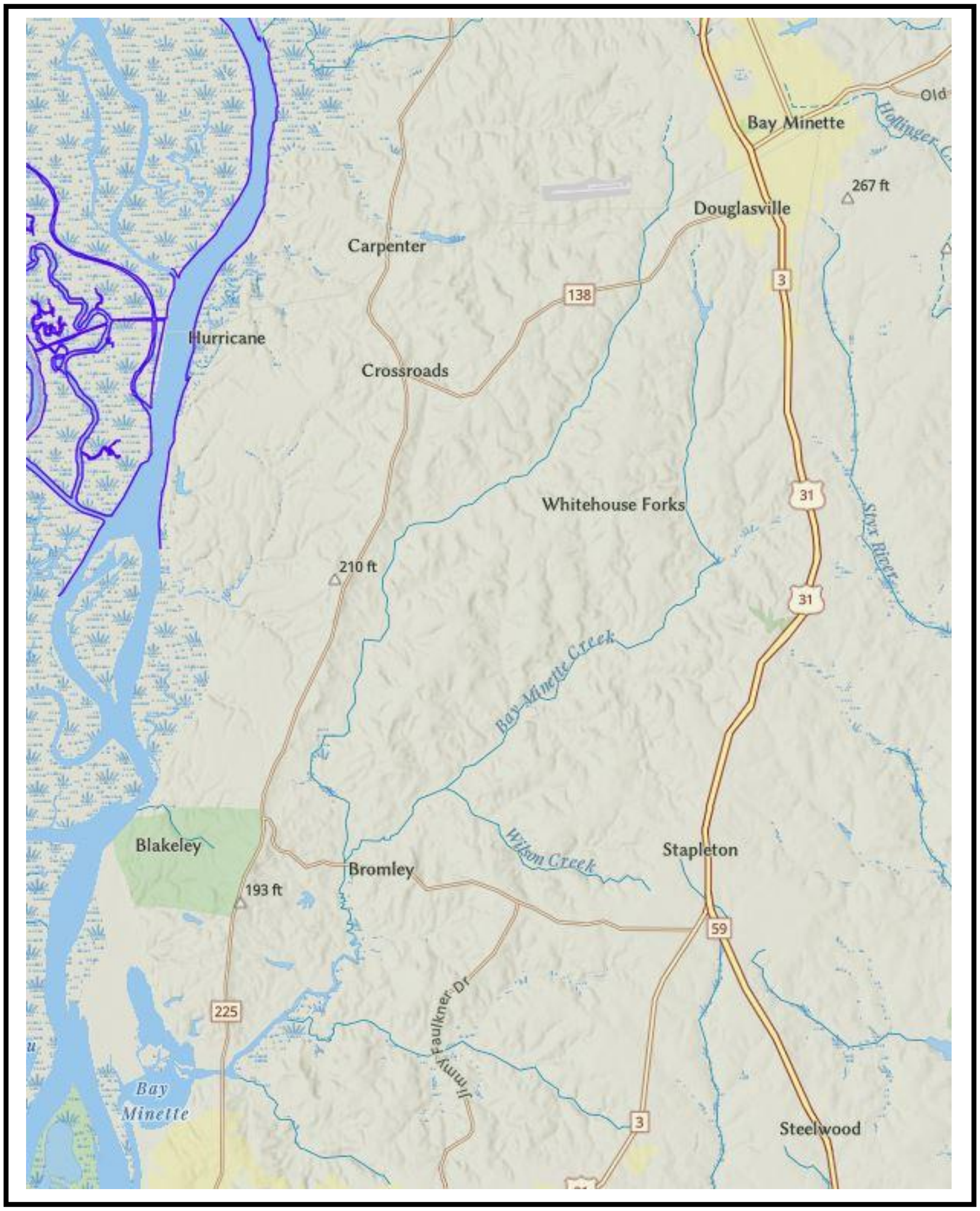
# PRE-RESTORATION ANALYSIS OF DISCHARGE, SEDIMENT TRANSPORT RATES, WATER QUALITY, AND LAND-USE IMPACTS FOR THE BAY MINETTE CREEK WATERSHED, BALDWIN COUNTY, ALABAMA



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By

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# INTRODUCTION

Bay Minette Creek flows southwestward for 17 miles through west-central Baldwin County, from the city of Bay Minette to its mouth in Bay Minette, in the lower Tensaw Delta (fig. 1). The watershed covers 71 square miles ($mi^2$) and is made up of 12 tributary subwatersheds. Most of the population in the Bay Minette Creek watershed is in the city of Bay Minette, in the headwaters of the watershed. The Bay Minette Creek watershed is an area with beautiful natural coastal landscapes and areas of rapidly expanding residential and commercial development.

The purpose of this investigation is to assess general hydrogeologic and water quality conditions and to estimate nutrient loads and sediment transport rates for the Bay Minette Creek watershed. 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.

# ACKNOWLEDGMENTS

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# PROJECT AREA

The Bay Minette Creek project area has five monitoring sites, three on Whitehouse Creek (the primary tributary to Bay Minette Creek) and two sites on Bay Minette Creek (fig. 1). Although the creek has 12 tributaries, the only road access is to Whitehouse and Bay Minette Creeks. Elevations in the project area vary from sea level at the mouth of Bay Minette Creek (Bay Minette) to 260 feet above mean sea level (ft MSL) at the headwaters of the creek on the west side of the city of Bay Minette (fig. 1).

Bay Minette Creek is included on the Alabama Department of Environmental Management (ADEM) 303(d) list of impaired waters in Alabama for mercury originating from atmospheric deposition (ADEM, 2020).

# PROJECT MONITORING STRATEGY AND SITE CHARACTERISTICS

The strategy employed for the Bay Minette Creek project was to select monitoring sites on all accessible tributary streams (table 1). Each stream reach was monitored over a wide range of measured discharge from base flow to high flow, from June to September 2021, including hurricane Ida in August 2021.

