51199, long -87.91859). The watershed upstream from site ES14 covers 832 acres (1.3 mi^2) (USGS, 2020) (fig. 3).

Site ES15 is on Point Clear Creek at Scenic Highway 98, about 4.6 mi from the headwaters (lat 30.48570, long -87.93219). The watershed upstream from site ES15 covers 2,368 acres (3.7 mi^2) (USGS, 2020) (fig. 4).

Site ES16 is on Bailey Creek at Scenic Highway 98, about 2.1 mi from the headwaters (lat 30.46119, long -87.91671). The watershed upstream from site ES16 covers 704 acres (1.1 mi^2) (USGS, 2020) (fig. 4).

LAND USE/LAND COVER

Land use is directly correlated with water quality, hydrologic function, ecosystem health, biodiversity, and the integrity of streams and wetlands. Land-use classifications for the project area were 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. 5).

Land use/land cover in the western part of the eastern shore watershed is dominated by developed residential and commercial and forested wetlands (fig. 5). The eastern part of the watershed is dominated by row crop agriculture, developed residential and commercial, and forested wetlands. Agriculture dominates headwaters and areas of higher elevation with crops consisting of peanuts, soybeans, corn, cotton, pecans, and pasture and hay (fig. 5). Most streams in the watershed flow through forested floodplains with substantial wetlands or urban areas with significant impervious surfaces. 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. This is particularly important along the eastern shore where agricultural land is being converted to residential or commercial development. Developed land is dominated by residences and commercial development, primarily along roadways, and residential development on land previously

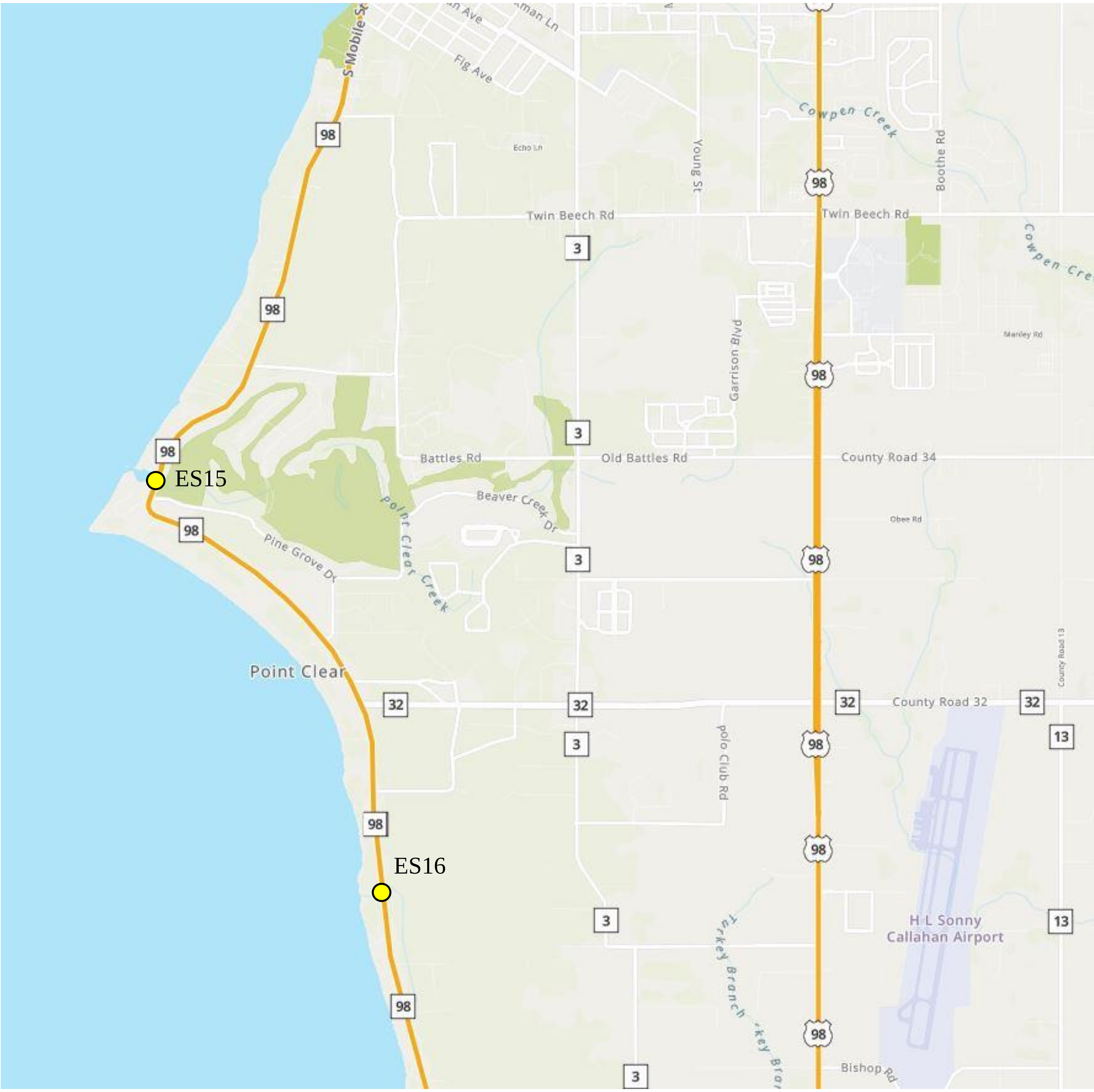

Figure 4.—Southern part of the monitored eastern shore watershed with monitoring sites.

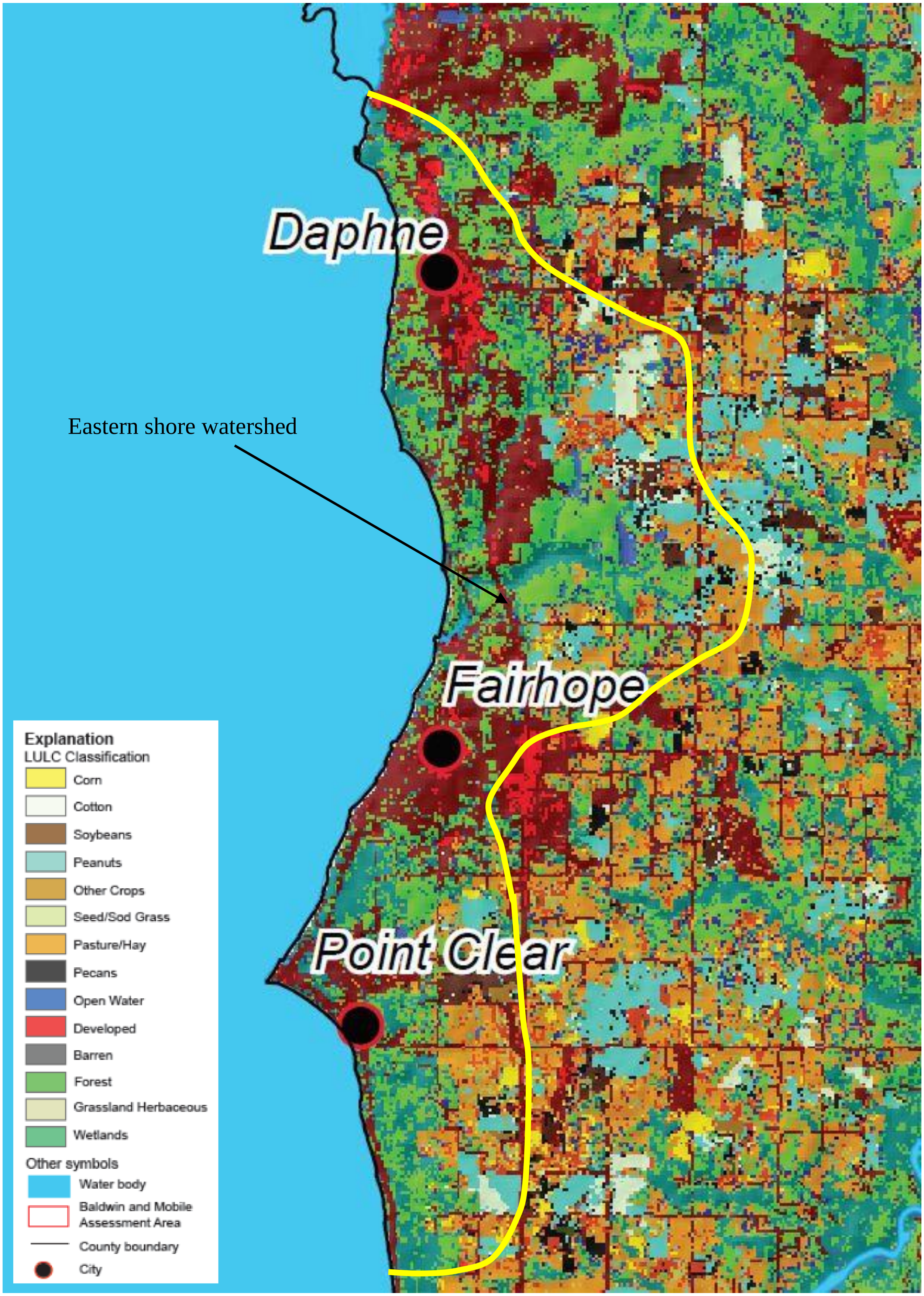

Figure 5.—Land use/land cover in the eastern shore watershed.

used for agriculture. On average, developed land covers about 37% and impervious surfaces cover about 8% of monitored watersheds along the eastern shore (USGS, 2020) (fig. 5). Land use/land cover 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 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 with increasing impervious surfaces. Headwaters of the monitored watersheds along the eastern boundary of the project area are characterized by relatively high elevation (maximum 170 ft MSL). All streams flow westward to Mobile Bay (sea level), with topography that decreases in relief from the north part of the project area at Daphne to the south part of the project area, near Point Clear where maximum elevation is less than 100 ft MSL. Stream gradients vary from 200 ft/mi for Fly Creek at Alabama Highway 13 to 21 ft/mi for Point Clear Creek (table 1).

Table 1.—Stream-flow characteristics for monitored sites in the eastern shore 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)
ES1 (Yancey Branch)	7.9	15	1.7	4.7	54
ES2 (Red Gully)	65.0	263	0.4	85.5	68
ES3 (Rock Creek)	238.0	840	10.0	58.1	33
ESFC4 (UT Fly Crk @ Headwater Rd)	22.0	88	1.2	16.9	79
ESFC5 (UT Fly Crk @ Woodland Dr)	2.5	12	0.0	7.6	164
ESFC6 (Fly Crk @ Scenic 98)	59.0[1]	220[1]	5.0[1]	8.2[1]	29
ESFC7 (Fly Crk @Co Rd 13)	173.0	950	8.0	44.4	200
ESFC8 (UT Fly Crk @ Hwy 104)	24.0	106	0.0	28.2	92
ESFC9 (UT Fly Crk @ Hwy 104)	20.0	88	0.0	54.1	141
ESFC10 (UT Fly Crk @ Hwy 104)	6.9	40	0.0	40.6	182
ES11 (Volanta Gully)	12.0	38	0.0	23.5	71
ES12 (Big Mouth Gully)	34.0	250	0.0	58.6	67
ES13 (Tatumville Gully @ Section St)	N/A	N/A	N/A	N/A	143
ES14(Tatumville Gully @ Scenic 98)	143.0	800	0.3	110.0	56
ES15(Bailey Crk @ Scenic 98)	N/A[1]	500[1]	N/A[1]	N/A[1]	21
ES16(Point Clear Crk @ Scenic 98)	N/A[1]	137[1]	N/A[1]	N/A[1]	41

[1]Discharge data not available or impacted by tidal influence.

A wide range of discharge events are required to adequately evaluate hydrologic conditions and water quality in the eastern shore watershed. Table 1 shows that sampling occurred during discharge conditions from base flow to flood, with the largest discharges occurring during Hurricane Barry on July 13, 2019 where discharge was estimated in Fly Creek at Baldwin Co. Road 13 (950 cfs) and Rock Creek at US Highway 98 (840 cubic ft per second (cfs)). Several smaller streams are intermittent and were dry during late winter, spring, and fall of 2019. Average daily discharge for each monitored stream is required to adequately estimate constituent loading. Discharge data collected at the USGS stream gaging site 02378500, Fish River near Silver Hill, Alabama, Alabama was used as a basis for average daily discharge calculation for each monitored stream.

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 eastern shore watershed), which is 6.94 mg/L (ADEM, 2020).

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 2 where observed DO is compared to the 100 percent dissolved oxygen saturation for the observed average stream temperature for each monitoring site.

Dissolved oxygen was measured at eastern shore watershed monitoring sites from February 2019 through October 2019. Stream water temperatures during the monitoring period varied from 16.9 to 27.6°C. Site ESFC4 (unnamed tributary to Fly Creek at Headwater Road) had the lowest average DO (5.7 mg/L) and site ES2 (Red Gully) had the highest average DO (8.1 mg/L) (table 2). Values lower than the ADEM Fish and Wildlife standard (5.0 mg/L) were measured at sites ES4, ES9, and ES10 (table 2).

