PRE-RESTORATION ANALYSIS OF DISCHARGE, SEDIMENT TRANSPORT RATES, AND WATER QUALITY IN TRIBUTARIES OF FOWL RIVER, MOBILE COUNTY, ALABAMA

GEOLOGICAL SURVEY OF ALABAMA

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By

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INTRODUCTION

Commonly, land-use and climate are major contributors to nonpoint source contaminants that impact surface-water quality. In much of Baldwin and Mobile Counties, population growth and economic development are critical issues leading to land-use change. When combined with highly erodible soils and Alabama's coastal climate, characterized by cyclonic storms that produce high intensity rainfall events, deleterious water-quality and biological habitat impacts can be severe. Previous investigations of sediment transport and general water quality performed by the Geological Survey of Alabama (GSA) have shown dramatic increases in sediment loading and loss of biological habitat in streams downstream from areas affected by rapid runoff and resulting erosion. These data are valuable in quantifying negative impacts so that limited remedial resources may be focused where needs are greatest. GSA investigations also identified relatively unimpacted watersheds, such as Yellow River in Covington County and Magnolia River in southwest Baldwin County, where remedial resources may be used to preserve and protect watersheds from threats of future impacts.

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

ACKNOWLEDGMENTS

Ms. Roberta Swann, Director, Mobile Bay National Estuary Program, and Mr. Tom Herder, Watershed Protection Coordinator, Mobile Bay National Estuary Program, provided coordination for the project. Mr. Lee Walters, Regional Vice President, Goodwin, Mills, and Cawood, provided information and guidance in the planning and implementation of the project.

PROJECT AREA

The Fowl River watershed covers 52,782 acres (82.5 square miles (mi^2) (Mobile Bay National Estuary Program (MBNEP), 2015) in southeastern Mobile County and includes monitoring sites on seven tributaries and the main stems of Fowl River and East

Fowl River (fig. 1). Fowl River flows southeast from its headwaters northwest of Theodore to its confluence with East Fowl River near Bellingrath Gardens where it flows along the northern shore of Mon Louis Island and empties into Mobile Bay (fig 1, plate 1). Elevations in the project area vary from more than 180 feet above mean sea level (ft MSL) to sea level (plate 2). The seven monitored tributaries include five unnamed streams, Muddy Creek, and Dykes Creek.

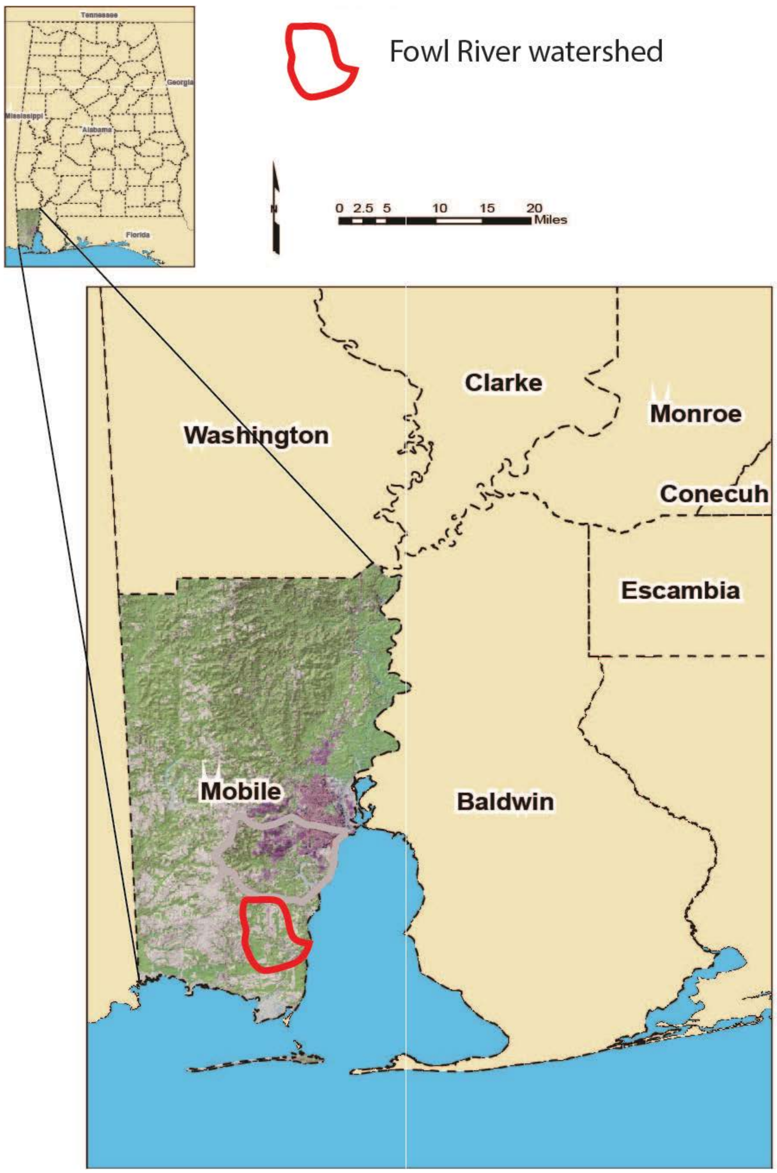

Figure 1.—Fowl River project area.

PROJECT MONITORING STRATEGY AND SITE CONDITIONS

The monitoring strategy employed for the Fowl River project was to collect water samples at each site over a wide range of discharge from base flow to flood for sediment load estimation and collect samples during high and low flow events for comprehensive analyses. A number of factors were considered during selection of monitoring sites, including site accessibility in rural areas, extensive wetlands and tidal influence that constrain stream flow and impact water chemical character, and site locations as far downstream as possible, to include cumulative impacts.

Site FR1 is on an unnamed tributary flowing southeastward in the west-central part of the Fowl River watershed (latitude (lat) 30.49775, longitude (long) -88.18629). The monitored site is at the Half Mile Road crossing, about 2,000 feet (ft) from its confluence with Fowl River. The watershed upstream from site FR1 covers 2.14 mi^2.

Site FR2 is on Fowl River in the central part of the watershed at the Half Mile Road crossing (lat 30.50103, long 88.18144). The watershed upstream from site FR2 covers 15.2 mi^2.

Site FR3 is on an unnamed tributary flowing southward in the central part of the Fowl River watershed (lat 30.50175, long -88.17647). The monitored site is at the Half Mile Road crossing, about 4,500 ft from its confluence with Fowl River. The watershed upstream from site FR3 covers 1.1 mi^2.

Site FR4 is on Muddy Creek at the Laurendine Road crossing (lat 30.50193, long -88.15719). Muddy Creek has its headwaters in the town of Theodore, where it drains the southern part of the urban area. The stream flows southward and eventually discharges into Fowl River, about 2.8 mi downstream from the monitoring site at the Half Mile Road crossing (lat 30.50175, long -88.17647). The watershed upstream from site FR4 covers 5.9 mi^2.

Site FR5 is on an unnamed tributary flowing southeastward in the west-central part of the Fowl River watershed (lat 30.46869, long -88.16890). The monitored site is at the Bellingrath Road crossing, about 2,200 ft from its confluence with Fowl River. The watershed upstream from site FR5 covers 4.0 mi^2.

Site FR6 is on Dykes Creek at the Fowl River Road crossing (lat 30.47238, long -88.14655). Dykes Creek forms the eastern boundary of the Fowl River watershed and flows southward to its confluence with Fowl River about 3,000 ft downstream from site FR6. The watershed upstream from site FR6 covers 4.2 mi^2.

Site FR7 is on an unnamed tributary flowing northeastward in the west-central part of the Fowl River watershed (lat 30.45633, long -88.16855). The monitored site is at the Bellingrath Road crossing, about 1.2 mi from its confluence with Fowl River. The watershed upstream from site FR7 covers 3.2 mi^2.

Site FR8 is on an unnamed tributary flowing eastward in the southwest part of the Fowl River watershed (lat 30.42883, long -88.14466). The monitored site is at the Rebel Road crossing, about 3,000 ft from its confluence with East Fowl River. The watershed upstream from site FR8 covers 0.5 mi^2.

Site FR9 is on East Fowl River at the Rebel Road crossing (lat 30.40863, long -88.14247). The monitored site is about 2.0 mi from its confluence with Fowl River. The watershed upstream from site FR9 covers 5.1 mi^2.

LAND USE AND STREAM FLOW CONDITIONS

Land use is directly correlated with water quality, hydrologic function, ecosystem health, biodiversity, and the integrity of streams and wetlands. Land use classification for the project area was calculated from the U.S. Department of Agriculture (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). Land use in the project area was subdivided into six classified groups defined as developed, forested, agricultural, grassland/shrub/scrub, wetlands, and open water (fig. 2).