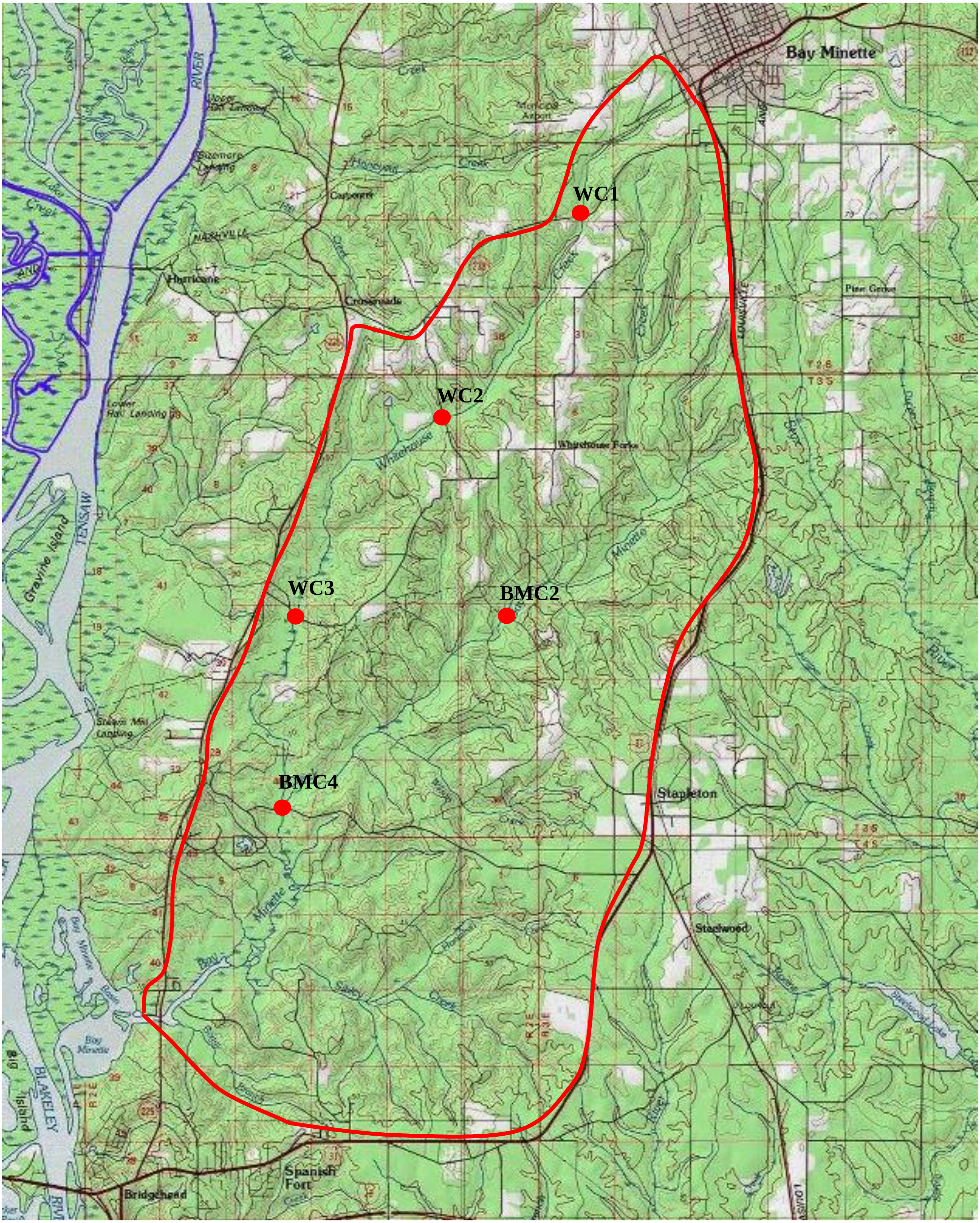


Figure 1.—Bay Minette Creek watershed with monitoring sites.

Table 1—Monitoring sites in the Bay Minette Creek watershed.

| Site | Site description |
|---|---|
| WC1 | Whitehouse Creek at Baldwin Co Road 138, 3.0 mi from the headwaters<br>Lat 30.85265°N Long -087.80838°W |
| WC2 | Whitehouse Creek at Baldwin Co Road 39, 6.4 mi the headwaters<br>Lat 30.81333°N Long -087.83876°W |
| WC3 | Whitehouse Creek at Baldwin Co Road 40, 10.3 mi from the headwaters<br>Lat 30.77623°N Long -087.87139°W |
| BMC2 | Bay Minette Creek at Baldwin Co Road 39, 7.7 mi from the headwaters<br>Lat 30.77611°N Long -087.82476°W |
| BMC4 | Bay Minette Creek at Bromley Road, 12.0 mi from the headwaters<br>Lat 30.73997°N Long -087.87572°W |

Water samples were collected for measurement of specific conductance, pH, temperature, turbidity, and dissolved oxygen. Laboratory analyses were performed for total suspended solids, nitrate+nitrite nitrogen, and total phosphorus. Daily and annual loads were estimated for suspended sediment. However, all monitored sites were characterized by deep water that precluded measurement of bed sediment.

## 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 Multi-Resolution Characteristics Consortium's National Land Cover Dataset 2011 land use data. This data set had a 16-class land cover classification scheme at 30-meter resolution. Land-use characteristics were also derived from the US Geological Survey (USGS) StreamStats program.

Land use/land cover in the upper and middle parts of the Bay Minette Creek watershed is dominated by forested lowlands, wetlands in stream floodplains, and upland forests and agriculture, consisting of pasture with minor acreage in row crop production. The lower part of the watershed is dominated by forested uplands and wetlands with tidal influence from the mouth of Bay Minette to the confluence of Whitehouse and Bay Minette Creeks. A small amount of pasture and row crop occurs at the highest elevations. Low density residential development occurs along roadways throughout the watershed. Wetlands are important because they provide water quality improvement and