Fourteen sites had measured DO values less than the ADEM reference standard (6.94 mg/L) (table 2). Average DO and water temperature values were compared with atmospheric DO saturation (table 8). Sites ES4 (unnamed tributary to Fly Creek at Headwater Road) and ESFC9 (unnamed tributary to Fly Creek at Alabama Highway 104) had the lowest percentage of atmospheric saturation (69%) and site ES1 (Yancey Branch at Harbor Place) had the highest percentage (93%) (table 2).

Table 2.—Dissolved oxygen measured in monitored streams in the eastern shore watershed.

Site	Dissolved oxygen (mg/L)			Average DO saturation (% atmospheric saturation)
	Maximum	Minimum	Average	
ES1	9.3	5.6	7.6	93
ES2	8.8	7.2	8.1	92
ES3	8.8	5.4	6.8	78
ES4	8.2	4.5	5.7	69
ESFC5	7.6	5.7	6.5	75
ESFC6	8.7	5.5	6.7	79
ESFC7	8.2	5.0	6.6	78
ESFC8	7.0	5.5	6.3	78
ESFC9-	7.1	5.0	5.9	69
ESFC10	7.4	4.9	6.2	77
ES11	7.9	5.3	6.5	76
ES12	8.0	5.4	6.5	78
ES14	9.6	6.6	7.7	89

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 eastern shore watershed.

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 3). Sites ES15 (Point Clear Creek) and ES16 (Bailey Creek) were influenced by tidal influx and were only monitored during Hurricane Barry (table 2). SC values during the storm were 1,230 and 3,170 µS/cm, respectively. 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 eastern shore watershed is 20.4 µS/cm (ADEM, 2020). Median measured SC for all eastern shore watershed sites, except site ESFC10 (unnamed tributary to Fly Creek at Alabama Highway 104) exceeded the ADEM standard (table 3).

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 6, illustrates that sites ES2 (Red Gully), ES14 (Tatumville Gully), and ES3 (Rock Creek) have the highest average turbidity (284, 168, and 165 NTUs, respectively).

Table 3.—Measured specific conductance values for eastern shore 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)
ES1	63	111	24	20.4	65
ES2	64	107	18	20.4	58
ES3	51	104	17	20.4	45
ESFC4	51	58	40	20.4	54
ESFC5	47	67	31	20.4	45
ESFC6	44	58	18	20.4	49
ESFC7	49	67	16	20.4	50
ESFC8	43	66	19	20.4	43
ESFC9	27	35	14	20.4	32
ESFC10	20	28	12	20.4	20
ES11	25	31	10	20.4	30
ES12	46	75	14	20.4	43
ES13	N/A	N/A	N/A	20.4	N/A
ES14	60	103	14	20.4	46
ES15	N/A	N/A	N/A	20.4	N/A
ES16	N/A	N/A	N/A	20.4	N/A

Commonly, excessive turbidity is closely tied to land uses that cause land disturbances, leading to erosion or to land uses that cause excessive runoff. Evaluation of land-use data indicates that watersheds with dominant urban development and/or row crop agriculture are more likely to have streams with significant turbidity concentrations. Streams with the highest turbidity in the eastern shore watershed receive runoff from major commercial and residential development in Daphne and Fairhope. Figure 7 relates average turbidity with percentage of urban development in each monitored watershed. It shows that sites ES2 (Red Gully), ES3 (Rock Creek), and ES14 (Tatumville Gully) have the highest average turbidity and the highest percentage of urban development. Volanta and Big Mouth Gullies are exceptions to this trend. However, these sites have small drainage areas upstream from the monitoring sites, which explains why turbidities are relatively low (fig. 7). The ADEM reference concentration for turbidity is 9.7 NTU for ecoregion 65f (90^{th} %ile) (ADEM, 2020). Average turbidity for all eastern shore watershed sites exceeded the ADEM standard by 1.7 to 29 times (fig. 6).

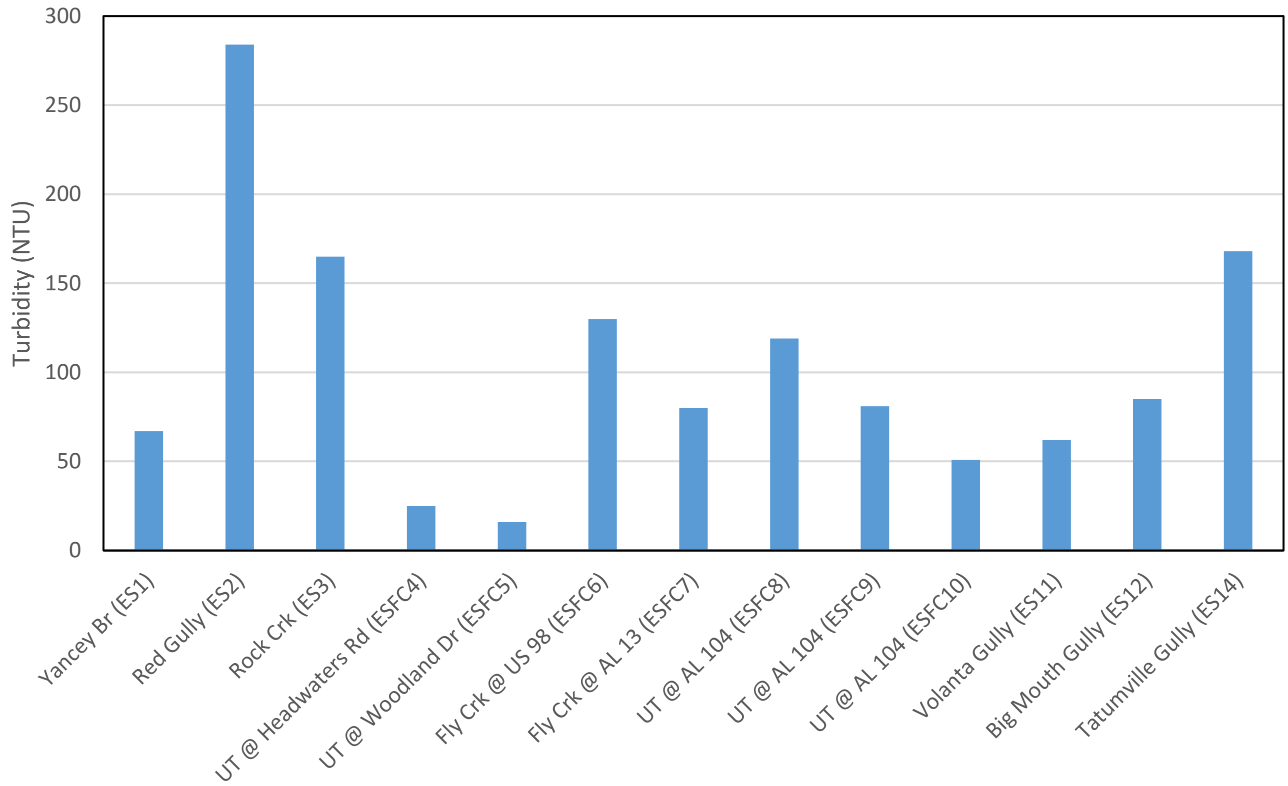

Figure 6.—Average turbidity for monitored sites in the eastern shore watershed.

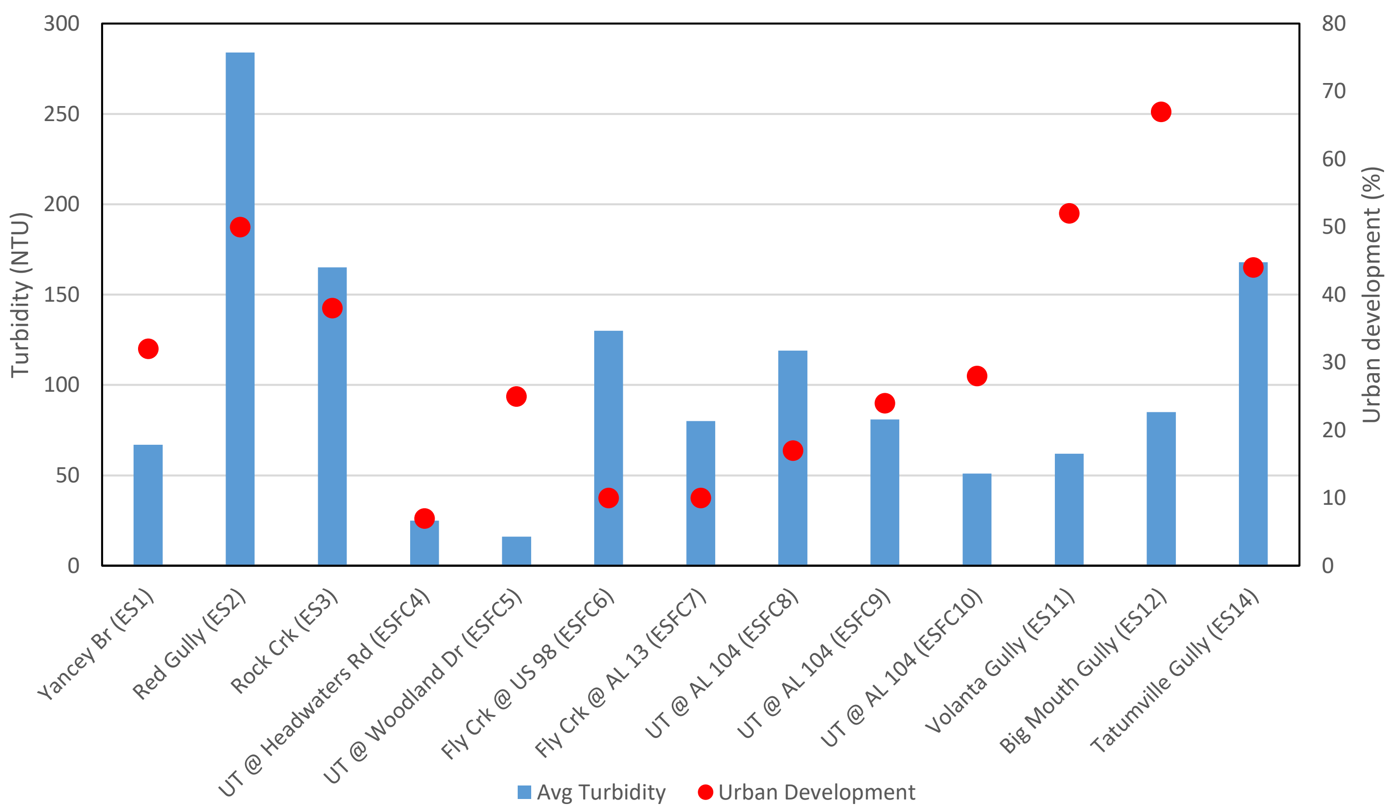

Figure 7.—Average turbidity and percentage of urban development in monitored eastern shore watersheds.

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 urbanization and impervious surfaces, agriculture, construction, timber harvesting, unimproved roadways, or any activity where soils or geologic units are exposed or disturbed. In the eastern shore watershed, relatively high percentages of urban development and impervious surfaces, increase runoff volumes and flow velocities, causing excessive stream bed and bank erosion. 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. All sediment transported by eastern shore streams is deposited directly into Mobile Bay, impeding near shore navigation, decreasing water clarity, and destroying submerged vegetation and fish and shellfish habitat.

Precipitation, stream gradient, geology, soils, and land use are all important factors that influence sediment transport characteristics of streams. Sediment transport conditions in the eastern shore watershed were evaluated and quantified by tributary, 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 eastern shore 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 several 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 constructed features to promote infiltration of precipitation and to store and slow runoff. Currently, the eastern shore watershed is characterized by an increasingly urban setting, dominated by commercial and residential development with stream channels designed to rapidly move runoff to Mobile Bay.