The dominant land use category in the Fowl River project area is herbaceous and woody wetlands (25.6 percent (%) of total land area). Wetlands are important because they provide water quality improvement and management services such as flood abatement, storm water management, water purification, shoreline stabilization, groundwater recharge, and streamflow maintenance. The second largest land use category

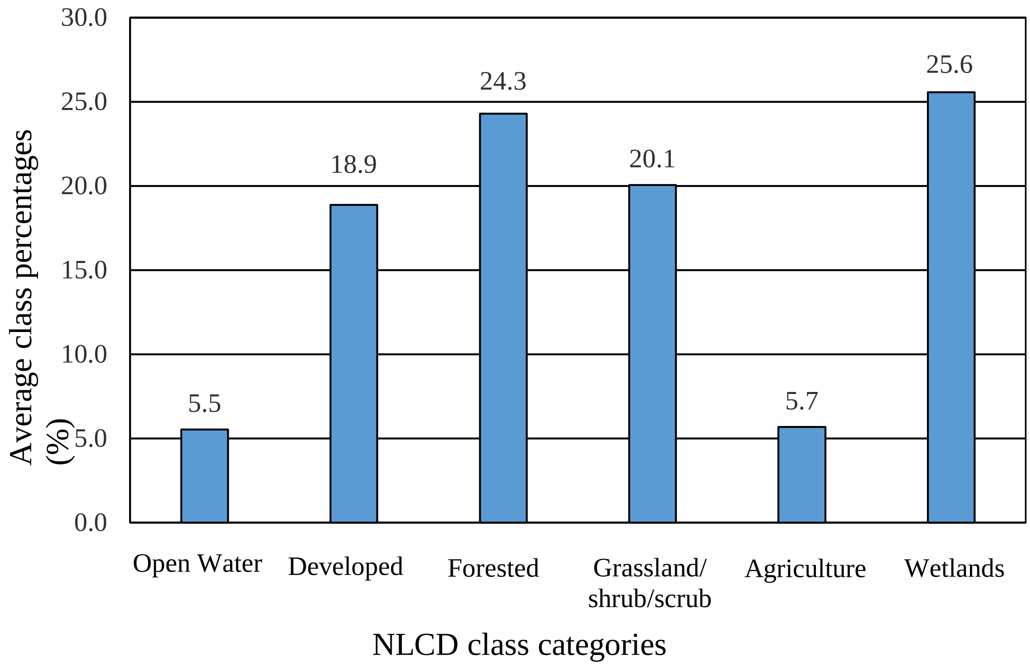

Figure 2.—Land-use classifications for the Fowl River project area.

is evergreen and mixed forest (24.3%). The third most common land use category is grassland/shrub/scrub (20.1%). This category is composed of fallow and idle cropland, grassland and pasture land, hay, and shrubland. The next most abundant category is developed land (18.9%), which includes part of the town of Theodore and the Interstate 10 and U.S. Highway 90 corridors. There are clusters of residential growth in the headwaters of Fowl River as well as a large industrial site along the eastern perimeter of the watershed. Agriculture accounts for 5.7% of the land use in the watershed and consists of peanuts, soybeans, corn, cotton, pecans, winter wheat, and a variety of double crops. Open water covers 5.5% of total land area, consisting of small lakes and ponds, Mobile Bay, East Fowl River, and Fowl River. Land use is shown on plate 3. Land uses for individual tributary watersheds and their impacts are discussed in various following sections of the report.

Unlike streams in Baldwin County, which are extremely flashy due to relatively high topographic relief and land-use change, or streams in the Dog River watershed that are also extremely flashy with relatively high velocities due to channelization and urbanization, the character of stream flows in Fowl River and its tributaries are relatively unimpacted by man and are primarily influenced by relatively low topographic relief, extensive wetlands, vegetation (anastomosing conditions), and tidal effects. The average gradient for streams in the Dog River watershed is 48.0 feet per mile (ft/mi) as compared to the Fowl River watershed, which is 10.3 ft/mi. The average flow velocity for Dog River sites was 2.1 feet per second (ft/s). Relatively small stream gradients for Fowl River streams are reflected in lower stream flow velocities, which averaged 0.7 ft/s (table 1).

A wide range of discharge events is required to adequately evaluate hydrologic conditions in Fowl River. Table 1 shows that sampling occurred in the Fowl River watershed during discharge conditions from base flow to flood. For example, the minimum discharge measured for Fowl River at Half Mile Road (site FR2) was 18 cubic feet per second (cfs) (September 28, 2014) and the maximum was 2,040 cfs, measured during an overbank flood on April 13, 2015. Average daily discharge for each monitored stream is also required to adequately assess constituent loading. Discharge data collected at site FR2 (U.S. Geological Survey (USGS) stream gaging site 02471078, Fowl River at Half Mile Road, near Laurendine, Alabama) was used as a basis for average daily discharge estimation for each monitored stream.

Table 1.--Stream flow characteristics for monitored sites in the Fowl River watershed.

Monitored site	Average discharge (cfs)	Maximum discharge (cfs)	Minimum discharge (cfs)	Average discharge per unit area (cfs/mi)	Average stream flow velocity (ft/s)	Stream gradient (ft/mi)
FR1	48	273	3.5	22.4	0.9	10.0
FR2	314	2,040	18	20.6	n/a	10.3
FR3	22	73	0[1]	19.8	0.4	13.9
FR4	87	604	0[1]	14.8	0.8	7.5
FR5	47	300	4.0	11.8	0.8	13.9
FR6	28	87	TI[2]	10.2	0.6	12.9
FR7	61	130	3.9	18.9	1.0	7.7
FR8	11	30	0[1]	20.4	0.2	12.0
FR9	59	135	TI[2]	11.5	0.6	4.2

[1]0–discharge too low to measure
[2]TI–tidal influence

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 and others, 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 and others, 1995). Turbidity values measured in nephelometric turbidity units (NTU) from water samples may be utilized to formulate a rough estimate of long-term trends of total suspended solids (TSS) measured in milligrams per liter (mg/L). This relationship of turbidity and TSS is observed in figure 3, where average turbidity and TSS values are plotted. Note that the highest average turbidity and TSS values were measured at sites FR3 and FR6.

Analyses of turbidity and stream discharge provide insights into hydrologic, land-use, and general water-quality characteristics of a watershed. Average measured turbidity and discharge, shown in figure 4, illustrates that, generally, monitored sites with the highest average discharge have the lowest average turbidity, which indicates that the

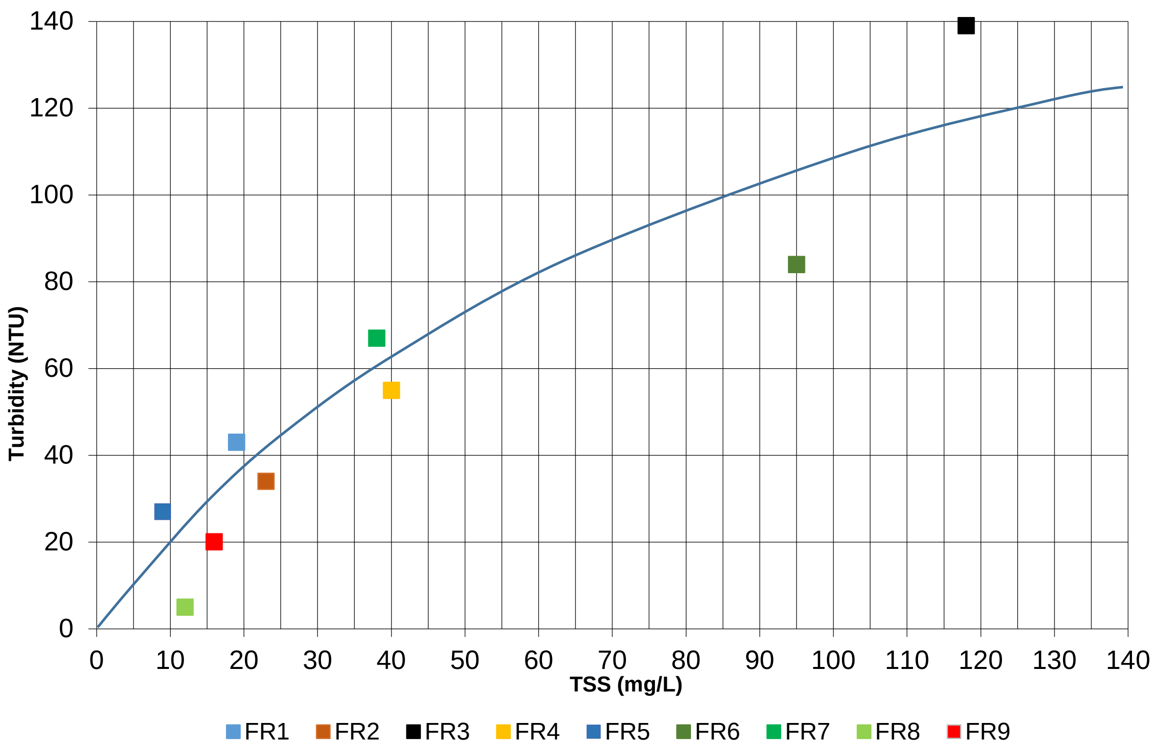

Figure 3.—Regression for average turbidity and TSS for all monitored Fowl River sites.