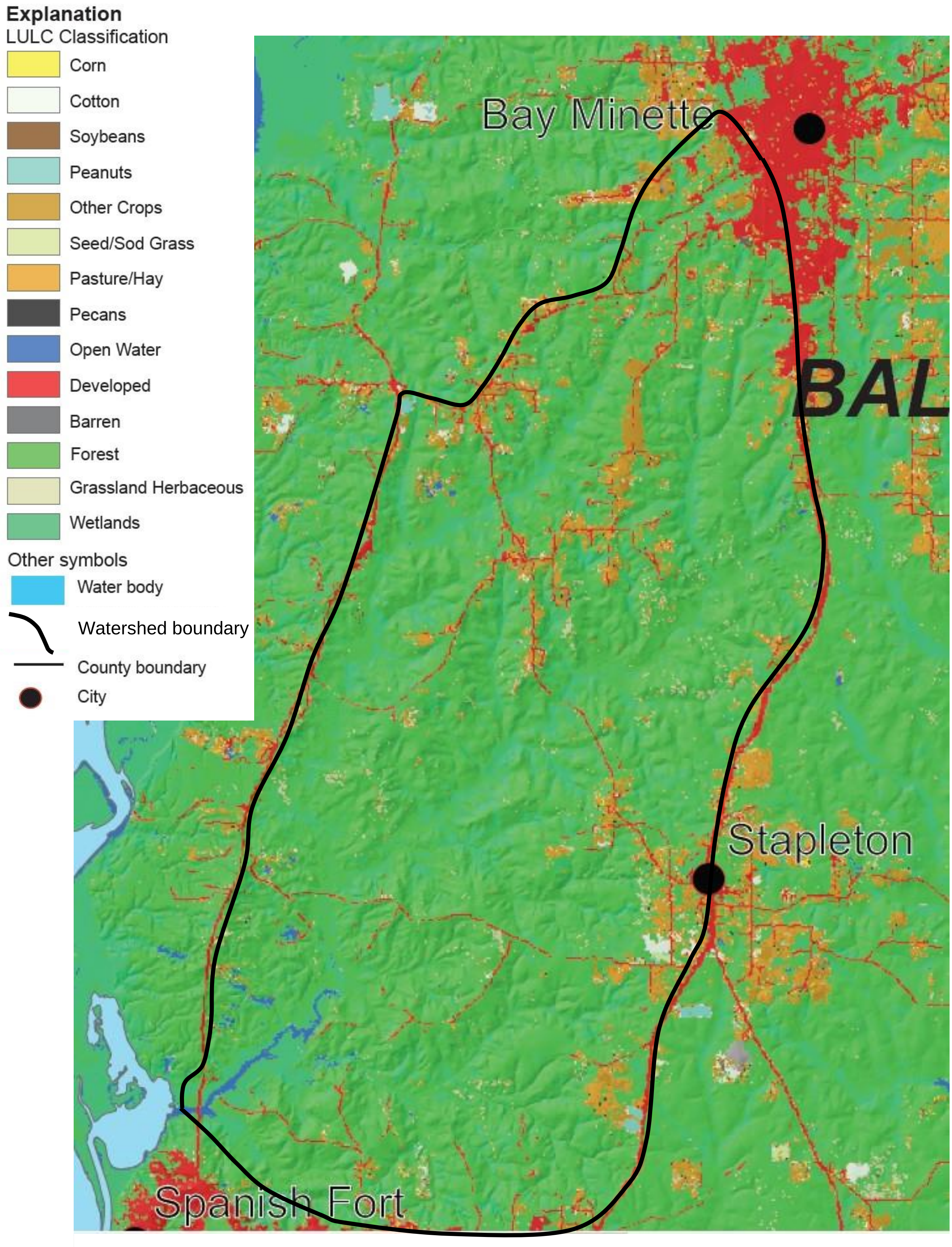


Figure 2.—Land use in the Bay Minette Creek watershed.

management services such as: flood abatement, storm water management, water purification, shoreline stabilization, groundwater recharge, and streamflow maintenance.

## STREAM FLOW CONDITIONS

Stream flow characteristics are determined by factors including climate, topography, hydrogeology, land use, and land cover. Streams in the Bay Minette Creek watershed exhibit flashy discharge due to relatively steep gradients. However, Whitehouse Creek and Bay Minette Creek streamflow conditions change significantly from the headwaters to the confluence where tidal influence begins.

The elevations of headwaters of Whitehouse and Bay Minette Creeks are 270 ft relative to mean sea level (MSL). The hydraulic gradient of Whitehouse Creek from the headwaters to monitoring site WC1 (3.0 miles) is 39 feet per mile (ft/mi). The gradient decreases to 17 ft/mi downstream from site WC1 to monitoring site WC2 (a distance of 3.4 miles). The gradient decreases further to 11 ft/mi from site WC2 to site WC3 (a distance of 3.9 miles). The gradient from site WC3 to the confluence with Bay Minette Creek (a distance of 3.1 miles) is 3.4 ft/mi.

The hydraulic gradient from Bay Minette Creek monitoring site BMC2 to the headwaters (a distance of 7.7 miles) is 29 ft/mi. The gradient from site BMC4, just downstream from the confluence with Whitehouse Creek) to site BMC2 (a distance of 4.3 miles) is 6.3 ft/mi. Table 2 shows streamflow characteristics for individual monitoring sites on Whitehouse and Bay Minette Creeks.

A wide range of discharge events are required to adequately evaluate hydrologic conditions and water quality in the Bay Minette Creek watershed. Table 2 shows that sampling occurred during discharge conditions from base flow to flood, with the largest discharges occurring during hurricane Ida on August 31, 2021, where discharge was bank full or out of banks at all monitored sites, as a result of more than 10 inches of rainfall. Flow velocities were measured at all sites and ranged between 0.5 to 2.5 ft/second. Average daily discharge for each monitored stream is required to adequately estimate constituent loading. Discharge data collected at the USGS stream gaging site 02377570, Styx River near Elsanor, Alabama, Alabama was used as a basis for average daily discharge calculation for each monitored stream.

Table 2.—Stream-flow characteristics for monitored sites in the Bay Minette Creek watershed.

| Monitored site | Average estimated annual daily discharge (cfs) | Maximum estimated annual daily discharge (cfs) | Minimum estimated annual daily discharge (cfs) | Average estimated discharge per unit area ($cfs/mi^2$) | Stream gradient (ft/mi) |
|---|---|---|---|---|---|
| WC1 (Whitehouse Creek @ Co Rd 138) | 27 | 247 | 10 | 7.3 | 39 |
| WC2 (Whitehouse Creek @ Co Rd 39) | 43 | 395 | 15 | 4.7 | 17 |
| WC3 (Whitehouse Creek @ Co Rd 40) | 108 | 988 | 39 | 7.2 | 11 |
| BMC2 (Bay Minette Creek @ Co Rd 39) | 103 | 939 | 37 | 5.6 | 29 |
| BMC4 (Whitehouse Creek @ Bromley Rd) | 173 | 1,581 | 62 | 3.6 | 6.3 |

## 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 Bay Minette Creek 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 3 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 Bay Minette Creek watershed monitoring sites from June 2021 through September 2021. Stream water temperatures during the monitoring period varied from 24 to 28°C. Sites WC2 (Whitehouse Creek Co Rd 39) and WC3 (Whitehouse Creek Co Rd 40) had the lowest average DO (6.4 mg/L) and site WC1 (Whitehouse Creek Co Rd 138) had the highest average DO (7.2 mg/L) (table 3). Values lower than the ADEM Fish and Wildlife standard (5.0 mg/L) were measured at all sites, except site WC1 (table 3). All sites had measured DO values less than the ADEM reference standard (6.94 mg/L) (table 3). Average DO and water temperature values were compared with atmospheric DO saturation. Sites WC2 and WC3 had the lowest percentage of atmospheric saturation (74%) and sites WC1 and BMC4 had the highest percentage (84%) (table 3).