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). Five eastern shore watershed monitoring sites had measurable suspended and bed sediment loads. Only suspended sediment could be measured at eight sites due to flow and channel conditions and two sites (ES15, Point Clear Creek and ES16, Bailey Creek) 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 8 is an x-y plot of average turbidity and average total suspended solids (TSS) for eastern shore watershed sites with adequate samples. It shows a good correlation between turbidity and TSS, except for site ES2 (Red Gully) where turbidity is relatively large compared to TSS. Also, the slope of the trend line steepens for turbidity values larger than 100 NTU, indicating that TSS is higher for comparable turbidity values. This occurs for streams with higher average discharge values (ESFC6,

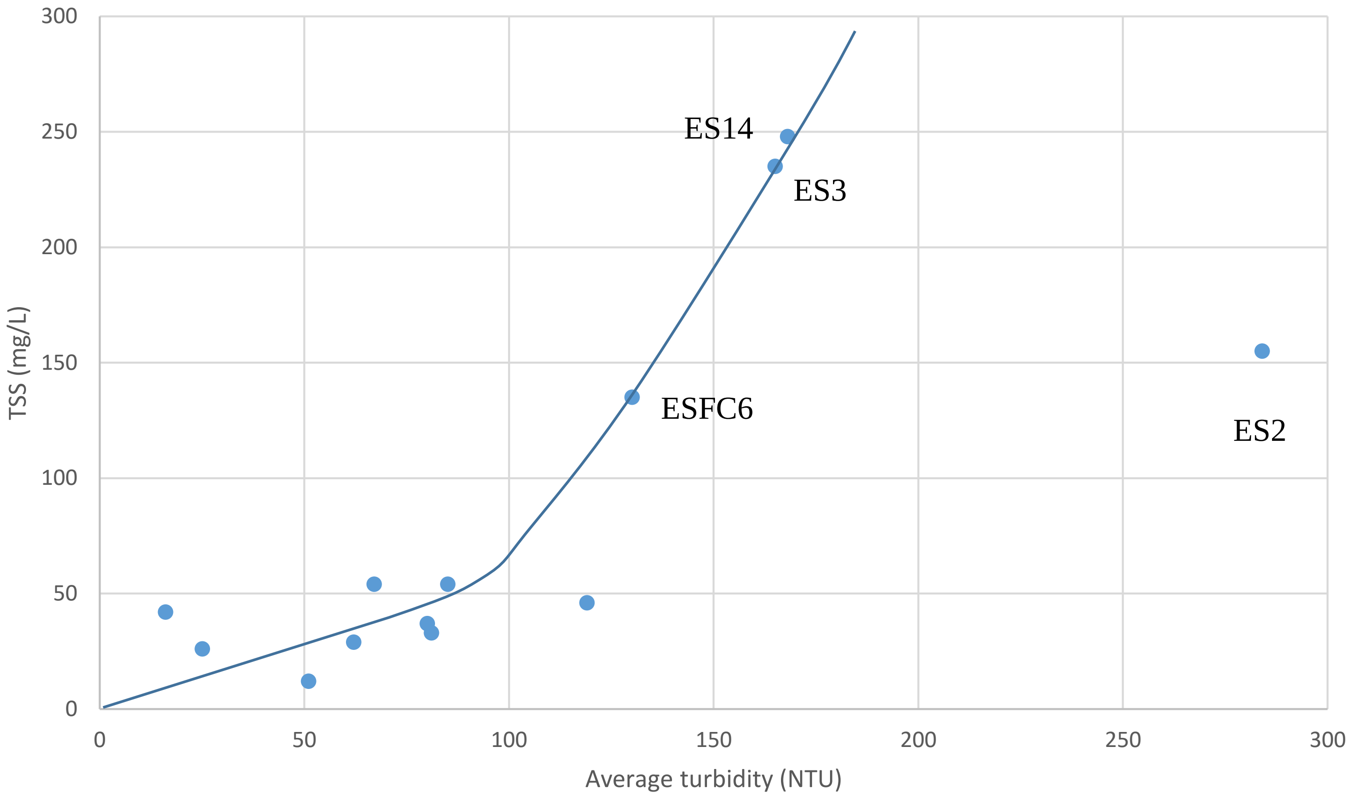

Figure 8.—Average turbidity and TSS values for monitored sites in the eastern shore watershed.

ES3, and ES14) (fig. 8). The largest average suspended solids concentrations were 248 mg/L at site ES14 (Tatumville Gully at Scenic Highway 98), 235 mg/L at site ES3 (Rock Creek), 155 mg/L at site ES2 (Red Gully), and 135 mg/L at site ESFC6 (Fly Creek at Scenic Highway 98) (table 4). The ADEM reference concentration for TSS for ecoregion 65f, which includes the eastern shore watershed is 13.2 mg/L (90^{th} %ile) (ADEM, 2020). All eastern shore monitored streams except site ESFC10 (unnamed tributary to Fly Creek at AL Highway 104) exceeded the reference concentration.

Annual suspended sediment loads were estimated for eastern shore 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, 02378500, Fish River near Silver Hill, Alabama (USGS, 2021).

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 (February 1, 2019 to January 31, 2020). Rock Creek at US Highway 98 (ES3), Tatumville Gully at Scenic US Highway 98 (ES14), Red Gully at Main Street (ES2), and Fly Creek at Scenic US Highway 98 (ESFC6), had the largest suspended sediment loads with 19,039, 6,269, 4,298, 3,965 tons per year (t/yr), respectively (table 4, fig. 9).

Table 4.—Measured discharge, turbidity, TSS, and estimated suspended sediment loads in monitored streams in the eastern shore 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)
ES1 (Yancey Branch)	3.2	67	215	54	13.2	168	365	214
ES2 (Red Gully)	12.3	284	930	155	13.2	458	4,298	5,372
ES3 (Rock Creek)	62.4	165	397	235	13.2	702	19,039	4,644
ESFC4 (UT Fly Crk @ Headwater Rd)	6.3	25	118	26	13.2	119	99	76
ESFC5 (UT Fly Crk @ Woodland Dr)	0.3	16	320	42	13.2	168	35	106
ESFC6 (Fly Crk @ Scenic 98)	15.7	130	581	135	13.2	856	3,965	551
ESFC7 (Fly Crk @Co Rd 13)	20.0	80	301	37	13.2	130	286	73
ESFC8 (UT Fly Crk @ Hwy 104)	1.6	119	190	46	13.2	74	158	185
ESFC9 (UT Fly Crk @ Hwy 104)	2.5	81	173	33	13.2	73	294	796
ESFC10 (UT Fly Crk @ Hwy 104)	1.2	51	82	12	13.2	19	39	230
ES11 (Volanta Gully)	3.0	62	88	29	13.2	57	113	221
ES12 (Big Mouth Gully)	5.5	85	144	54	13.2	113	459	791
ES14 (Tatumville Gully)	11.3	168	597	248	13.2	634	6,269	4,822

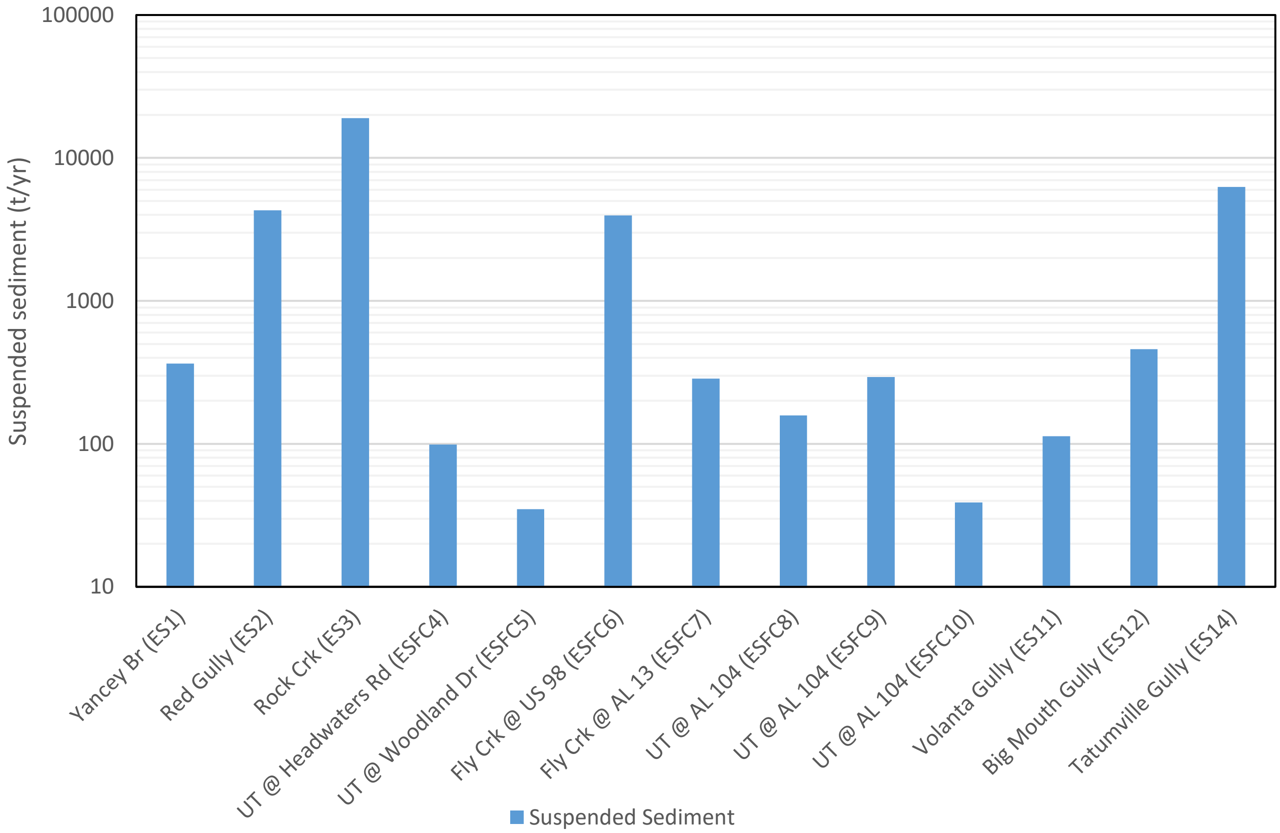

Figure 9.—Suspended sediment loads for monitored streams in the eastern shore watershed.

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 for monitored sites in the eastern shore watershed are portrayed on figure 10, which shows the largest normalized suspended sediment loads at Red Gully at Bay Shore Drive (ES2) (5,372 t/mi^2/yr), Tatumville Gully at Scenic US Highway 98 (ES14) (4,822 t/mi^2/yr), and Rock Creek at US Highway 98 (ES3) (4,644 t/mi^2/yr) (table 4, fig. 10).

BED SEDIMENT

Transport of streambed material is controlled by several factors including stream discharge and flow velocity, erosion and sediment supply, stream base level, and physical properties of the streambed material. Most streambeds are in a state of constant flux 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

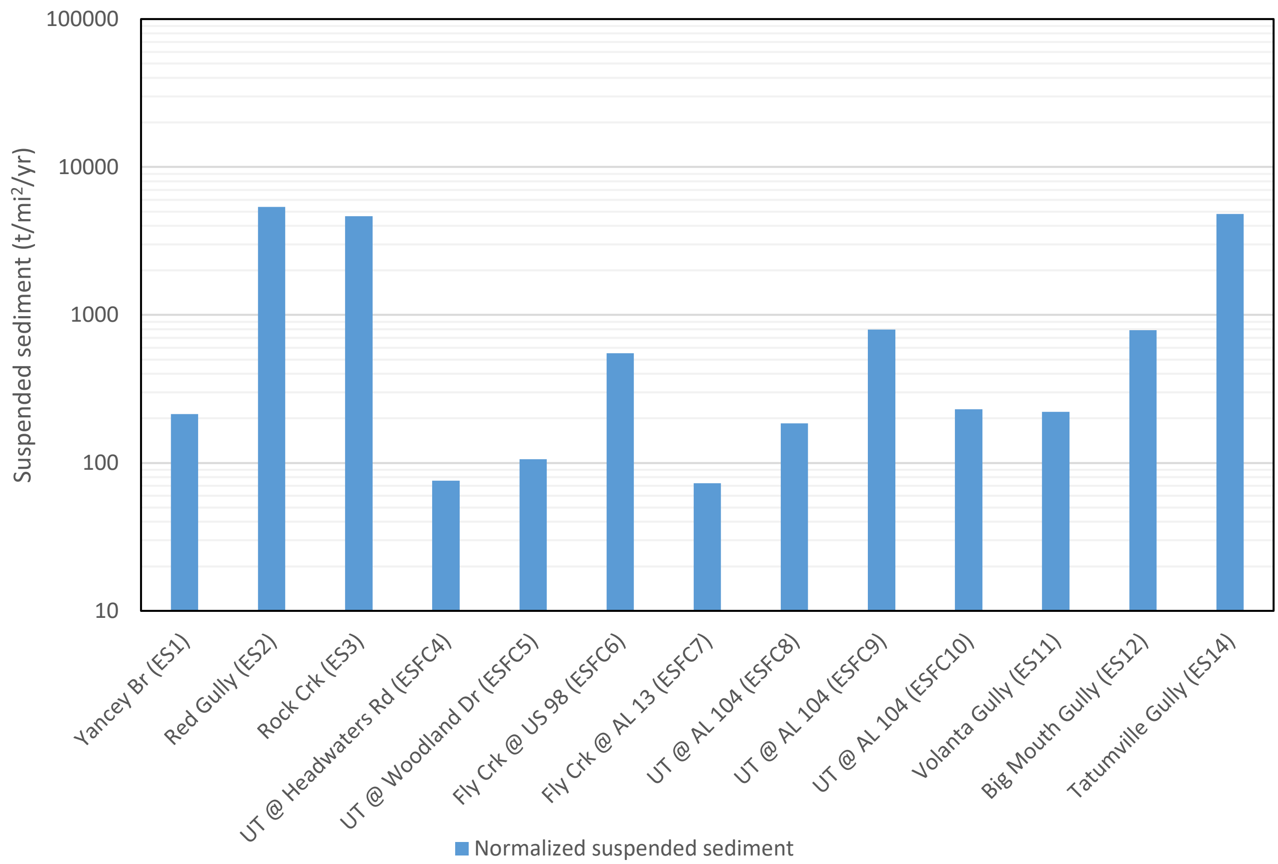

Figure 10.—Normalized suspended sediment loads for monitored streams in the eastern shore watershed.

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 five eastern shore watershed sites (ES1, ES2, ESFC5, ES12, and ES14). 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. Table 5 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. Figure 11 shows estimated annual bed sediment loads for sites with measurable bed sediment. Figure 12 shows estimated annual bed sediment loads normalized with respect to watershed drainage area. Table 5 shows that discharge and bed sediment loads do not correlate well in streams with measurable bed sediment in the eastern shore watershed. This is particularly true for site ES2 (Red Gully) where urban runoff is flashy and excessive upstream erosion contributes a disproportionately large amount of bed sediment.