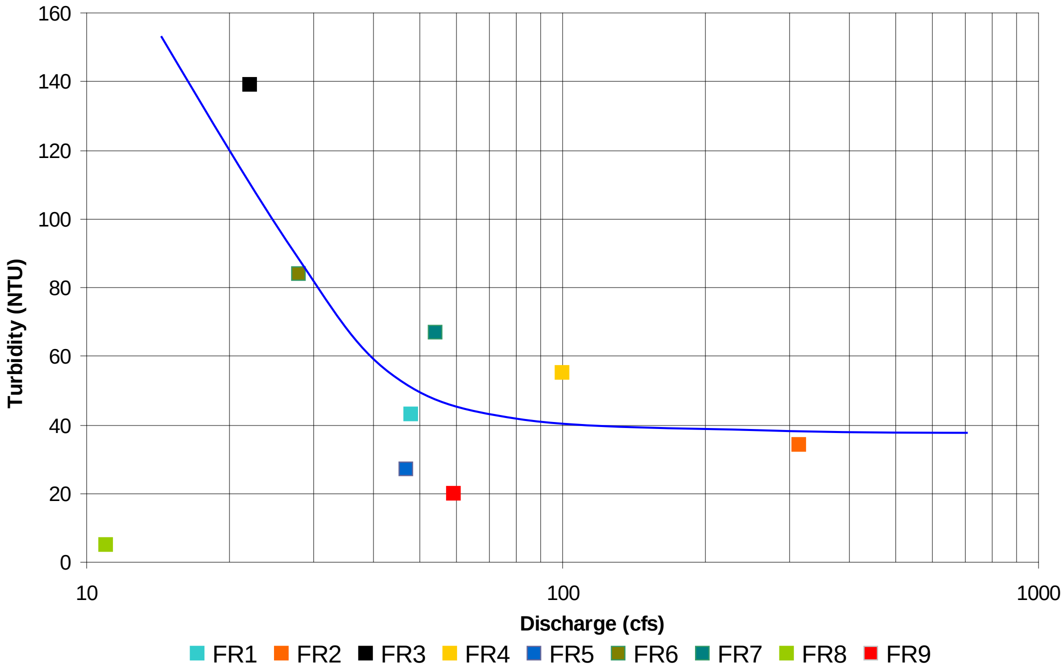

Figure 4.—Regression for average turbidity and discharge for all monitored Fowl River sites.

monitored Fowl River watersheds have limited sources of turbidity so that elevated discharge provides dilution, resulting in relatively low turbidity. Sites FR3 and FR6 have the highest turbidity to discharge ratio (6.3 and 3.0 NTU/cfs, respectively), while site FR2 (Fowl River at Half Mile Road) has the lowest (0.1 NTU/cfs) (fig. 4).

The shape of turbidity and discharge curves are also useful in assessing watershed characteristics that impact water quality and habitats. For example, figure 5 illustrates the most commonly observed curve (positive correlation) of increasing turbidity with increasing discharge. The curve for site FR2 (Fowl River at Half Mile Road) shows rapidly increasing turbidity during the first flush, followed by a slowing of the rate of turbidity increase as discharge continues to increase. Figure 5 shows that turbidity increases at a rate of 50 NTU/100 cfs for the discharge range of 0 to 100 cfs. The second phase shows a rate of 6 NTU/100 cfs for the discharge range of 100 to 500 cfs and a third phase with a rate of 0.7 NTU/100 cfs for the discharge range of 500 to 2,200 cfs. This

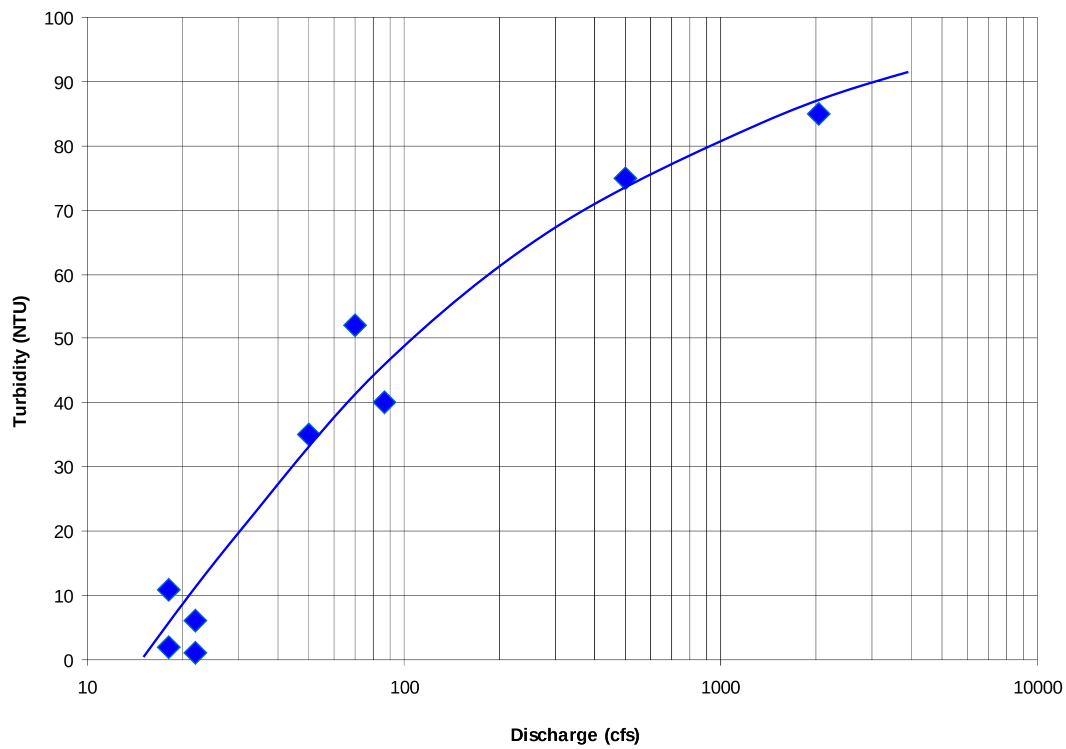

Figure 5.—Regression with positive correlation for measured turbidity and discharge for site FR2 (Fowl River at Half Mile Road).

curve shape indicates local sources of turbidity followed by upstream discharge with limited sources of turbidity, or a limited source of turbidity in the monitored watershed that is diluted with relatively low turbidity runoff as discharge increases.

A second type of curve illustrates rapidly increasing turbidity during the first flush followed by decreasing turbidity as discharge continues to increase (fig. 6). Site FR1 (unnamed tributary to Fowl River at Half Mile Road) has increasing turbidity at a rate of 1.6 NTU/cfs for a discharge range of 0 to 50 cfs followed by decreasing turbidity at a rate of 0.15 NTU/cfs for a discharge range of 50 to 300 cfs (fig. 6). This characterizes a watershed with limited sources for turbidity. Only one large flow event was monitored at site FR1, therefore additional data is needed to confirm the decreasing turbidity limb of the regression curve.