Table 3.—Dissolved oxygen measured in monitored streams in the Bay Minette Creek watershed.

| Site | Dissolved oxygen (mg/L) | | | Average DO saturation (% atmospheric saturation) |
|---|---|---|---|---|
| | Maximum | Minimum | Average | |
| WC1 | 8.2 | 5.3 | 7.2 | 84 |
| WC2 | 7.1 | 4.9 | 6.4 | 74 |
| WC3 | 7.7 | 3.9 | 6.4 | 74 |
| BMC2 | 8.3 | 4.6 | 7.1 | 83 |
| BMC4 | 8.3 | 3.9 | 7.0 | 84 |

## 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. Table 4 shows SC in monitored streams in the Bay Minette Creek 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 4). 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 Bay Minette watershed is 20.4 µS/cm (ADEM, 2020). Median measured SC for all Bay Minette Creek watershed sites exceeded the ADEM standard (table 4).

Table 4.—Measured specific conductance values for Bay Minette Creek 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 | 51 | 81 | 40 | 20.4 | 26 |
| WC2 | 33 | 38 | 29 | 20.4 | 33 |
| WC3 | 26 | 31 | 20 | 20.4 | 25 |
| BMC2 | 26 | 30 | 24 | 20.4 | 26 |
| BMC4 | 29 | 39 | 26 | 20.4 | 27 |

## 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 2, illustrates that site BMC2 (Bay Minette Creek at Co Rd 39) has the highest average turbidity (24 NTU).

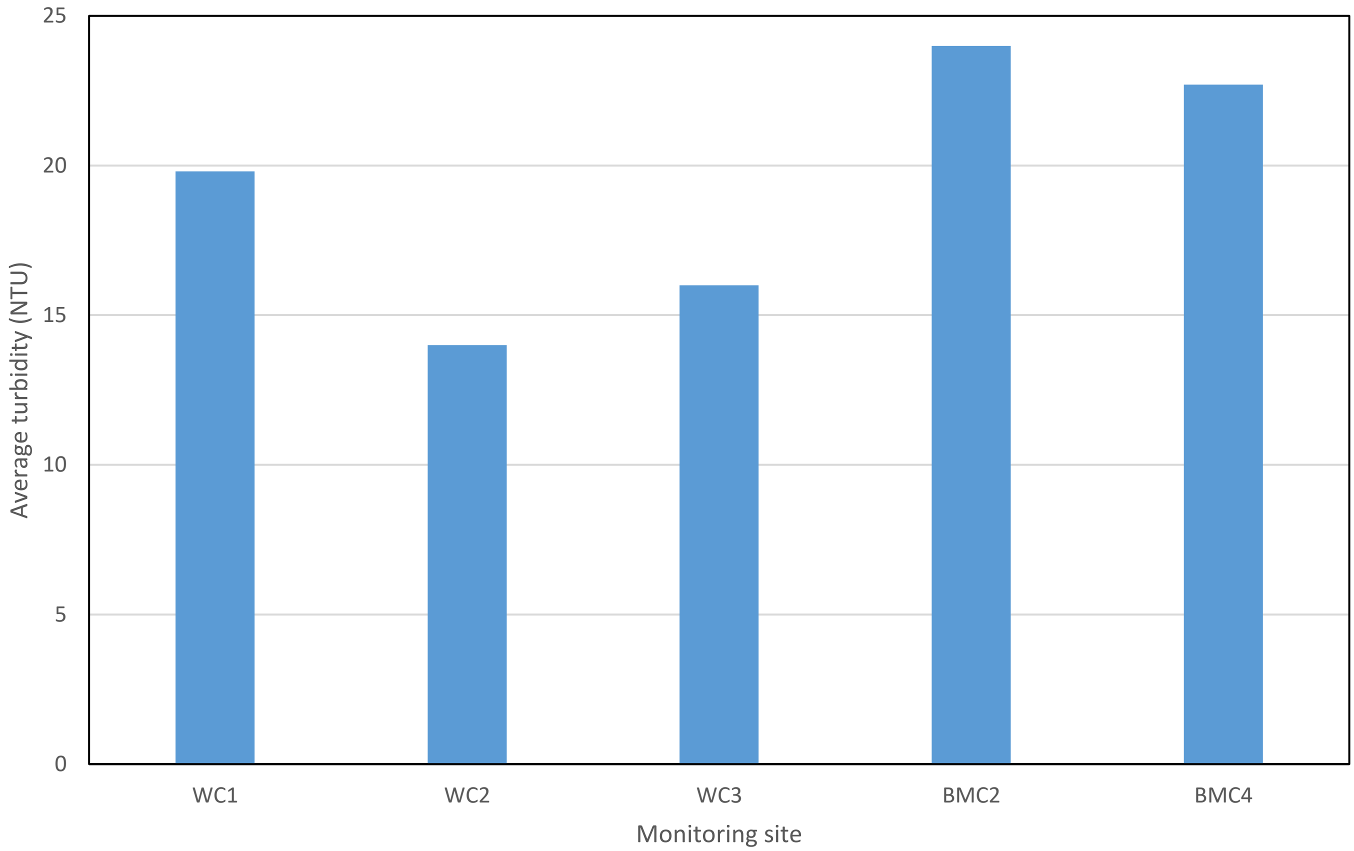


Figure 3.—Average measured turbidity for Bay Minette Creek watershed monitoring sites.