Table 5—Average measured discharge and estimated bed sediment loads for monitoring sites on streams with measurable bed sediment in the project area.

Monitored site	Average daily discharge (cfs)	Estimated annual bed sediment loads (tons/yr)	Estimated normalized annual bed sediment loads (tons/mi^2/yr)
ES1 (Yancey Branch)	3.2	992	584
ES2 (Red Gully)	12.3	8,174	10,218
ESFC5 (UT Fly Crk @ Woodland Dr)	0.3	505	1,530
ES12 (Big Mouth Gully)	5.5	13	22
ES14 (Tatumville Gully)	11.3	986	759

TOTAL SEDIMENT LOADS

Total sediment load in a stream is composed of suspended and bed sediment. Four monitored sites had both suspended and bed sediment loads. On average, bed sediment makes up 50% of the total sediment loads for streams with measurable suspended and bed sediment. Table 6 and figures 13 and 14 show total sediment loads for monitored reaches in the eastern shore watershed. Rock Creek at US Highway 98 (ES3), Red Gully at Bay Shore Drive (ES2), Tatumville Gully at Scenic Highway 98 (ES14), and Fly Creek at Scenic Highway 98 (ESFC6) had the largest total sediment loads (19,039, 12,472, 7,255, and 3,965 t/yr, respectively) (table 6, fig. 13).

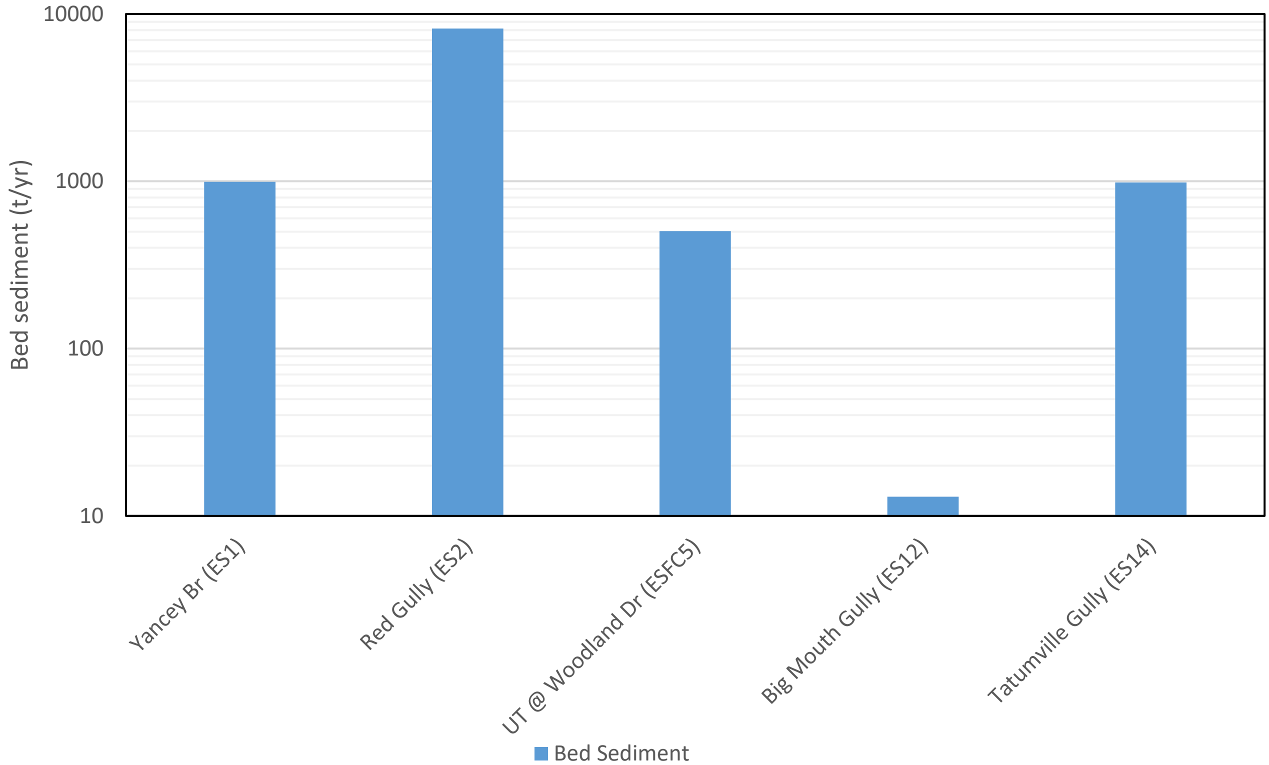

Figure 11.—Estimated bed sediment loads for streams with measurable bed sediment in the eastern shore watershed.

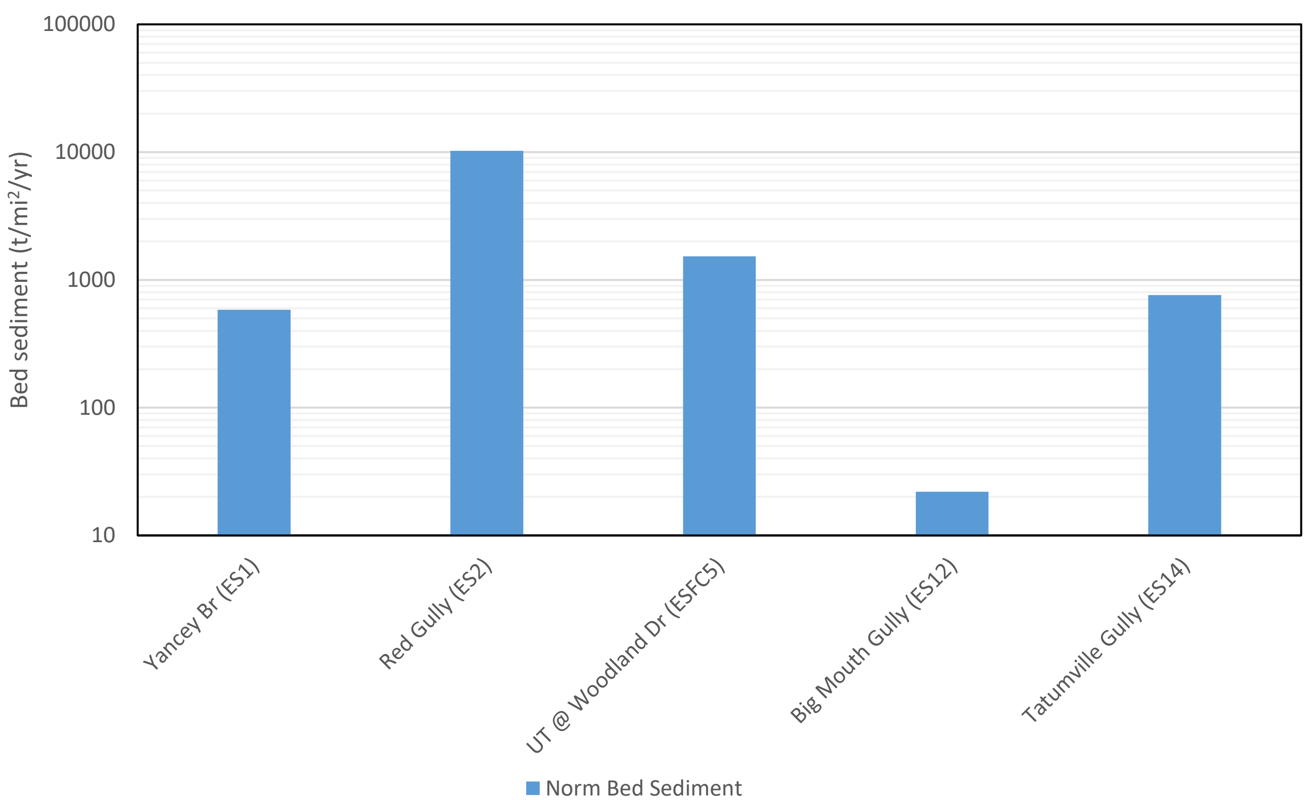

Figure 12.—Estimated normalized bed sediment loads for streams with measurable bed sediment in the eastern shore watershed.

Table 6—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 ($tons/mi^2/yr$)
ES1 (Yancey Branch)	1.7	3.2	1,357	798
ES2 (Red Gully)	0.8	12.3	12,472	15,590
ES3 (Rock Creek)	4.1	62.4	19,039	4,644
ESFC4 (UT Fly Crk @ Headwater Rd)	1.3	6.3	99	76
ESFC5 (UT Fly Crk @ Woodland Dr)	0.3	0.3	540	1,636
ESFC6 (Fly Crk @ Scenic 98)	7.2	15.7*	3,965	551
ESFC7 (Fly Crk @Co Rd 13)	3.9	20.0	286	73
ESFC8 (UT Fly Crk @ Hwy 104)	0.9	1.6	158	185
ESFC9 (UT Fly Crk @ Hwy 104)	0.4	2.5	294	796
ESFC10 (UT Fly Crk @ Hwy 104)	0.2	1.2	39	230
ES11 (Volanta Gully)	0.5	3.0	113	221
ES12 (Big Mouth Gully)	0.6	5.5	472	813
ES14 (Tatumville Gully)	1.3	11.3	7,255	5,581
ES15(Point Clear Creek)	3.7	N/A*	N/A*	N/A*
ES16 (Bailey Creek)	1.1	N/A*	N/A*	N/A*

*Discharge impacted by tidal influence.

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 eastern shore watershed are portrayed on figure 14, which shows the largest normalized total sediment loads at Red Gully at Bay Shore Drive (ES2), (15,590 $t/mi^2/yr$), Tatumville Gully at Scenic Highway 98 (ES14), (5,581 $t/mi^2/yr$), Rock Creek at US Highway 98 (ES3), (4,644 $t/mi^2/yr$), and the unnamed tributary to Fly Creek at Woodland Drive (ESFC5) (1,636 $t/mi^2/yr$).

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 all monitored watersheds were from 1.1 to 244 times greater than the geologic erosion rate (fig. 14).

Land use is a major factor in the magnitude of erosion and stream sediment loading. Figure 15 shows an excellent correlation between estimated total sediment loads and percentage of urban development in monitored eastern shore streams and documents impacts of impervious surfaces on surface-water runoff and resulting excessive stream discharge and flow velocities on erosion and stream sediment loads carried into Mobile

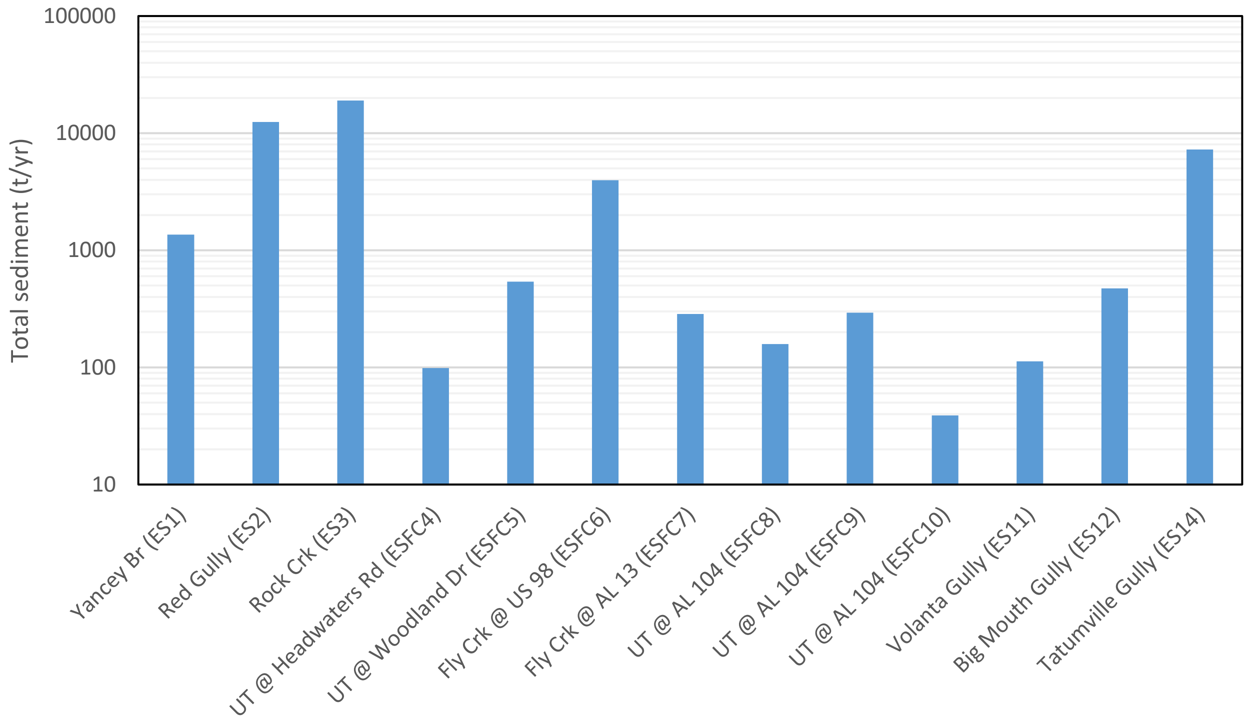

Figure 13.—Estimated total sediment loads for streams in the eastern shore watershed.