A third type of egression curve illustrates constant turbidity values with increasing discharge. Figure 7 depicts no increase in turbidity for a discharge range of 3

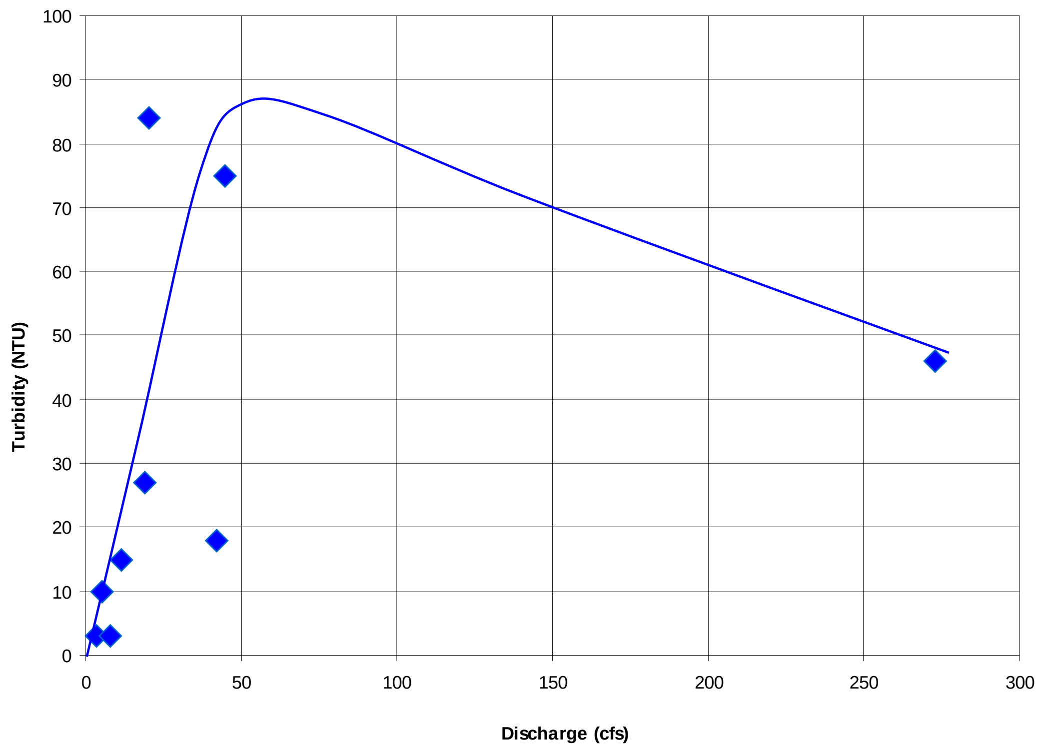

Figure 6.—Regression with positive correlation at low discharge and negative correlation at high discharge for site FR1 (unnamed tributary at Half Mile Road).

to 20 cfs followed by a relatively rapid turbidity increase of 1.5 NTU/cfs for a discharge range of 20 to 30 cfs. This characterizes a watershed with turbidity sources well upstream from the monitoring site or watershed with turbidity sources that require significant discharge to mobilize sediment and other suspended material.

Commonly, excessive turbidity is closely tied to land uses that cause land disturbances that lead to erosion or to land uses that cause excessive runoff. Figures 8 and 9 show correlations between agriculture, wetlands, and turbidity. Figure 8 shows a strong positive correlation between increasing agricultural land percentage and increasing turbidity. Figure 9 shows a strong negative correlation between turbidity and increasing wetland area.

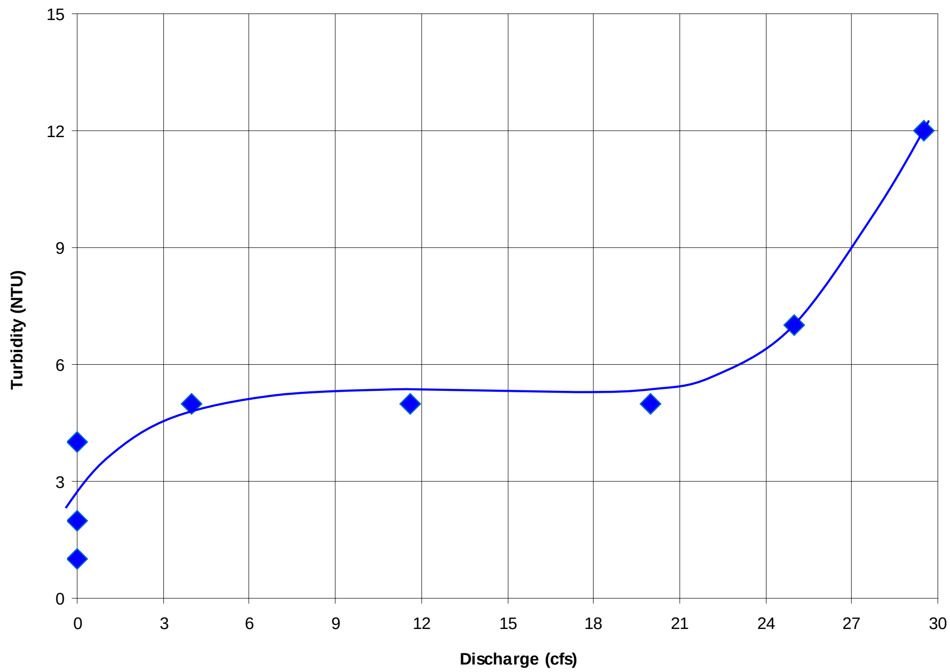

Figure 7.—Regression showing relatively constant turbidity values over the lower 70% of the discharge range and increasing turbidity for the high discharge range for site FR8 (unnamed tributary at Rebel Road).

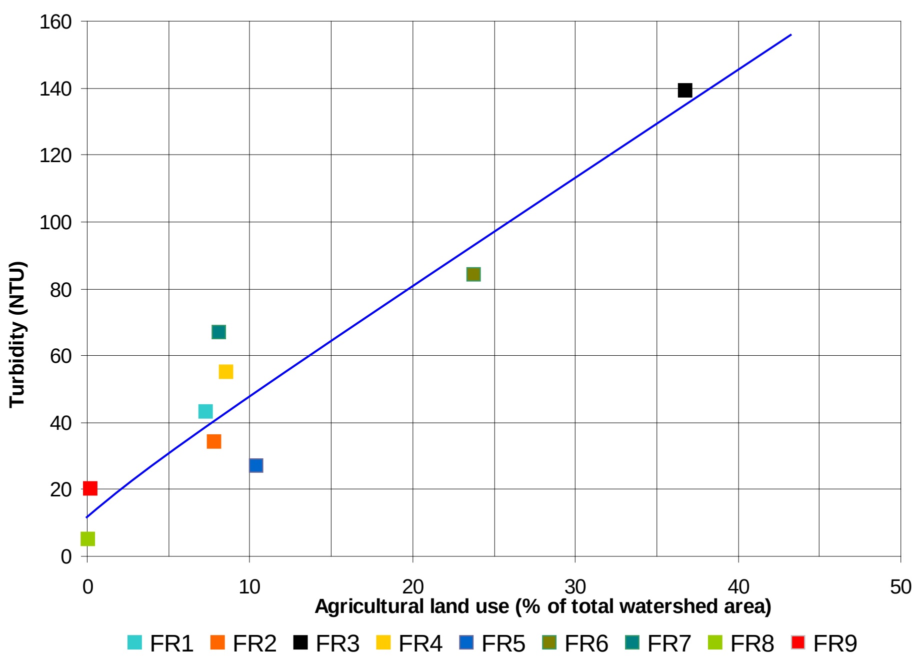

Figure 8.—Average turbidity and agricultural land use for monitored Fowl River sites.

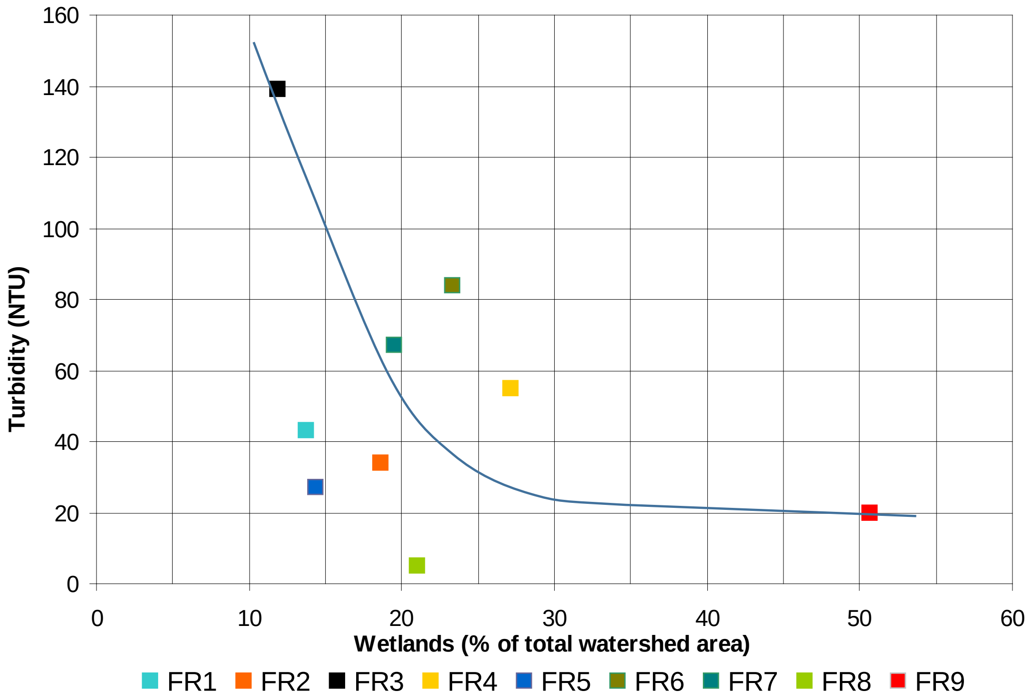

Figure 9.—Average measured turbidity and wetlands at monitored Fowl River sites.