Commonly, excessive turbidity results from land uses that cause land disturbances, leading to erosion or to land uses that cause excessive runoff. Also, turbidity usually increases from upstream to downstream in response to increased runoff and discharge. However, in the Bay Minette Creek watershed, the highest average turbidity was measured at the upstream monitoring sites in Whitehouse and Bay Minette Creeks. Evaluation of land-use data indicates that most urban development and resulting suspended sediment occurs in the headwaters. As this sediment is transported downstream through forested and wetland dominated floodplains, much of it is filtered out and stored. This is illustrated by comparisons of average turbidity with percentage of urban development upstream of each monitored site (fig. 3). It shows that urban development decreases downstream in the Whitehouse and Bay Minette Creek watersheds with decreasing average turbidity. Upstream sites WC1 (Whitehouse Creek at Co Rd 138), and BCM2 (Bay Minette Creek at Co Rd 39) have the highest average turbidity and the largest amount of urban development. The ADEM reference concentration for turbidity is 9.7 NTU for ecoregion 65f (90$^{th}$ %ile) (ADEM, 2020). Average turbidity for all Bay Minette Creek watershed sites exceeded the ADEM standard (fig. 2).

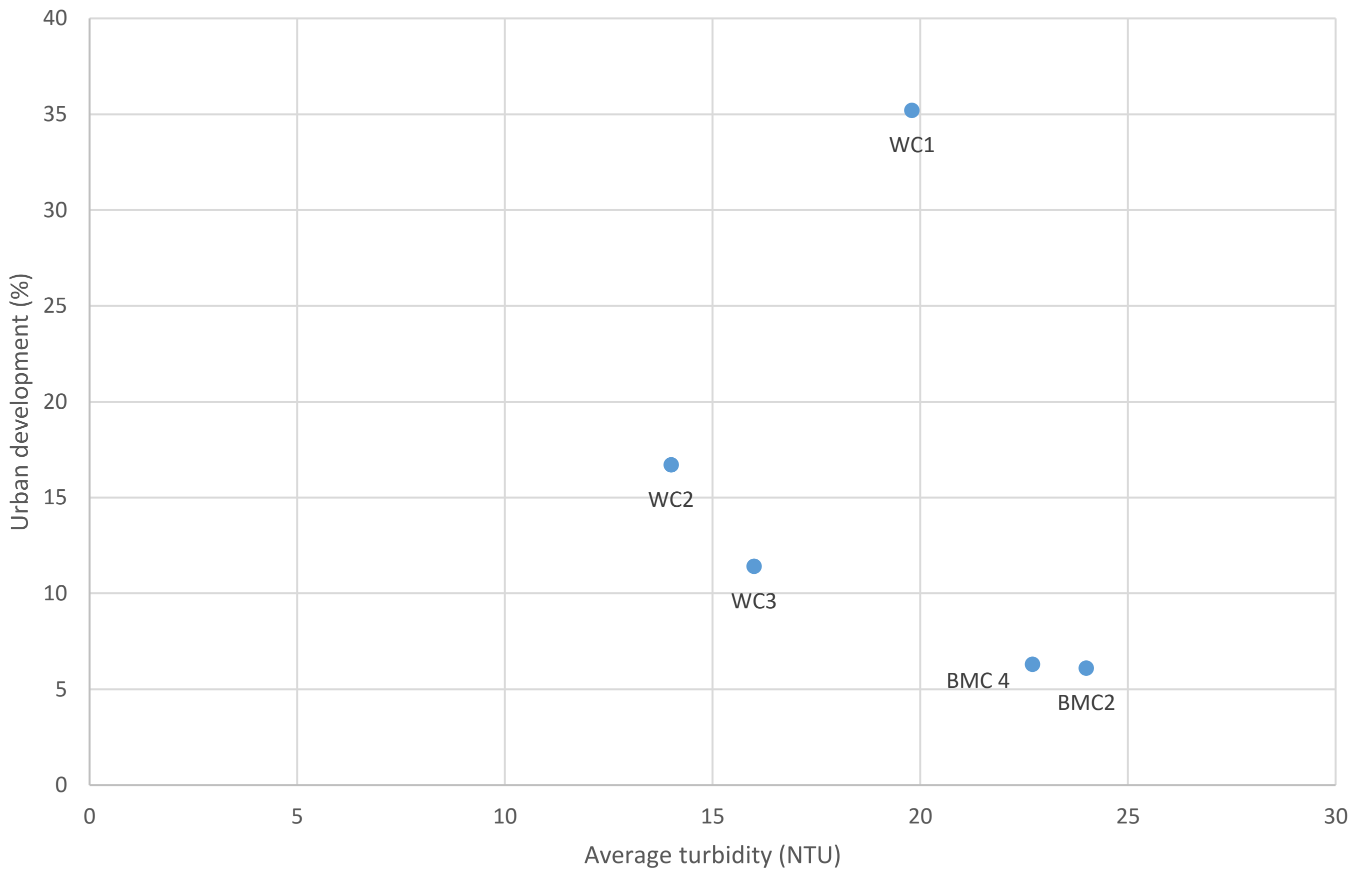


Figure 4.—Average measured turbidity and percentage of urban development for Bay Minette Creek monitoring sites.

**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. 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 Bay Minette Creek watershed were evaluated and quantified by stream reach, 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 Bay Minette Creek 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 2.

## 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 Bay Minette Creek watershed is characterized by an increasingly urban setting, dominated by residential development.

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). All accessible areas of Bay Minette Creek monitoring sites were characterized by deep, relatively fast flowing water that precluded bed sediment measurement. Little bed sediment was observed due to high velocity flow that suspends most sediment in the water column. Only suspended sediment could be measured due to flow and channel conditions.

## *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 4 is an x-y plot of measured turbidity and total suspended solids (TSS) for individual water samples collected at Bay Minette Creek watershed monitoring sites. It shows a good correlation between turbidity and TSS, except for a few outliers. Average suspended solids concentrations were relatively low and ranged from 5.7 mg/L at site WC1 (Whitehouse Creek at Co Rd 138) to 11.7 mg/L at site BMC2 (Bay Minette Creek at Co Rd 39) (table 5).

Annual suspended sediment loads were estimated for the Bay Minette Creek 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.