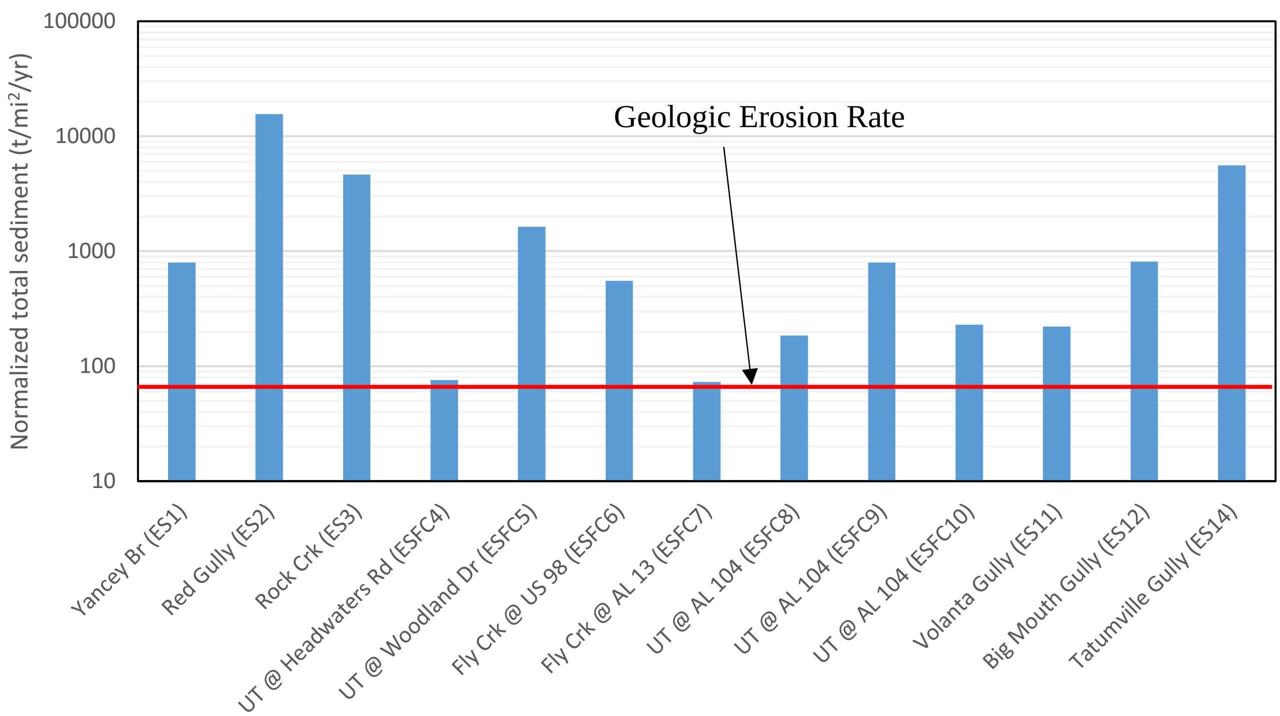

Figure 14.—Normalized estimated total sediment loads for streams in the eastern shore watershed.

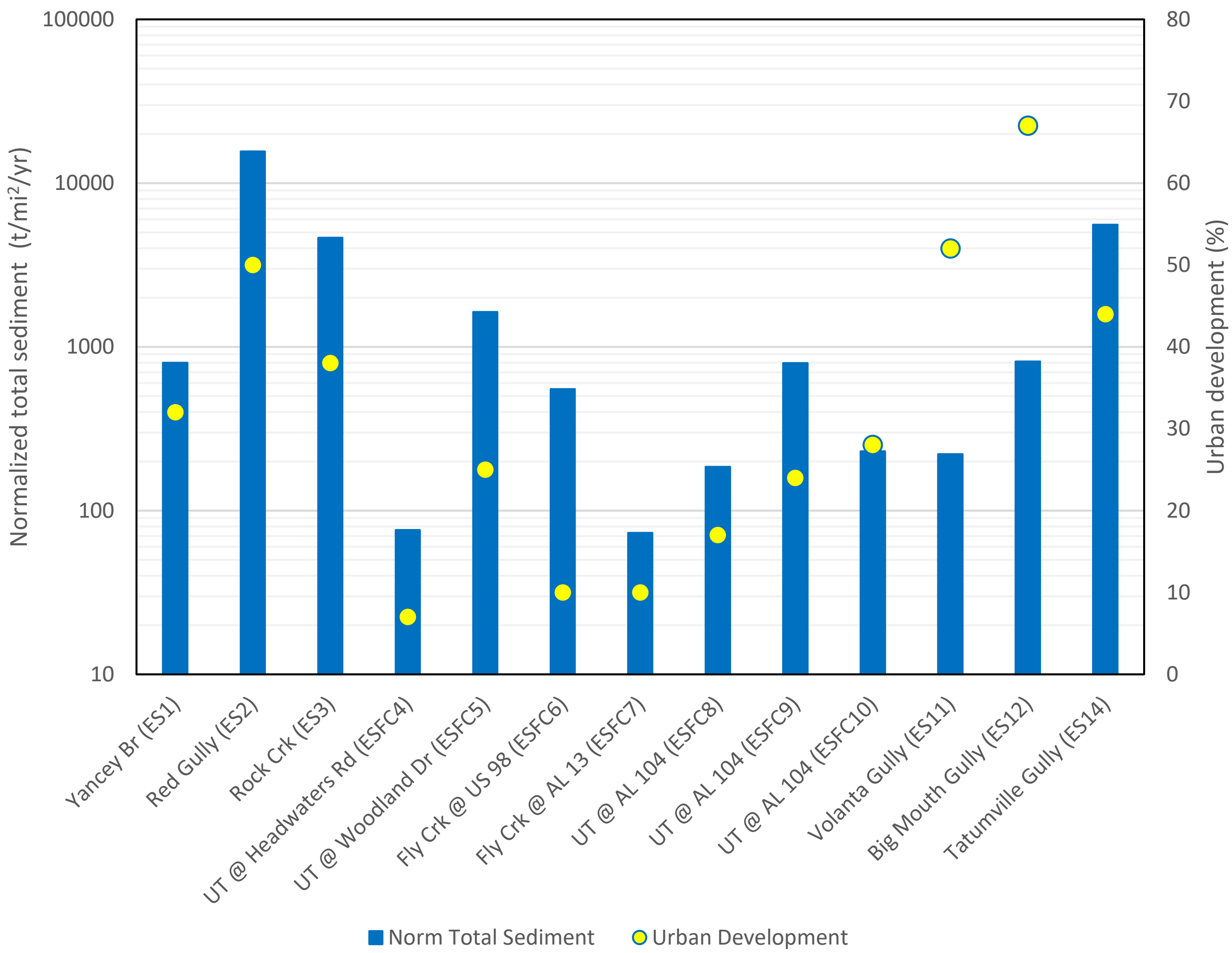

Figure 15.—Normalized estimated total sediment loads and percentage of urban development for monitored eastern shore watersheds.

Bay. Three major urban development/sediment load relationships are identified on the graph.

First are watersheds with relatively large urban develop (>20%) and corresponding, relatively large sediment loads (>500 t/mi^2/yr), which includes sites ES1 (Yancey Branch), ES2 (Red Gully), ES3 (Rock Creek), ESFC5 (unnamed tributary to Fly Creek at Woodland Drive), ESFC9 (unnamed tributary to Fly Creek at Alabama Highway 104), ESFC12 (Big Mouth Gully), and ESFC14 (Tatumville Gully (fig. 15). Floodplains upstream from these sites have larger percentages of impervious surfaces with streambed and bank erosion, which results in flashy runoff with high velocity flow. Although site ES12 (Big Mouth Gully) is included above, it has a smaller than expected sediment load. Big Mouth Gully flows through two large detention areas on the east side of North

Section Street, which effectively trap sediment and slow flow velocities upstream from Mobile Bay.

The second are watersheds with relatively large urban development (>20%) and relatively small sediment loads (<500 t/mi^2/yr), which includes site ES11 (Volanta Gully (fig. 15). Although the cause is unclear, the floodplain upstream from this site is densely forested, which may slow flow velocities and limit erosion.

The third is watersheds with relatively small urban development (<20%) and relatively large sediment loads (>500 t/mi^2/yr), which includes site ESFC6 (Fly Creek at Scenic US Highway 98) (fig. 15). Although the lower part of the floodplain is forested, the watershed upstream from this site has extensive row crop agriculture in the headwaters and has a history of point source erosion from construction.

Comparisons of sediment loads from other watersheds are helpful in determining the severity of erosion problems in a watershed of interest. Figure 16 shows comparisons of estimates of normalized total sediment loads from eastern shore watershed sites ES2 (Red Gully), ES14 (Tatumville Gully), and ESFC6 (Fly Creek at Scenic US 98) with sites in seven 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), Fish River site FR14 (Fish River at Baldwin County Road 32) (Cook, 2016), Magnolia River site MR4 (at U.S. Highway 98) (Cook, 2009), Bon Secour River site BSR3 (County Road 12 in Foley) (Cook, 2013), and Wolf Bay site WC10 (Wolf Creek at Doc McDuffie Road) (Cook, 2017) (fig. 16).

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

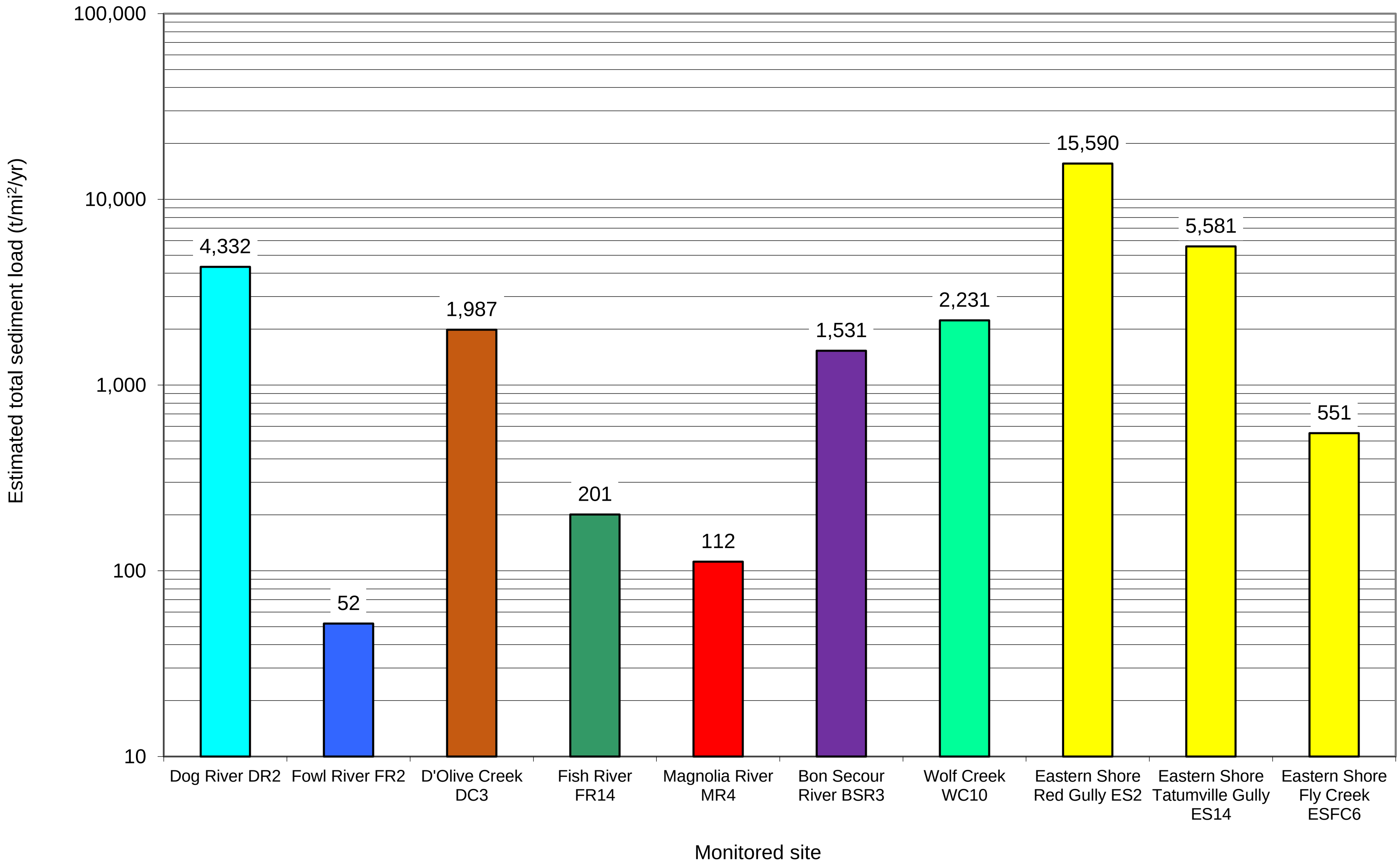

Figure 16.—Comparisons of estimated normalized total sediment loads for monitored watersheds in Mobile and Baldwin Counties.