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 water flow with rill and gully development. Lowland or flood plain transport occurs in streams of varying order, where upland sediment joins sediment eroded from flood plains, stream banks, and stream beds. Erosion rates are accelerated by human activity related to agriculture, construction, timber harvesting, unimproved roadways, or any activity where soils or geologic units are exposed or disturbed. Excessive sedimentation is detrimental to water quality, destroys biological habitat, reduces storage volume of water impoundments, impedes the usability of aquatic recreational areas, and causes damage to structures.

Precipitation, stream gradient, geology and soils, and land use are all important factors that influence sediment transport characteristics of streams. Sediment transport conditions in the Fowl River watershed area are evaluated and quantified by tributary, in order to evaluate factors impacting erosion and sediment transport at a localized scale. In addition to commonly observed factors mentioned above, wetlands, vegetation, and tidal effects also play prominent roles in sediment transport and overall water quality. 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. Average observed stream flow conditions are shown in table 1.

Sediment loads in streams are composed of relatively small particles suspended in the water column (suspended solids) and larger particles that move on or periodically near the streambed (bed load). A pre-monitoring assessment of sediment characteristics indicated that relatively little bed sediment was present in the streams at selected Fowl River monitoring sites. Therefore, total sediment loads were assumed to be suspended.

SEDIMENT LOADS TRANSPORTED BY PROJECT STREAMS

The rate of transport of sediment is a complex process controlled by a number of factors related to land use, precipitation runoff, erosion, stream discharge and flow velocity, stream base level, and physical properties of the transported sediment. Highly erodible soils formed from sand, clayey sand, and sandy clay of the undifferentiated Miocene Series, Citronelle Formation, and alluvial, coastal, and low terrace deposits (plate 4), combined with relatively high topographic relief related to the formation of Mobile Bay and land disturbance related to development and agriculture are major contributing factors to high rates of erosion and sedimentation.

Excessive sedimentation causes changes in base level elevation of streams in the watershed and triggers downstream movement of the material as streams reestablish base level equilibrium. Deterrents to excessive erosion and sediment transport include wetlands, forests, vegetative cover and field buffers for croplands, limitations on impervious surfaces, and a number of constructed features to promote infiltration of precipitation and to store and slow runoff. Currently, the East Fowl River and upper Fowl River watersheds maintain a relatively healthy hydrologic environment characterized by a relatively rural setting, minimal row crop agriculture, low topographic relief, abundant wetlands, and anastomosing and natural stream channels.

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 3 shows that turbidity and suspended sediment are closely related in the Fowl River watershed. Turbidity, TSS, suspended sediment loads, and discharge values for all monitoring sites are shown in table 2.

Table 2.—Total suspended solids (TSS) and suspended sediment loads measured in monitored streams.

Monitored site	Average measured discharge (cfs)	Average turbidity (NTU)	Maximum turbidity (NTU)	Average TSS (mg/L)	Maximum TSS (mg/L)	Estimated suspended sediment load (t/yr)	Estimated normalized suspended sediment load ($t/mi^2/yr$)
FR1	48	43	84	19	75	251	117
FR2	314	34	85	23	108	795	52
FR3	22	139	740	118	446	336	303
FR4	87	55	182	40	121	414	70
FR5	47	27	56	9	19	256	64
FR6	28	84	255	95	300	1,139	271
FR7	61	67	147	38	134	415	128
FR8	11	5	12	12	42	34	63
FR9	59	20	37	16	55	412	80

Annual suspended sediment loads were estimated for Fowl River monitored streams using the computer regression model Regr_Cntr.xls (*Regression with Centering*) (Richards, 1999). The program is an Excel adaptation of the USGS seven-parameter regression model for load estimation in perennial streams (Cohn and others, 1992). The regression with centering program requires 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 eight of nine Fowl River monitored sites, it was estimated by establishing a ratio between periodic measured discharge in project streams and discharge values for the same times obtained from site FR2, which is also a USGS stream gaging site (02471078, Fowl River at Half Mile Road, near Laurendine, Alabama).

Concentrations of TSS in mg/L were determined by laboratory analysis of periodic water grab samples. These results were used to estimate the mass of TSS for the period of stream flow (May 1, 2014 through April 30, 2015). Sites FR6 (Dykes Creek at Fowl River Road), FR2 (Fowl River at Half Mile Road) and FR7 (unnamed tributary at Bellingrath Road) had the largest suspended sediment loads with 1,139, 795, and 415 tons per year (t/yr), respectively (table 2, fig. 10). For comparison, the largest suspended sediment loads in the Dog River watershed were Eslave Creek, Spencer Branch, and Spring Creek (sites 10, 7, and 2) with 10,803, 5,970, and 5,198 t/yr, respectively (Cook and Moss, 2012). The smallest loads were at sites FR8 (unnamed tributary at Rebel Road), FR5 (unnamed tributary at Bellingrath Road) and FR3 (unnamed tributary at Half Mile Road) with 34, 256, and 336 t/yr, respectively (table 2, fig. 10).

Discharge and watershed area are two of the primary factors that influence sediment transport rates in the Fowl River watershed. Figure 11 depicts average annual daily discharge (calculated from discharge estimates based on average daily discharge measured at the Fowl River at Half Mile Road USGS gage station for the period May 1, 2014 to April 30, 2015) and estimated suspended sediment loads and shows that, generally, increased discharge results in increased suspended sediment loads.

Normalizing suspended sediment loads to unit watershed area permits comparison of monitored watersheds and lessens the influence of drainage area size and discharge on sediment loads. Sites FR3 (unnamed tributary at Half Mile Road), FR6 (Dykes Creek at

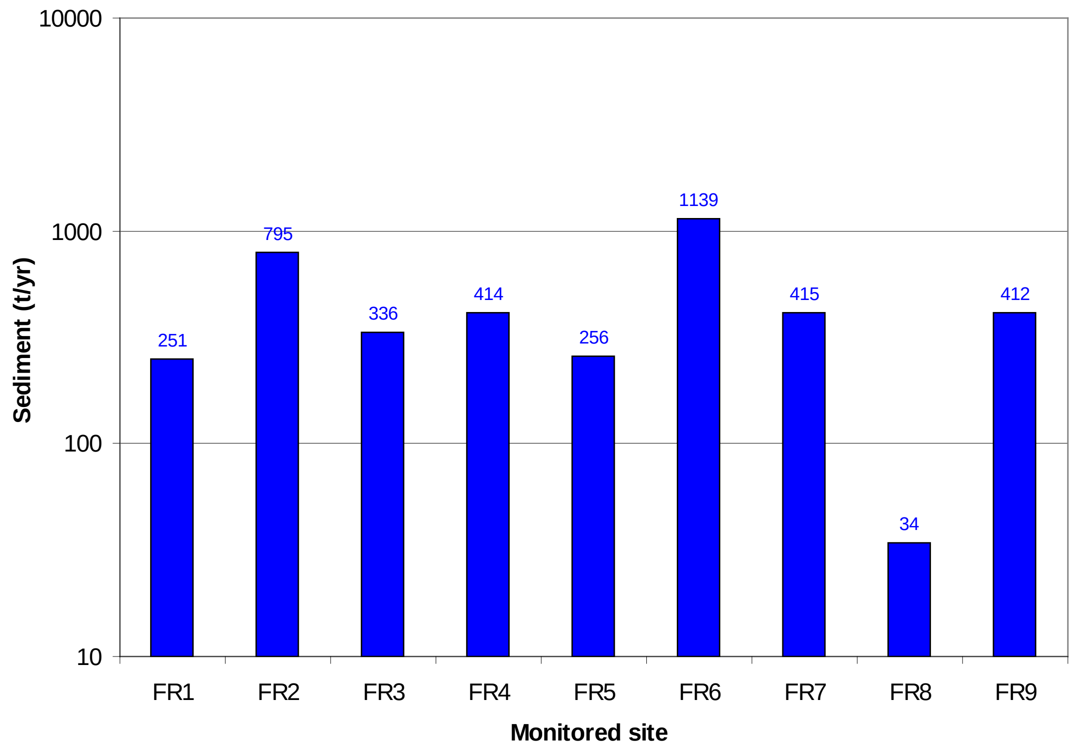

Figure 10.—Estimated suspended sediment loads for monitored Fowl River sites.