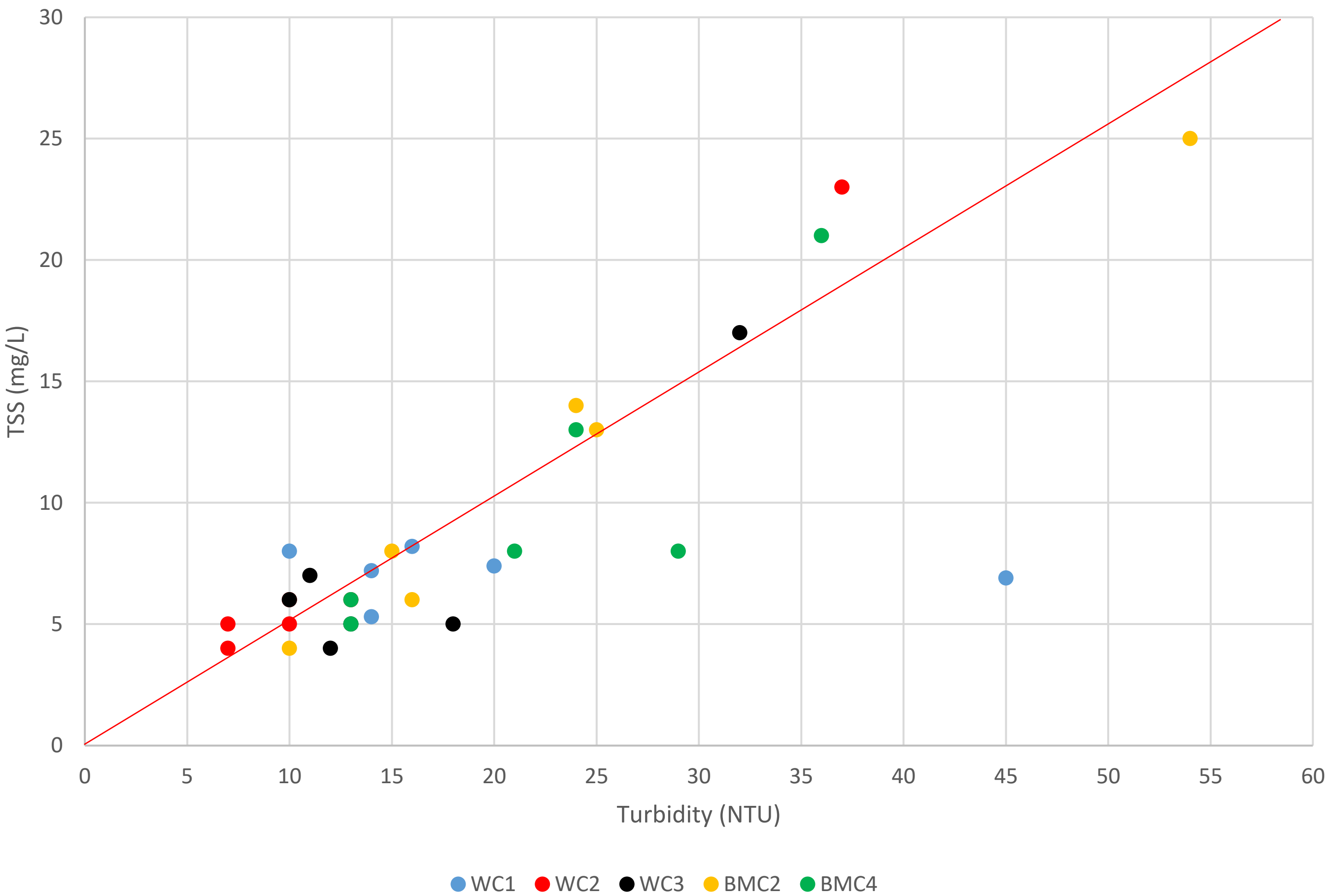


Figure 5.—Graph showing an X-Y plot of measured turbidity and TSS values for Bay Minette Creek watershed monitoring sites.

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 02377570, Styx River near Elsanor, Alabama (USGS, 2023).

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 (January 1, 2021 to December 31, 2021). As expected, monitoring sites on streams with the largest discharge had the highest suspended sediment loads, including BMC4 (Bay Minette Creek at Bromley Rd ), BMC2 (Bay Minette Creek at Co Rd 39), and WC3 (Whitehouse Creek at Co Rd 40) with 1,914, 1,152, and 985 tons per year (t/yr), respectively (table 5).

Table 5.—Measured discharge, turbidity, TSS, and estimated suspended sediment loads in monitored streams in the Bay Minette Creek watershed.

| Monitored site | Average Estimate annual daily discharge (cfs) | Average turbidity (NTU) | Average TSS (mg/L) | ADEM Level IV Ecoregion 65f reference standard for TSS (mg/L) | Estimated suspended sediment load (t/yr) | Estimated normalized suspended sediment load ($t/mi^2/yr$) |
|---|---|---|---|---|---|---|
| WC1 (Whitehouse Creek @ Co Rd 138) | 27 | 20 | 5.7 | 13.2 | 171 | 46 |
| WC2 (Whitehouse Creek @ Co Rd 39) | 43 | 14 | 8.2 | 13.2 | 365 | 40 |
| WC3 (Whitehouse Creek @ Co Rd 40) | 108 | 16 | 7.3 | 13.2 | 985 | 65 |
| BMC2 (Bay Minette Creek @ Co Rd 39) | 103 | 24 | 12 | 13.2 | 1,152 | 63 |
| BMC4 (Whitehouse Creek @ Bromley Rd) | 173 | 23 | 10 | 13.2 | 1,914 | 39 |

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 Bay Minette Creek watershed are in table 5, which shows the largest normalized suspended sediment loads at WC3 (Whitehouse Creek at Co Rd 40), (65 $t/mi^2/yr$), and BMC2 (Bay Minette Creek at Co Rd 39) (63 $t/mi^2/yr$). It is interesting to note that site WC2 had a smaller normalized load than the upstream site WC1, indicating that the watershed between sites WC1 and WC2 contributed little sediment to Whitehouse Creek (table 5). This is also the case for the Bay Minette Creek watershed between sites BMC2 and BMC4. This shows the impact of the headwaters, which are characterized by more urban development related to the city of Bay Minette and higher hydraulic gradients of Whitehouse and Bay Minette Creeks.