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+nitrite nitrogen 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 for selected discharge events were collected and analyzed for nitrogen. To compare eastern shore 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 (ADEM, 2020). Nitrogen and discharge commonly form negative regressions, indicating that increased discharge results in decreased concentrations of nitrogen. The largest nitrate+nitrite nitrogen concentrations were in the Fly Creek watershed at sites ESFC5 (unnamed tributary to Fly Creek at Woodland Drive), ESFC6 (Fly Creek at Scenic US Highway 98), ESFC7 (Fly Creek at Baldwin Co Rd 13), and ESFC8 (unnamed tributary to Fly Creek at Alabama Highway 104) with 1.10, 1.19, 0.96, and 0.71 mg/L, respectively. The downstream part of the watershed at site ESFC5 receives runoff from the Woodlands at Fairhope subdivision. The upstream part receives runoff from row crop agriculture at the Auburn University State Agricultural Experiment Station farm. The watershed upstream from site ESFC8 receives runoff from row crop agriculture at the Auburn University State Agricultural Experiment Station farm. The Fly Creek sites receive cumulative runoff from various land used and land covers in the Fly Creek watershed.

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 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 eastern shore watershed) of 0.04 mg/L (90^{th} %ile) (ADEM, 2020). In many streams phosphorus is the primary nutrient that influences excessive biological activity. These streams are termed "phosphorus limited."

Most eastern shore watershed monitoring sites had phosphorus concentrations above the 0.04 mg/L reference criterion. The largest concentrations occurred during a large discharge event on June 7, 2019 and included eastern shore sites ES2 (Red Gully at Bay Shore Drive) and ESFC8 (unnamed tributary to Fly Creek at Alabama Highway 104) with concentrations of 0.86 and 0.53 mg/L, respectively. Land use upstream from site ES2 is primarily urban and land use upstream from site ESFC8 is primarily agricultural.

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

Evaluations of sediment transport and water-quality analyses led to conclusions concerning which streams in the eastern shore watershed have impairments and should be considered for further evaluation and possible remedial actions. Evaluations of land-use data, aerial imagery, and field assessments give insight to probable sources of water quality and habitat impairments. Stream flow conditions are important factors that influence erosion, sediment transport, and attenuation of nutrients and other contaminants that impact water quality in a watershed. Topographically, 13 of 15 monitored stream reaches are characterized by high gradients that result in flashy discharge with high flow velocities. The other two (ES15, and ES16) are characterized by deep water, lower flow velocities, and tidal influence.

Land use/cover is also an important factor influencing erosion, sediment transport, and overall water quality. Generally, larger monitored watersheds, including Rock Creek, Fly Creek, and Point Clear Creek have three primary land uses/covers. Headwaters are primarily rural with forest cover or open fields used for pasture or row crop agriculture, and forested floodplains. Central parts of the watersheds are primarily forested with moderate residential development and forested floodplains with extensive wetlands. The central parts of Rock Creek and Point Clear Creek have golf courses. The downstream parts of the watersheds have extensive residential and commercial development with substantial impervious surfaces, and moderate forest cover. Floodplains are narrow with encroaching urban development, forested, with extensive wetlands, and receive significant impacts from flashy urban runoff.

Severe impacts from urbanization are observed in smaller watersheds such as Red Gully, Volanta Gully, Big Mouth Gully, and Tatumville Gully, where impervious surfaces (average 14 percent impervious cover) cause excessive runoff and high flow velocities. Streams are characterized by scoured stream channels with eroding banks and beds. During Hurricane Barry on July 13, 2019, Tatumville Gully at Scenic US Highway 98 was flowing at more than six feet per second.

One monitored stream is currently on the ADEM 303-D list of impaired waters. Fly Creek is listed for excessive pathogens (E. coli) caused by animal grazing (ADEM, 2020).

Dissolved oxygen was measured during each monitored event. Site ESFC4 (unnamed tributary to Fly Creek at Headwater Road) had the lowest average DO (5.7 mg/L) and site ES2 (Red Gully) had the highest average DO (8.1 mg/L). Values lower than the ADEM Fish and Wildlife standard (5.0 mg/L) were measured at sites ES4 (unnamed tributary to Fly Creek at Headwater Road), ES9 (unnamed tributary to Fly Creek at Alabama Highway 104), and ES10 (unnamed tributary to Fly Creek at Alabama Highway 104). Fourteen of fifteen monitored sites had measured DO values less than the ADEM reference standard (6.94 mg/L).

Sediment loads in streams are composed of suspended and bed sediment. Rock Creek at US Highway 98 (ES3), Tatumville Gully at Scenic US Highway 98 (ES14), Red

Gully at Main Street (ES2), and Fly Creek at Scenic US Highway 98 (ESFC6), had the largest suspended sediment loads with 19,039, 6,269, 4,298, 3,965 tons per year (t/yr), respectively. The largest normalized suspended sediment loads occurred in Red Gully at Main Street (ES2) (5,372 t/mi^2/yr), Tatumville Gully at Scenic US Highway 98 (ES14) (4,822 t/mi^2/yr), and Rock Creek at US Highway 98 (ES3) (4,644 t/mi^2/yr).

Five monitored sites had measurable bed sediment. Red Gully (ES2), Yancey Branch (ES1), and Tatumville Gully (ES14) had the largest bed sediment loads with 8,174, 992, and 986 t/yr, respectively. After normalization of bed sediment loads relative to drainage area, Red Gully had the largest load, with 10,218 tons/mi^2/yr. The unnamed tributary to Fly Creek at Woodland Drive (ESFC5) and Tatumville Gully had 1,530 and 759 tons/mi^2/yr, respectively. On average, bed sediment makes up 50% of total sediment loads for streams with measurable bed sediment.

When compared to seven previously monitored sites in Mobile and Baldwin Counties, total sediment loads at Red Gully (ES2) and Tatumville Gully (ES14) are the largest, showing the impacts of flashy urban runoff. However, the unnamed tributary to Fly Creek at Headwater Road (ESFC5) and Fly Creek at Baldwin County Road 13 (ESFC7) are among the smallest loads, due to watersheds and floodplains that are primarily forested.

Comparisons of sediment transport rates and water quality parameters in previously monitored watersheds in Baldwin and Mobile Counties indicate that monitored eastern shore watersheds have highly variable sediment loads and generally good water quality, which is attributed to percentages of urban development, wetlands and forest cover.

Since all streams in the eastern shore watershed discharge into Mobile Bay, an examination of satellite imagery along the Baldwin county shoreline was performed to determine sediment deposition patterns and excessive sedimentation impacts. Beginning at the north end of the watershed, Yancey Branch flows into Mobile Bay at Village Point, at the south end of D'Olive Bay. Long-term excessive sediment deposition from D'Olive Creek and Yancey Branch have transformed D'Olive Bay into a shallow sand flat. Previous investigations documented excessive sediment transport by D'Olive Creek and damage to submerged aquatic vegetation in D'Olive Bay. Currently, 1,357 t/yr (2,512 cubic yards/yr (yd^3/yr)) of sediment are estimated to be deposited into D'Olive Bay by

Yancey Branch. Figure 17 (left) is 1985 imagery showing an alluvial fan about 900 ft long and 600 ft wide, extending into D'Olive Bay from the mouth of Yancey Branch. Figure 17 (right) is a November 2019 image showing that deposition of new sediment is significantly less than in 1985. Vegetation has established on the alluvial fan and the spit on the west side of the fan has narrowed and extended about 300 ft northwestward.

Figure 17.—Sediment deposition into D'Olive Bay at the mouth of Yancey Branch in 1985(left) and 2019 (right) (Google Earth, 2020).

Red Gully discharge along with its sediment load (12,472 t/yr or about 23,000 (yd^3/yr) empties into Mobile Bay just south of the Daphne city limits. Reworking of this sediment by Mobile Bay currents along the eastern shore in 1985 formed a triangular-shaped alluvial van about 500 ft long and 500 ft wide. November 2019 imagery shows that the alluvial fan has been removed by Mobile Bay currents. However, plumes of turbidity can be seen flowing southwestward into Mobile Bay. USGS topobathymetric mapping in 2013 shows that Mobile Bay water depths at the mouth of Red Gully are 0 to 1.3 ft (USGS, 2013) (fig. 18).

Figure 18.—Sediment deposition into Mobile Bay at the mouth of Red Gully in 1985 (left) and 2019 (right) (Google Earth, 2020).

Fly Creek has long been the subject of observations concerning excessive sediment transport. Erosion from major construction projects in the watershed contributed large amounts of sediment that were transported downstream and deposited in the tidal reach and at the mouth of the stream. Figure 19 shows sediment in lower Fly Creek, deposited as point bars and channel fill in the lower part of the stream, in the yacht basin, and at the mouth. Fly Creek currently transports an estimated 3,965 t/yr (7,343 yd^3/yr) of silt and sand. However, little evidence of sediment deposition is seen on 2019 imagery (fig. 20).

Big Mouth Gully currently transports an estimated 472 t/yr (874 yd^3/yr) of sediment, which is deposited into Mobile bay at its mouth just north of downtown Fairhope. However, sediment deposition rates were much higher in the past, as evidenced

Figure 19.—Sediment deposition in the tidally influenced reach and yacht basin of Fly Creek in 1985 (Google Earth, 2020).

by USGS topographic maps (USGS, 1953 and 1982) and topobathymetric mapping (USGS, 2013), which show that about 35 acres of additional land mass was created by sediment deposition from Big Mouth Gully (fig. 21). As previously discussed, current sediment transport rates are limited by detention areas on the east side of North section Street.

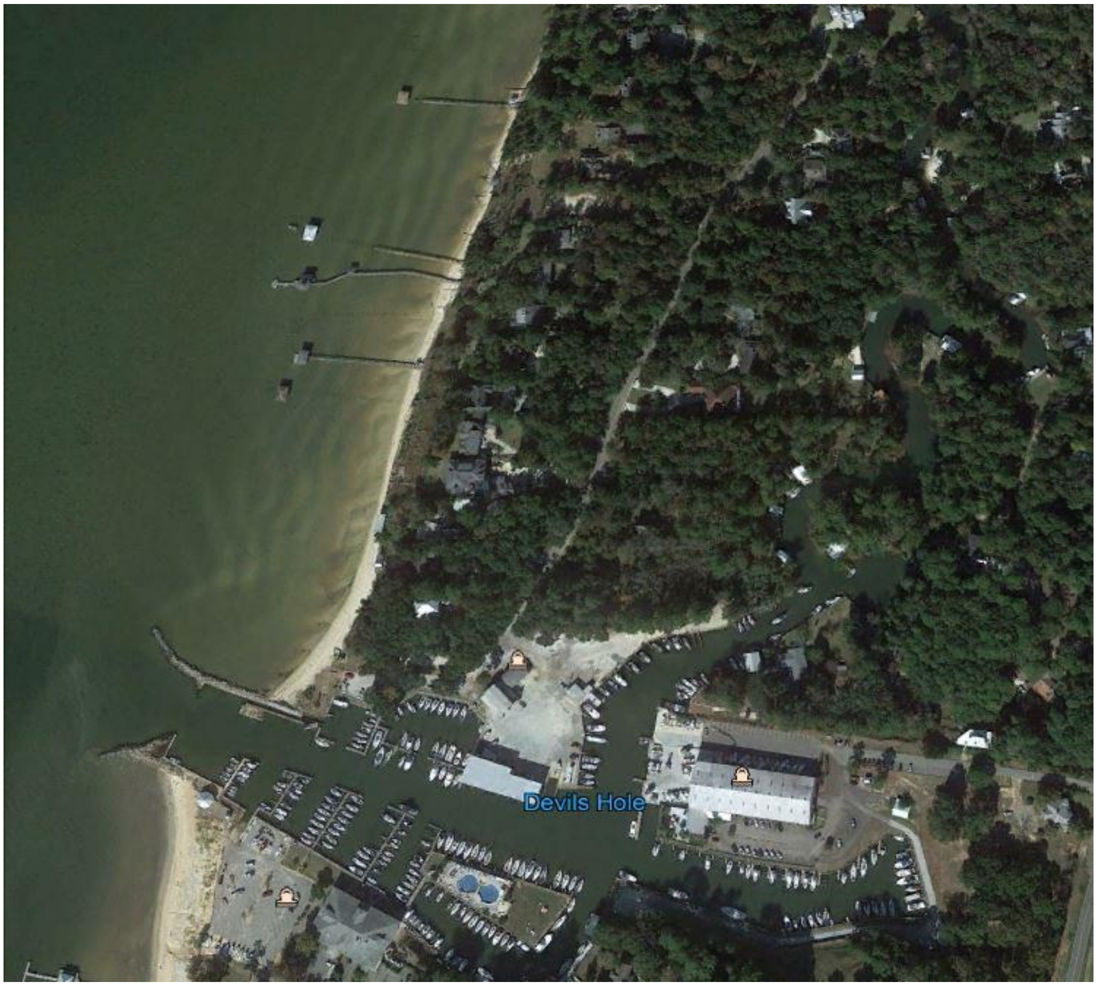

Figure 20.—Lower Fly Creek shown on 2019 satellite imagery (Google Earth, 2020)

Tatumville Gully has an estimated sediment transport rate of 7,255 t/yr, which is deposited into Mobile Bay just south of downtown Fairhope. Satellite imagery from 1985 shows a sediment/turbidity plume extending southwestward into Mobile Bay from the Tatumville Gully mouth (fig. 22). USGS topobathymetric mapping shows that an alluvial fan has developed into Mobile Bay, covering about 30 acres (fig. 23). Water depths at the Tatumville Gully mouth range from 0 to 3 ft. (USGS, 2013). Satellite imagery from 2019 continues to show a sediment plume extending into Mobile Bay from the mouth of Tatumville Gully (fig. 24). Figure 25 is a 2019 satellite image showing sediment/turbidity plumes extending into Mobile Bay from the mouths of Rock Creek, Big Mouth Gully and Tatumville Gully along with discharge from Fly Creek that is less turbid than Mobile Bay.