Fowl River Road, and FR7 (unnamed tributary at Bellingrath Road) had the largest normalized loads with 303 and 271, and 128 tons per square mile per year (t/mi^2/yr), respectively (table 2). For comparison, the largest normalized suspended sediment loads in the Dog River watershed were Spencer Branch, Spring Creek, and Eslava Creek (sites 2, 7, 10) with 4,332 and 2,985, and 1,662 t/mi^2/yr, respectively (Cook and Moss, 2012). Figure 12 consists of normalized suspended sediment loads and average annual daily discharge and depicts a negative correlation, indicating that when normalized suspended sediment loads are compared to monitored watershed area, then land use and hydrologic characteristics, not area, are the controlling factors that determine sediment load transport in the Fowl River watershed. However, site FR8 does not conform to the regression curve for normalized suspended sediment and discharge (fig. 12). This is most likely due to transport of the vast majority of sediment during a few large discharge events as shown on figure 7 where minimal turbidity was measured except during the largest discharge events.

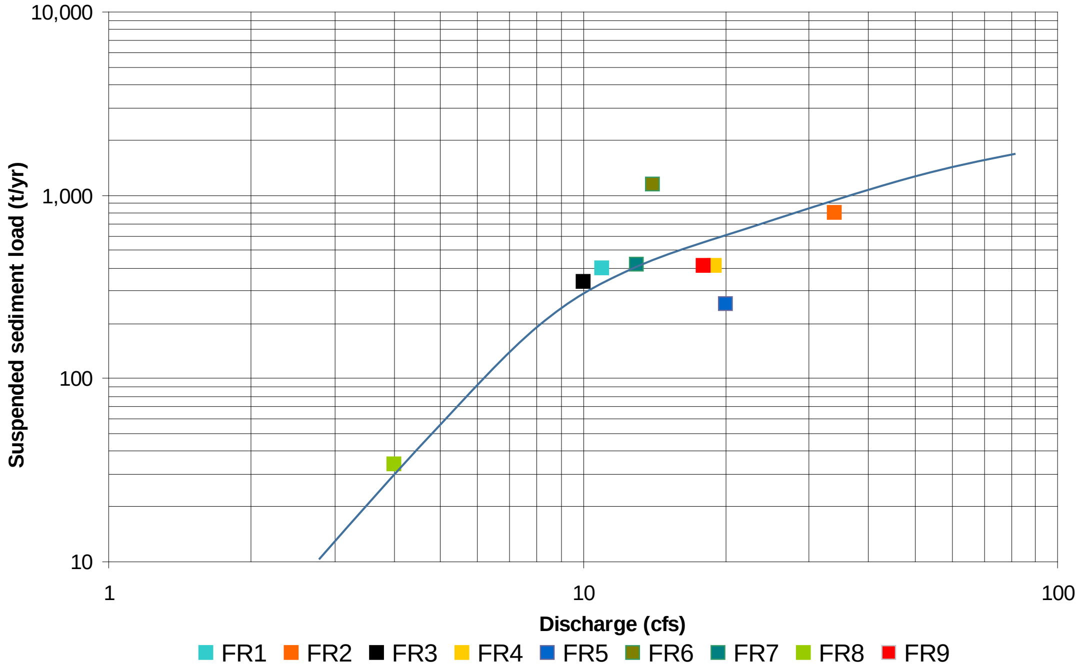

Figure 11.—Average annual daily discharge and suspended sediment loads for monitored Fowl River sites.

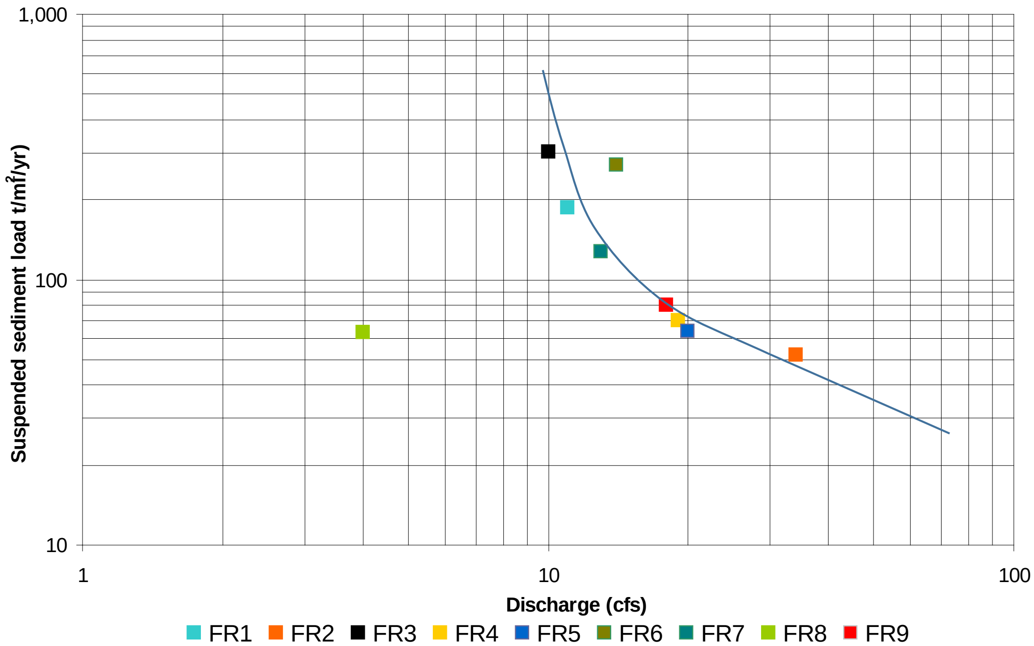

Figure 12.—Average annual daily discharge and normalized suspended sediment loads for monitored Fowl River sites.

BED SEDIMENT

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

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

Due to a number of factors, including relatively small areas of development or land disturbance, limited sources of coarse-grained sediment, relatively low stream gradients and stream flow velocities, and extensive wetlands that slow stream flow velocities and detain sediment, all monitored streams had bed sediment loads that were too small to measure. Therefore, all sediment loads are assumed to be suspended.

TOTAL SEDIMENT LOADS

Without human impact, erosion rates in the watershed, called the geologic erosion rate, would be 64 t/mi^2/yr (Maidment, 1993). Normalized sediment loads for sites FR2 (Fowl River at Half Mile Road), FR8 (unnamed tributary at Rebel Road), and FR5 (unnamed tributary at Bellingrath Road) were at or below the geologic erosion rate. Calculated non-normalized geologic erosion rate loads are compared to total estimated loads in figure 13.

Comparisons of sediment loads from other watersheds are helpful in determining the severity of erosion problems in a watershed of interest. Estimates of total sediment loads from Dog River site 2 (Spencer Branch at Cottage Hill Road in the city of Mobile) (Cook and Moss, 2012), D'Olive Creek site 3 (D'Olive Creek at U.S. Highway 90 in Daphne) (Cook and Moss, 2008), Tiawasee Creek site 7 (Tiawasee Creek upstream from Lake Forest) (Cook and Moss, 2008), in Baldwin County, Joes Branch site 10 (at North Main Street in Daphne) (Cook and Moss, 2008), Magnolia River site 4 (at U.S. Highway 98) (Cook and others, 2009), and Bon Secour River site 3 (County Road 12 in Foley) (Cook and others, 2014) are compared to Fowl River monitored sites in figure 14. GSA has now estimated sediment loads for more than 60 streams in Alabama. Figure 14 compares the total sediment load estimated for Fowl River with loads from other selected streams throughout Alabama and shows that Fowl River sediment loads are among the smallest of any monitored watershed in the state.