## *TOTAL SEDIMENT LOADS*

As mentioned previously, accessible monitoring sites for Whitehouse and Bay Minette Creek are characterized by deep water with relatively high velocity flows, which precluded measurement of bed sediment. Observations indicated that most of the sediment transported by both streams at the monitoring sites was suspended and is accounted for in the suspended sediment load estimations. Therefore, it is assumed that suspended sediment and total sediment loads are similar.

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 sites WC3 and BMC2 are near the geologic erosion rate. Since the same methodology was used to estimate sediment loads for more than 130 monitoring sites in Mobile and Baldwin County, comparisons of loads from one watershed to another is useful in determining magnitudes of stream and watershed impairment. Table 6 shows total sediment loads for previously monitored watersheds in Mobile and Baldwin Counties and comparisons with Whitehouse and Bay Minette Creeks watersheds.

Table 6—Comparisons of normalized total sediment loads for monitored watersheds in Mobile and Baldwin Counties.

| Monitored site | Estimated normalized annual total sediment loads (tons/mi$^2$/yr) |
|---|---|
| DR2 (Dog River) | 4,332 |
| ES2 (Red Gully) | 15,590 |
| FR2 (Fowl River) | 52 |
| DC3 (D'Olive Creek) | 1,987 |
| FR14 (Fish River) | 201 |
| MR4 (Magnolia River) | 112 |
| BSR3 (Bon Secour River) | 1,531 |
| WC10 (Wolf Creek) | 2,231 |
| ES14 (Tatumville Gully) | 5,581 |
| PB10 (Styx River) | 148 |
| WC3 (Whitehouse Creek) | 65 |
| BMC4 (Bay Minette Creek) | 39 |

## 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+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 Bay Minette Creek 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. Although most samples were below detection limit and detected concentrations were small, the largest nitrate+nitrite nitrogen concentrations were at sites BMC4 (Bay Minette Creek at Bromley Rd) (0.095 mg/L) and BMC2 (Bay Minette Creek at Co Rd 39) (0.097). Table 7 shows average nitrate concentrations for monitored Bay Minette Creek watershed sites.

## ***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 Bay Minette Creek 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.” Only one Bay Minette watershed monitoring site (WC2) water sample had detected phosphorus (0.13 mg/L).

Table 7.—Estimated annual daily discharge, and measured average nitrate concentrations in monitored streams in the Bay Minette Creek watershed.

| Monitored site | Average estimated annual daily discharge (cfs) | Average nitrate (mg/L) |
|---|---|---|
| WC1 (Whitehouse Creek @ Co Rd 138) | 27 | BDL |
| WC2 (Whitehouse Creek @ Co Rd 39) | 43 | BDL |
| WC3 (Whitehouse Creek @ Co Rd 40) | 108 | BDL |
| BMC2 (Bay Minette Creek @ Co Rd 39) | 103 | 0.059 |
| BMC4 (Whitehouse Creek @ Bromley Rd) | 173 | 0.034 |

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

Evaluations of sediment transport and water-quality analyses led to conclusions concerning which areas in the Bay Minette 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. Overall, considering physical and chemical parameters evaluated for this investigation, conditions in the Bay Minette watershed are very good, especially when compared to many other evaluated watersheds in the Mobile Bay and Alabama Gulf Coast.

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, the upper half of Whitehouse and Bay Minette Creeks are characterized by high gradients that result in flashy discharge with high flow velocities. The lower half is characterized by deep water, lower flow velocities, and tidal influence in Bay Minette Creek.

Land use/cover is also an important factor influencing erosion, sediment transport, and overall water quality. Generally, the Bay Minette Creek watershed has three primary land uses/covers. Headwaters are in the western urban perimeter of the city of Bay Minette, which is primarily residential development. Residential development is expanding with new subdivisions throughout the watershed, primarily at higher elevations along and near roadways. Rural areas are characterized by forest cover with minimal open fields used for pasture or row crop agriculture, and forested floodplains. Floodplains have extensive wetland areas that increase towards lower topographic relief in the lower parts of the watershed.

The Bay Minette Creek watershed is currently on the ADEM 303-D list of impaired waters for mercury caused by atmospheric deposition (ADEM, 2022).

Dissolved oxygen was measured during each monitored event. Downstream Whitehouse Creek sites WC2 and WC3 had the lowest average DO (6.4 mg/L) and upstream site WC3 had the highest average DO (7.2 mg/L). Values lower than the ADEM Fish and Wildlife standard (5.0 mg/L) were measured at all sites except site WC2 during July and August, 2021. All 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. Whitehouse Creek sites WC1 and WC2 had the smallest suspended sediment loads with 171 and 365 t/yr, respectively. The largest loads were at Bay Minette Creek sites BMC 2 and BMC4 with 1,152 and 1,914 t/yr, respectively The largest normalized suspended sediment loads occurred at site BMC2 (63 $t/mi^2/yr$), and site WC3 (65 $t/mi^2/yr$).

No monitored sites had measurable bed sediment due to deep, high velocity flow. However, observations revealed that most transported sediment at monitored sites was suspended and bed sediment was minimal.

When compared to ten previously monitored sites in Mobile and Baldwin Counties, sediment loads in the Bay Minette Creek watershed are similar to loads estimated for Perdido Bay, Magnolia River and Fish River and are near or below the geologic erosion rate of 64 $t/mi^2/yr$.

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 $90^{th}$ percentile). Average nitrate+nitrite nitrogen concentrations for all Whitehouse Creek sites were below the laboratory detection limit of 0.05 mg/L. Average nitrate+nitrite nitrogen concentrations for Bay Minette Creek sites were 0.059 for site BMC2 and 0.034 for site BMC4.

Although no official water-quality criterion for phosphorus has been established in the United States, total phosphorus should not exceed 0.05 mg/L in any stream or 0.025 mg/L within a lake or reservoir in order to prevent the development of biological nuisances. ADEM established a reference standard of 0.04 mg/L for total phosphorus for level IV ecoregion 65f. Only one Bay Minette watershed monitoring site (WC2) water sample had total phosphorus above the laboratory detection limit of 0.1 mg/L (0.13 mg/L).