Figure 21.—USGS topographic and topobathymetric maps, showing sediment deposition at the mouth of Big Mouth Gully.

The critical nitrate concentration in surface water for excessive algae growth is 0.5 mg/L. The ADEM reference concentration for Ecoregion 65f is 0.3258 mg/L nitrate+nitrite nitrogen, which equals the 90th percentile). The largest concentrations of nitrate+nitrite nitrogen were in the Fly Creek watershed at sites ESFC5 (unnamed tributary to Fly Creek at Woodland Drive), ESFC6 (Fly Creek at Scenic US Highway 98), ESFC7 (Fly Creek at Baldwin Co Rd 13), and ESFC8 (unnamed tributary to Fly Creek at Alabama Highway 104) with 1.10, 1.19, 0.96, and 0.71 mg/L, respectively

Figure 22.—Sediment plume shown on 1985 satellite imagery, extending southwestward into Mobile Bay from the mouth of Tatumville Gully (Google Earth, 2020).

Concentrations at all other monitoring sites were near or below the detection limit (0.3 mg/L).

Although no official water-quality criterion for phosphorus has been established in the United States, total phosphorus should not exceed 0.05 mg/L in any stream or 0.025 mg/L within a lake or reservoir in order to prevent the development of biological nuisances. ADEM established a reference standard of 0.04 mg/L for total phosphorus for level IV ecoregion 65f. Eastern shore sites ES2 (Red Gully at Bay Shore Drive) and ESFC8 (unnamed tributary to Fly Creek at Alabama Highway 104) had the largest

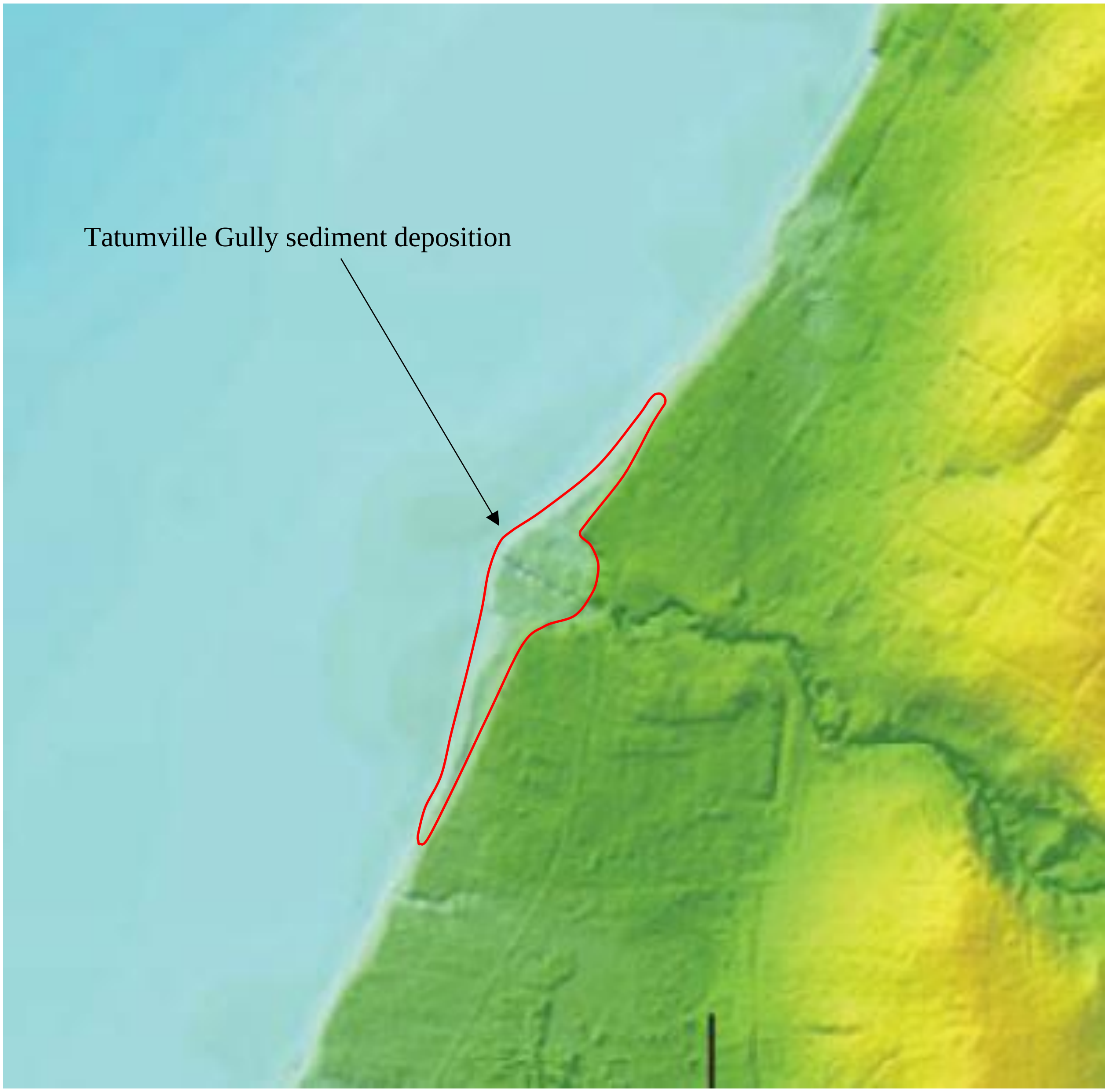

Figure 23.--USGS topobathymetric map, showing historic sediment deposition at the mouth of Tatumville Gully, forming additional land mass in Mobile Bay.

concentrations, 0.86 and 0.53 mg/L, respectively. Most other eastern shore watershed monitoring sites had phosphorus concentrations above the 0.04 mg/L reference criterion.

Nutrient concentrations in monitored eastern shore streams are impacted by land use/cover. Generally, the monitored watersheds with limited anthropogenic impacts, dominated by forest and wetlands have no detectable nitrogen or phosphorus. Streams with the highest nutrient concentrations are dominated by urban runoff, such as sites ES2

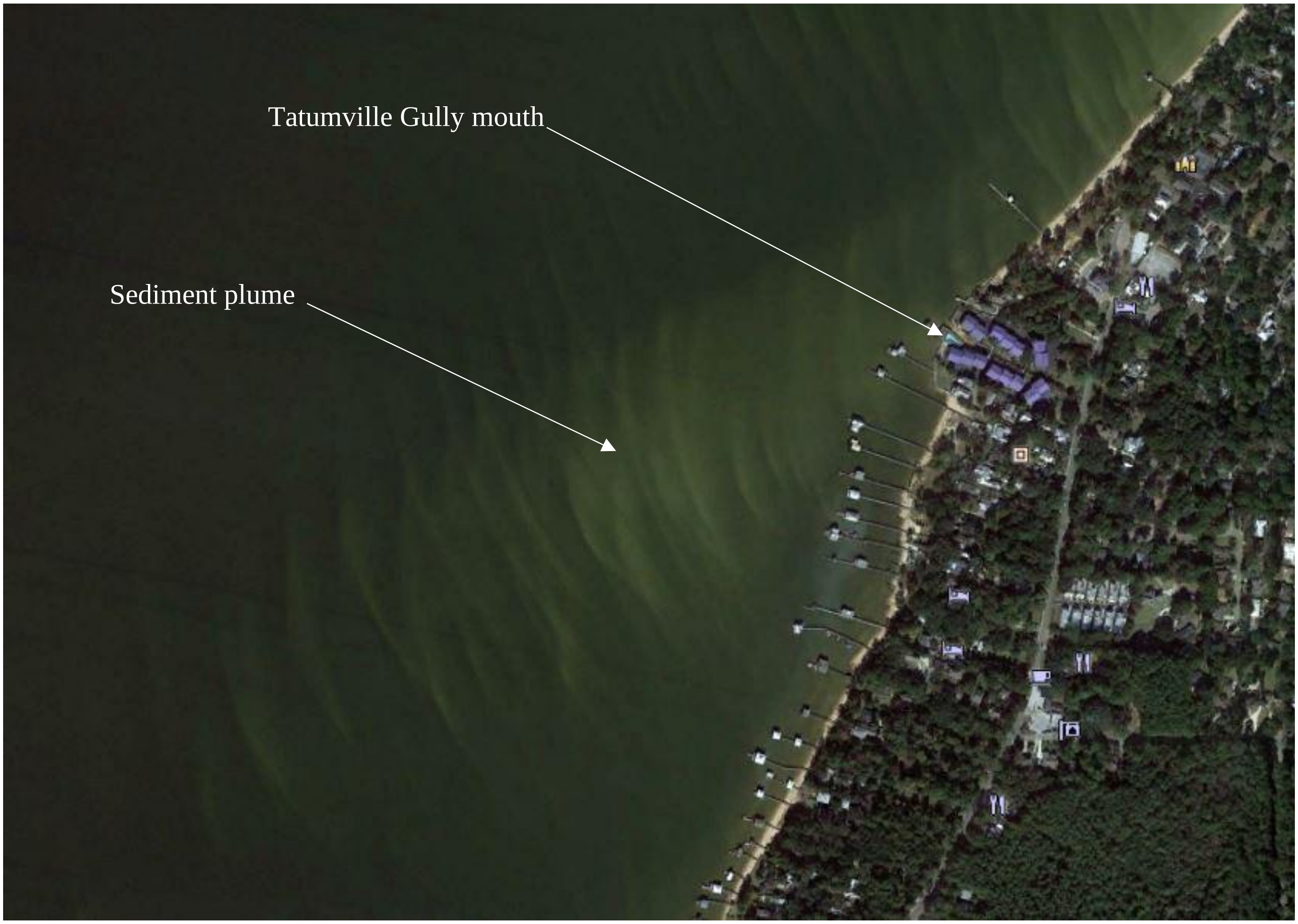

Figure 24.—Sediment plume from the mouth of Tatumville Gully shown on 2019 satellite imagery (Google Earth, 2020).

and ESFC5 and those dominated by agriculture, such as ESFC7 and ESFC8 and those with a combination of urban and agricultural runoff, such as ESFC6.

Based on the findings of this assessment, with respect to water quality and potential remediation and restoration, Red Gully, Tatumville Gully, Rock Creek, and Fly Creek (downstream from Baldwin County Road 13) have the highest degree of impairment and should be considered for various types of remediation and restoration. Volanta Gully, Big Mouth Gully, Yancey Branch, and the unnamed tributary to Fly Creek at Woodland Drive also show impairment and should be considered for specific remedial attention. However, additional field assessment will be required to refine sources of impairment and specific remedial strategies.