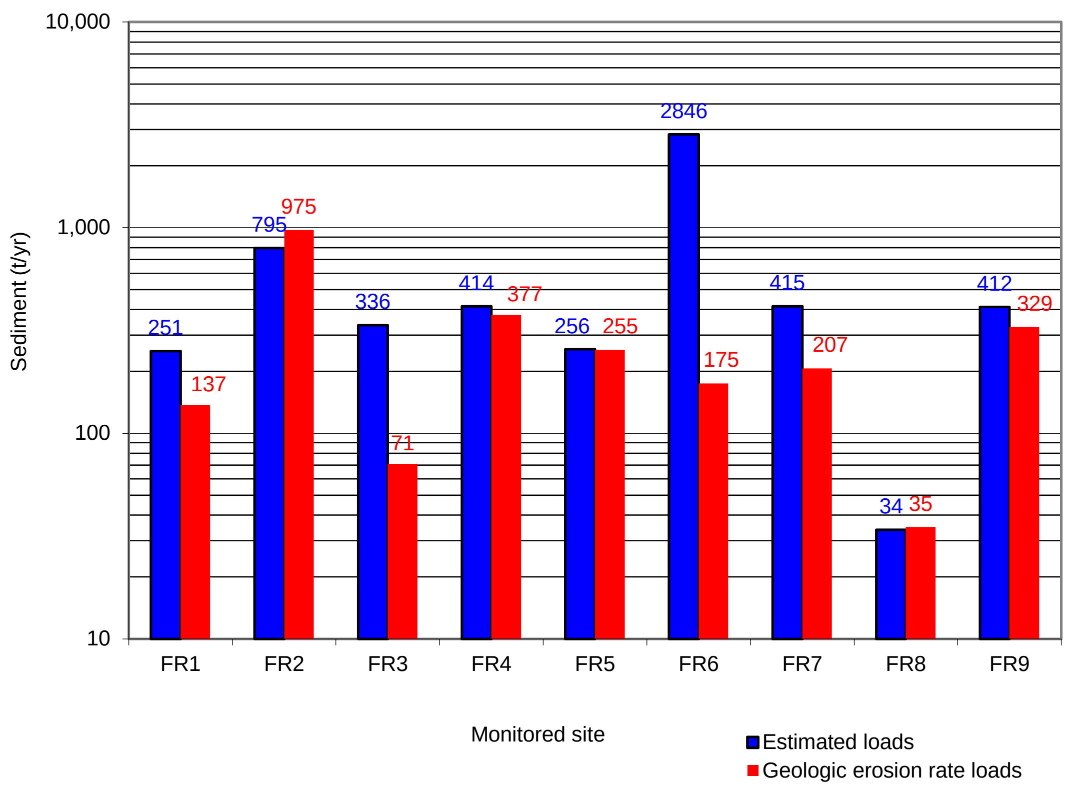

Figure 13.—Estimated sediment loads and calculated geologic erosion rate loads for monitored Fowl River sites.

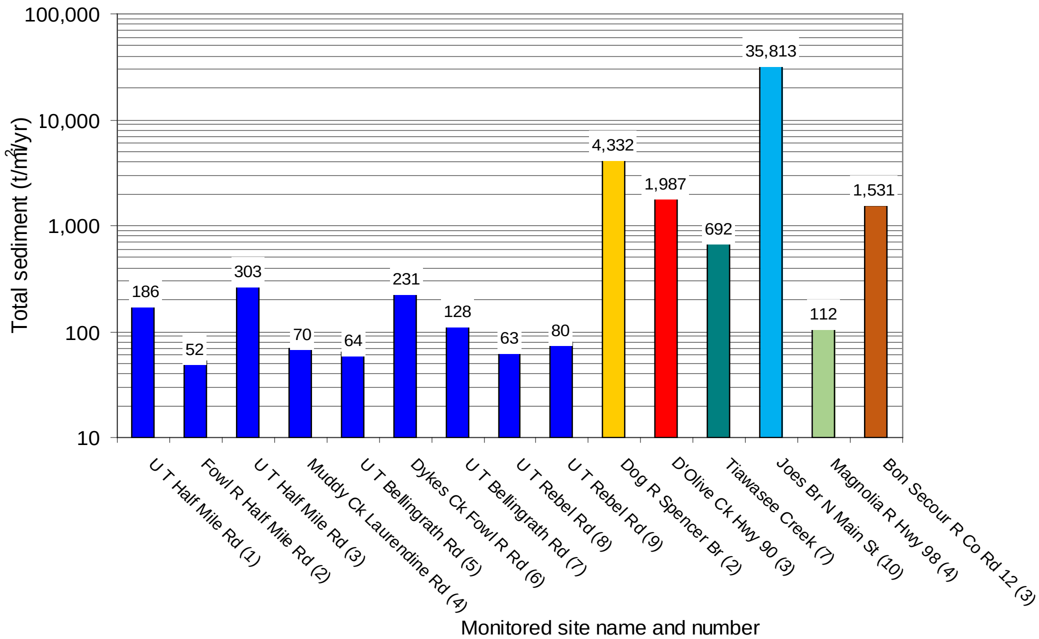

Figure 14.—Comparisons of normalized estimated sediment loads for selected Baldwin and Mobile County and monitored Fowl River sites.

GEOCHEMICAL ASSESSMENT

An assessment of geochemical constituents was performed from grab samples collected during a low flow period (Sept. 28, 2014) and a high flow event (Mar. 10, 2015). Although not comprehensive, this assessment is meant to provide a synoptic view of water quality conditions related to nutrients, metals, and limited organic constituents. A review of the Alabama Department of Environmental Management (ADEM) (Woods, 2006) water quality assessment of Fowl River, Muddy Creek and East Fowl River from October 2004 to September 2006 reveals that five of seven monitored sites were in tidally influenced parts of the watershed. ADEM site FLR1 near the headwaters of Fowl River at Pascagoula Road and FLR2 on Muddy Creek at Laurendine Road (GSA site FR4) were the only monitored sites upstream from tidal influence. The sites were sampled monthly and no discharge was measured, although visual observations by ADEM field personnel and turbidity data indicate that most samples were collected during times of low flow. Therefore, the ADEM data has little utility to supplement or for comparison with GSA data. However, ADEM dissolved oxygen, bacteria, and sediment geochemical analyses may be useful in assessing the biological health and possible industrial impacts on Fowl River.

NUTRIENTS

Excessive nutrient enrichment is a major cause of water-quality impairment. Excessive concentrations of nutrients, primarily nitrogen and phosphorus, in the aquatic environment may 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. 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 evaluated during this study were nitrate (NO_3-N) and phosphorus (P-total).

NITRATE

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

Water samples were collected from low and high flow events for all Fowl River sites during the monitoring period. The critical nitrate concentration in surface water for excessive algae growth is 0.5 mg/L (Maidment, 1993). The 0.5 mg/L nitrate level was exceeded in the low flow samples at sites FR1 (unnamed tributary at Half Mile Road) (0.62 mg/L), FR2 (Fowl River at Half Mile Road) (0.61 mg/L), and FR9 (East Fowl River at Rebel Road) (1.65 mg/L) (fig. 15). The nitrate concentration at site FR2 is expected since it represents the cumulative impact of land uses for the entire Fowl River watershed upstream from the site. However, excessive concentrations at sites FR1 and

FR9 are surprising since the watershed upstream from site FR1 has relatively little agriculture or development and the East Fowl River watershed upstream from site FR9 has the highest percentage of wetlands (50.7) and one of the lowest percentages of agriculture (0.2) of any monitored watershed. The 0.5 mg/L nitrate criterion was not exceeded in any high flow samples (fig. 15). Lower concentrations of nitrate are common during high flows due to dilution.

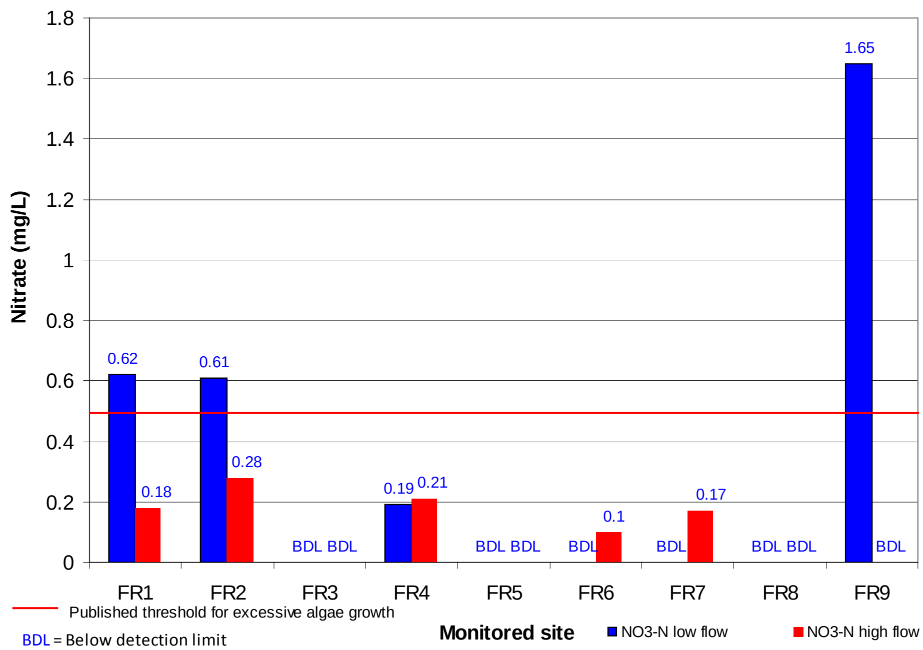

Figure 15.—Measured nitrate concentrations for low and high flow sampled events in monitored Fowl River sites.