Based on the findings of this assessment, with respect to water quality and potential remediation and restoration, no significant impairments were observed. The Bay Minette Creek watershed is comparable to the most pristine watersheds in Mobile and Baldwin Counties. However, based on construction activity and transition of forest and agricultural land to residential developments, future impairments are almost certain to occur. Monitoring and field observations should be conducted on a regular basis to identify problem areas so that remediation plans and activities can occur to prevent degradation of habitats and water quality.

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# APPENDIX A

# FIELD AND ANALYTICAL DATA

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Whitehouse Creek at Co Rd 138 | | | Lat 30.85265 | Area | | | | | | | |
| | | | Long 87.8083 | 3.7 mi2 | | | | | | | |
| Site | Date | Time | Dis | Temp | Conduct | Turb | pH | DO | TSS | Nitrate | Total P |
| | | | cfs | °C | mS/cm | NTU | | mg/L | mg/L | mg/L | mg/L |
| WC1 | 06/23/21 | 900 | 32 | 25 | 40 | 14 | 6.6 | 7.2 | 4 | <.05 | <.1 |
| WC1 | 07/13/21 | 1525 | 43 | 26 | 51 | 20 | 6.4 | 7.4 | 6 | <.05 | <.1 |
| WC1 | 07/21/21 | 1010 | 34 | 27 | 44 | 16 | 7.1 | 8.2 | 5 | <.05 | <.1 |
| WC1 | 08/03/21 | 1350 | 32 | 27 | 44 | 14 | 6.3 | 5.3 | 3 | <.05 | <.1 |
| WC1 | 08/31/21 | 1115 | 103 | 26 | 81 | 45 | 5.4 | 6.9 | 13 | | |
| WC1 | 09/17/21 | 1540 | 22 | 25 | 45 | 10 | 6.3 | 8 | 3 | <.05 | <.1 |
| | | | | | | | | | | | |
| Whitehouse Creek at Co Rd 39 | | | Lat 30.81333 | Area | | | | | | | |
| | | | Long 87.8387 | 9.2 mi2 | | | | | | | |
| WC2 | 06/23/21 | 940 | 68 | 25 | 29 | 10 | 6 | 6.9 | 5 | <.05 | <.1 |
| WC2 | 07/13/21 | 1510 | 73 | 26 | 33 | 10 | 6 | 6.8 | 6 | <.05 | <.1 |
| WC2 | 07/21/21 | 940 | 95 | 26 | 38 | 13 | 6.9 | 6 | 6 | <.05 | <.1 |
| WC2 | 08/03/21 | 1330 | 58 | 28 | 33 | 7 | 6.1 | 4.9 | 5 | <.05 | 0.013 |
| WC2 | 08/31/21 | 1135 | 258 | 28 | 38 | 37 | 5.7 | 6.5 | 23 | | |
| WC2 | 09/17/21 | 1530 | 50 | 25 | 29 | 7 | 6 | 7.1 | 4 | <.05 | <.1 |
| | | | | | | | | | | | |
| Whitehouse Creek at Co Rd 40 | | | Lat 30.77623 | Area | | | | | | | |
| | | | Long 87.8713 | 15.1 mi2 | | | | | | | |
| WC3 | 06/23/21 | 1025 | 182 | 25 | 25 | 13 | 5.4 | 7 | 5 | <.05 | <.1 |
| WC3 | 07/13/21 | 1440 | 145 | 26 | 28 | 11 | 5.8 | 7.1 | 7 | <.05 | <.1 |
| WC3 | 07/21/21 | 1130 | 240 | 26 | 20 | 18 | 5.7 | 3.9 | 5 | <.05 | <.1 |
| WC3 | 08/03/21 | 1305 | 130 | 27 | 31 | 10 | 6.2 | 5.6 | 6 | <.05 | <.1 |
| WC3 | 08/31/21 | 1215 | 412 | 27 | 25 | 32 | 5 | 7 | 17 | | |
| WC3 | 09/17/21 | 1505 | 155 | 25 | 27 | 12 | 5.5 | 7.7 | 4 | <.05 | <.1 |
| | | | | | | | | | | | |
| Bay Minette Creek at Co Rd 39 | | | Lat 30.77611 | Area | | | | | | | |
| | | | Long 87.8247 | 18.4 mi2 | | | | | | | |
| BMC2 | 06/23/21 | 1005 | 225 | 24 | 24 | 24 | 5.8 | 7.5 | 14 | <.05 | <.1 |
| BMC2 | 07/13/21 | 1500 | 150 | 24 | 24 | 15 | 5.8 | 8.3 | 8 | 0.094 | <.1 |
| BMC2 | 07/21/21 | 1100 | 235 | 26 | 26 | 25 | 6.4 | 4.6 | 13 | 0.097 | <.1 |
| BMC2 | 08/03/21 | 1325 | 97 | 26 | 26 | 10 | 6.1 | 6.1 | 4 | 0.051 | <.1 |
| BMC2 | 08/31/21 | 1150 | 515 | 27 | 30 | 54 | 5.2 | 7.1 | 25 | | |
| BMC2 | 09/17/21 | 1515 | 158 | 25 | 26 | 16 | 5.7 | 9 | 6 | 0.0525 | <.1 |

| Site | Date | Time | Dis | Temp | Conduct | Turb | pH | DO | TSS | Nitrate | Total P |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | cfs | °C | mS/cm | NTU | | mg/L | mg/L | mg/L | mg/L |
| Bay Minette Creek at Bromley Rd | | | Lat 30.73997 | Area | | | | | | | |
| | | | Long 87.8757 | 48.6 mi2 | | | | | | | |
| BMC4 | 06/23/21 | 1040 | 440 | 27 | 27 | 24 | 5.2 | 7.4 | 13 | <.05 | <.1 |
| BMC4 | 07/13/21 | 1425 | 120 | 26 | 29 | 13 | 5.8 | 8.3 | 5 | 0.095 | <.1 |
| BMC4 | 07/21/21 | 1150 | 740 | 26 | 28 | 29 | 5.6 | 3.9 | 8 | <.05 | <.1 |
| BMC4 | 08/03/21 | 1250 | 130 | 26 | 39 | 13 | 6.3 | 6.9 | 6 | 0.076 | <.1 |
| BMC4 | 08/31/21 | 1235 | 1288 | 27 | 26 | 36 | 4.9 | 6.9 | 21 | | |
| BMC4 | 09/17/21 | 1450 | 300 | 25 | 27 | 21 | 5.4 | 8.8 | 8 | <.05 | <.1 |