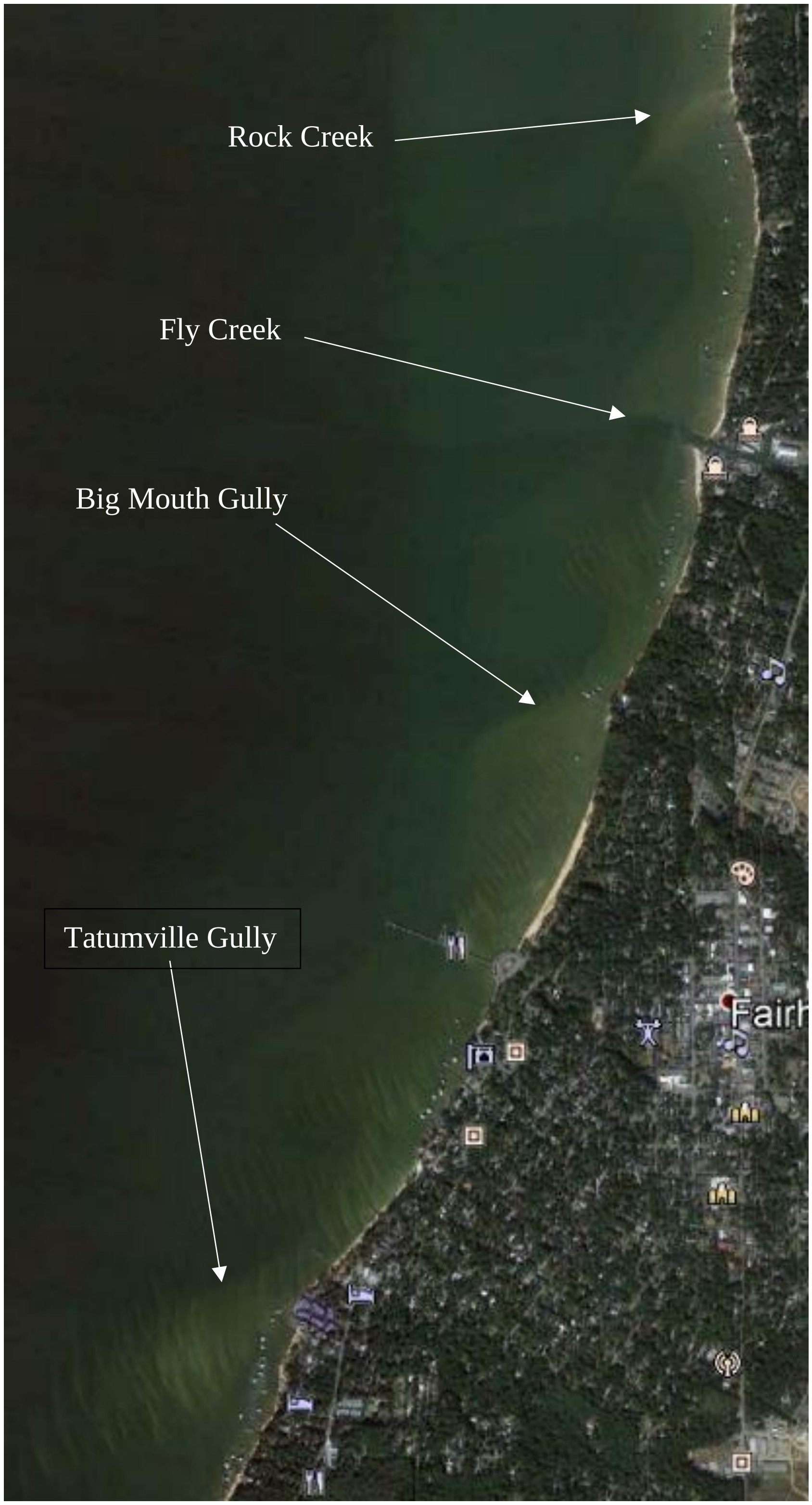

Figure 25.—Discharge and sediment plumes shown on November 18, 2019 satellite imagery, extending from the mouths of Rock Creek, Fly Creek, Big Mouth Gully, and Tatumville Gully (Google Earth, 2020.

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APPENDIX A

FIELD AND ANALYTICAL DATA

Yancy Branch at Harbor Place					Lat 30.626982			Area				
					Long 87.914488			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/day	mg/L	mg/L
ES1	02/26/19	845	4.0	16.2	71	6	6.1	8.5	3	1	0.36	0.03
ES1	03/04/19	900	10.2	17.3	32	90	6.1	7.7	82	12		
ES1	04/13/19	1000	2.4	21.6	58	10	6.2	9.3	5.0	3.2		
ES1	05/13/19	920	13.0	22.5	28	180	6.1	7.6	142.0	15.0		
ES1	06/06/19	1800	6.4	24.7	80	20	6.1	5.3	17	6.4		
ES1	07/13/19	1000	15.0	24.8	24	215	6.2	7.9	168.0	20.0	0.12	0.14
ES1	09/20/19	915	1.7	23.2	98	5	6.3	5.6	5.0	0.8		
ES1	10/22/19	1350	2	22.4	111	9	6.1	9.2	6.0	1.2		
Red Gully at Bay Shore Drive					Lat 30.578396			Area				
					Long 87.904789			0.8 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/day	mg/L	mg/L
ES2	02/26/19	940	0.42	17.4	82	3	6.5	8.5	2	0.6		
ES2	03/04/19	925	58	17.8	50	430	6.3	8.4	260	108		
ES2	04/04/19	1315	0.63	18.3	107	64	6.2	7.6	52	1.6		
ES2	04/13/19	1050	0.6	21.4	75	10	6.6	8.8	4	4.5		
ES2	05/13/19	950	170	23	48	640	6.6	8.2	330	110		
ES2	06/07/19	1100	263	24.6	41	930	6.8	7.8	458	210	0.058	0.86
ES2	07/13/19	1040	25.7	24.5	18	170	6.7	8	130	87.6	0.07	0.21
ES2	10/22/19	1420	1.1	25.2	91	21	6.8	7.2	5	5.2		
Rock Creek at US Hwy 98					Lat 30.56295			Area				
					Long 87.89425			4.1 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
ES3	02/20/19	1000	10	19.6	104	7	5.4	6.6	2		0.65	<.05
ES3	03/04/19	950	620	19.2	38	360	6.3	6.9	560			
ES3	04/04/19	1350	20.4	18.5	65	333	6.5	7.1	28			
ES3	04/13/19	1215	15.6	22.7	51	14	6.6	8.8	4			
ES3	06/06/19	1900	24.1	24.5	32	66	6.3	5.4	30			
ES3	06/07/19	1145	840	24.7	32	397	6.6	6.1	702		0.13	0.4
ES3	07/13/19	1145	358	24.5	17	135	6.9	7.4	90.0		0.1	0.16
ES3	09/20/19	940	12.2	25.2	68	9	6.8	6.2	3.0			

Unnamed Tributary to Fly Creek @ Headwater Road						Lat 30.56295				Area		
						Long 87.89425				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
ESFC4	02/20/19	1100	15.1	19.6	55	5	6	4.5	7		0.05	<.05
ESFC4	03/04/19	1020	8.9	21.2	54	6	6.3	5.1	10			
ESFC4	04/13/19	1200	1.2	24.6	48	4	6.1	8.2	4.0			
ESFC4	05/13/19	1020	10.5	26.1	47	7	6.2	6.1	12.0			
ESFC4	06/07/19	1430	42	27.6	40	43	6.6	4.7	34.0			
ESFC4	07/13/19	1415	88	26.2	53	118	7.9	6.9	119.0		0.01	0.3
ESFC4	09/20/19	1000	7.3	27.2	55	8	6.2	5.5	14.0		0.03	<.05
ESFC4	10/22/19	1440	2.1	26.8	58	5	6.2	4.8	5.0			
Unnamed tributary to Fly Creek at Woodlands Drive						Lat 30.551447				Area		
						Long 87.888478				0.3 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/day	mg/L	mg/L
ESFC5	02/20/19	1230	0									
ESFC5	03/04/19	1040	0.6	17.1	42	38	6.7	6.2	14	62		
ESFC5	04/04/19	1445	0.03	18	47	26	6.8	7.6	13	33		
ESFC5	05/13/19	1050	1.1	21.2	34	78	6.7	6.8	30	8		
ESFC5	06/07/19	1400	2.9	24.4	67	124	7.0	5.7	42	19.6	1.1	0.49
ESFC5	07/13/19	1430	12.2	24.8	31	320	6.7	6.4	168	52	0.31	0.88
ESFC5	09/20/19	1030	3.3	26.8	58	160	6.9	6.5	65	25		
ESFC5	10/22/19	1500	0									
Fly Creek at Main Street						Lat 30.55102				Area		
						Long 87.89881				7.2 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
ESFC6	02/20/19	1200	7	20.5	54	8	6.3	6.2	5		1.19	<.05
ESFC6	04/04/19	1430	14	18.1	49	25	6.3	7	10			
ESFC6	04/13/19	1400	8	26.3	49	14	6.2	8.7	8			
ESFC6	06/06/19	1920	81	24.3	36	162	6.1	5.7	75			
ESFC6	06/07/19	1200	220	24.8	34	581	4.9	5.5	856		0.24	0.28
ESFC6	07/13/19	1120	130	24.2	18	210	6.9	8	105		0.45	0.17
ESFC6	09/20/19	1115	5	25.8	58	5	6.7	5.8	4			
ESFC6	10/22/19	1520	10	26.2	52	34	6.8	6.9	15			

Fly Creek at Baldwin County Road 13						Lat 30.553600				Area		
						Long 87.869121				3.9 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
ESFC7	01/20/19	1255	10	20.6	59	5	5.8	5.5	4		0.96	<.05
ESFC7	04/04/19	1730	24	18.2	47	80	5.8	5.5	38			
ESFC7	04/13/19	1415	16	25	52	16	6.2	8.2	8			
ESFC7	06/06/19	1945	80	24.8	47	72	6.1	5	40			
ESFC7	06/07/19	1545	280	27.3	41	148	6.5	5.3	67		0.15	0.12
ESFC7	07/13/19	1520	950	25.1	16	301	7.2	7.5	130		0.21	0.38
ESFC7	09/20/19	1140	8	23.8	61	4	6.1	7.2	3			
ESFC7	10/22/19	1600	14	21.7	67	14	5.9	8.2	8			
Unnamed tributary to Fly Creek at Alabama Hwy 104 (West)									Lat 30.553600			Area
									Long 87.869121			0.9 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
ESFC8	02/20/19	1238	0									
ESFC8	04/04/19	1700	0									
ESFC8	04/13/19	1310	0									
ESFC8	06/07/19	1450	89	27.2	66	75	6.9	5.5	18.0		0.71	0.53
ESFC8	07/13/19	1440	106	24.7	19	115	7.5	7.0	56.0		0.39	0.44
ESFC8	09/20/19	1200	0									
ESFC8	10/22/19	1620	0									
Unnamed tributary to Fly Creek at Alabama Hwy 104 (Mid)									Lat 30.545184			Area
									Long 87.864910			0.4 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
ESFC9	02/20/19	1304	0									
ESFC9	04/04/19	1710	2	16.9	35	61	5.6	5.7	2.0			
ESFC9	04/13/19	1325	0									
ESFC9	06/07/19	1500	69	25.9	32	29	6.6	5	7.0		0.064	0.11
ESFC9	07/13/19	1450	88	24.9	14	83	7.4	7.1	64.0		0.081	0.25
ESFC9	09/20/19	1220	0									
ESFC9	10/22/19	1635	0									
Unnamed tributary to Fly Creek at Alabama Hwy 104 (East)									Lat 30.545253			Area
									Long 87.860322			0.2 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
ESFC10	02/20/19	1242	0									
ESFC10	04/13/19	1340	0									
ESFC10	6/7/2019	1515	15	27	28	22	6.6	4.9	4		0.1	0.23
ESFC10	07/13/19	1500	40	24.8	12	60	7.3	7.4	15		0.12	0.42
ESFC10	09/20/19	1235	0									
ESFC10	10/22/19	1650	0									

Volanta Gully at Main Street						Lat 30.536396				Area		
						Long 87.900164				0.5 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
ES11	02/26/19	1015	0									
ES11	04/04/19	1510	0.4	18.4	30	42	6.9	7	16			
ES11	04/13/19	1230	0									
ES11	05/13/19	1120	12.2	23.1	31	62	6.3	6.1	23			
ES11	06/07/19	1230	31	25.1	18	83	6.1	5.3	39		0.11	0.12
ES11	07/13/19	1200	37.5	24.6	10	88	7.1	7.9	57		0.057	0.14
ES11	09/20/19	1310	10.1	22.3	29	55	6.4	6.8	20			
ES11	10/22/19	1715	2.3	23.5	31	44	6.2	5.9	18			
Big Mouth Gully at N Bancroft Street						Lat 30.528779				Area		
						Long 87.901655				0.6 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/day	mg/L	mg/L
ES12	02/26/19	1030	0									
ES12	04/04/19	1540	0									
ES12	04/13/19	1235	0									
ES12	05/13/19	1145	3.1	24.1	43	60	6.6	6.1	32	25	0.11	0.11
ES12	06/07/19	1300	4.5	25.7	32	78	6.8	5.4	40	31.3	0.055	0.22
ES12	07/13/19	1225	250	24.4	14	144	7.2	8	113	97		
ES12	09/20/19	1325	10.1	23.6	64	92	6.6	6.9	61	62		
ES12	10/22/19	1730	2.3	25.9	75	53	6.5	6.1	25	20		
Tatumville Gully at Scenic Hwy 98						Lat 30.51179				Area		
						Long 87.917939				1.3 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/day	mg/L	mg/L
ES14	02/26/19	1140	0.31	18.9	103	3	7	8.1	2	0.12		
ES14	04/04/19	1620	12.1	18.1	50	132	6.9	6.8	200	16.6		
ES14	05/13/19	1210	18.6	21	42	185	7.1	7.1	270	20		
ES14	04/13/19	1350	0.41	23	98	3	7	9.6	4	0.6	0.18	<.05
ES14	06/07/19	1330	280	23.4	34	320	7	8.3	400	40	0.072	0.045
ES14	07/13/19	1300	800	24.2	14	597	7.2	8.0	634	55		
ES14	09/20/19	1350	31	24.4	40	97	6.9	6.8	160.0	27		
ES14	10/22/19	1745	1.1	25.2	98	5	7.0	6.6	10.0	2.6		

Point Clear Creek at Scenic Hwy 98						Lat 30.485624				Area		
						Long 87.931925				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/day	mg/L	mg/L
ES15	07/13/19	0:00	500	25.1	1,230	100	7.3	5.2	56	0.12	0.62	0.2
Bailey Creek at Scenic Hwy 98						Lat 30.461169				Area		
						Long 87.916468				1.1 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/day	mg/L	mg/L
ES16	07/13/19	1340	137.0	25.2	3,170	56	7.2	6.8	38	0.12	0.069	0.17