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). In many streams phosphorus is the critical nutrient that influences excessive biological activity. These streams are termed "phosphorus limited."

The 0.05 mg/L phosphorus criterion was exceeded in the low flow samples at sites FR3 (unnamed tributary at Half Mile Road) (0.314 mg/L), FR4 (Muddy Creek at Laurendine Road) (0.510 mg/L), FR6 (Dykes Creek at Fowl River Road) (0.077 mg/L), and FR7 (unnamed tributary at Bellingrath Road) (0.129 mg/L) (fig. 16). The 0.05 mg/L phosphorus criterion was exceeded in the high flow samples at sites FR3 (unnamed tributary at Half Mile Road) (0.235 mg/L), FR4 (Muddy Creek at Laurendine Road) (0.140 mg/L), FR5 (unnamed tributary and Bellingrath Road) (0.095 mg/L), and FR7 (unnamed tributary at Bellingrath Road) (1.39 mg/L) (fig. 16). Excessive concentrations of phosphorus may be explained by land use, since the watersheds upstream from sites with samples that exceeded the criterion have the largest percentage of land area in agriculture.

METALLIC CONSTITUENTS

The USEPA compiled national recommended water quality criteria for the protection of aquatic life and human health in surface water for approximately 150 pollutants. These criteria are published pursuant to Section 304(a) of the Clean Water Act (CWA) and provide guidance for states and tribes to use in adopting water quality standards (USEPA, 2009). The criteria were developed for acute (short-term exposure) and chronic (long-term exposure) concentrations.

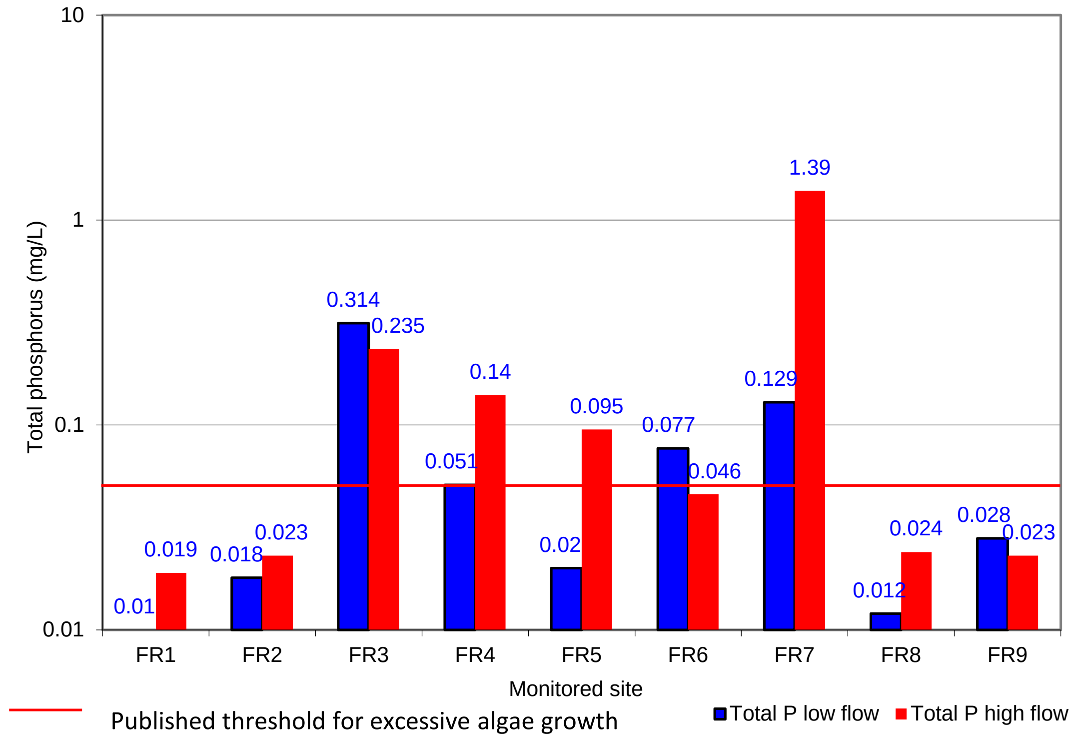

Figure 16.—Measured phosphorus concentrations for low and high flow sampled events in monitored Fowl River sites.

Numerous metals are naturally present in streams in small concentrations. However, toxic metals in Alabama streams, particularly in large concentrations are usually a result of man's activities. Table 3 shows acute and chronic recommended criteria for protection of aquatic life and maximum concentrations measured in analyzed samples collected from monitored sites. Metals detected in water samples are normally a result of the erosion of fine-grained sediments. This is true of relatively large, pervasive concentrations of aluminum and iron observed at all monitored sites (table 3). Generally, the largest concentrations of aluminum occurred during the high flow sampled event, indicating erosion of aluminum-rich clays in sediments in the monitored watersheds. Conversely, the largest iron concentrations occurred during the low flow event, indicating major accumulations of iron hydroxide, the waste product of iron-consuming bacteria present in the monitored streams.

Other metals exceeding the criteria were cadmium at site FR9 and copper and nickel at site FR6. Lead is also pervasive in all monitored watersheds and exceeded the criteria at all sites except FR1 and FR2. Lead is pervasive in streams throughout the

Alabama coastal plain and is thought to originate from atmospheric deposition. However, detection of cadmium and copper are relatively rare and may be from local sources. Although not included in USEPA criteria, barium, manganese, magnesium, and strontium were also detected in most samples. These are common in Alabama streams and are a result of dissolution or erosion of rocks and sediment.

Although not a metallic constituent, pH is included in table 3 due to its importance in the occurrence and solubility of metals. It was consistently low as is common in coastal streams with large organic content, relative to the USEPA criteria in water samples collected in the Fowl River watershed. Another nonmetallic constituent detected in water samples collected at all sites is boron. Although no water quality criteria for boron has been established, concentrations as small as 1 mg/L may be toxic to plant life (Hem, 1985). Boron is naturally associated with igneous rocks and is present in active volcanic areas. In areas without a natural source, it may originate from cleaning wastes and may be present in sewage and industrial wastes (Hem, 1985). Boron was detected in 16 of 18 samples and had a maximum concentration of 1.2 mg/L at site FR9.

ORGANIC CONSTITUENTS

Organic compounds are commonly used in our society today. Frequently, these compounds appear in streams and groundwater aquifers. Many of these compounds are harmful to human health and to the health of the aquatic environment. Selected organic constituents including total organic carbon, phenols, and oil and grease were analyzed from samples collected at Fowl River sites in order to make a general determination of the presence of organic anthropogenic contaminants in the watershed.

Total organic carbon (TOC) analysis is a well-defined and commonly used methodology that measures the carbon content of dissolved and particulate organic matter present in water. Many water utilities monitor TOC to determine raw water quality or to evaluate the effectiveness of processes designed to remove organic carbon. Some wastewater utilities also employ TOC analysis to monitor the efficiency of the treatment process. In addition to these uses for TOC monitoring, measuring changes in TOC concentrations can be an effective surrogate for detecting contamination from organic compounds (e.g., petrochemicals, solvents, pesticides). Thus, while TOC analysis does not give specific information about the nature of the threat, identifying changes in TOC

Table 3.—Metallic constituent concentrations related to USEPA standards for protection of aquatic life.

Metallic constituent	USEPA standards for protection of aquatic life (µg/L[a])		Maximum concentrations (µg/L)			
	Acute	Chronic	FR1	FR2	FR3	FR4
Aluminum	750.0	87.0	482.00	171.00	259.00	304.00
Arsenic	340.0	150.0	1.00	1.10	2.97	1.47
Cadmium	2.0	0.3	<0.1[b]	<0.1	<0.1	<0.1
Chromium (Cr_3)[c]	570.0	74.0	<0.3	<0.3	<0.3	<0.3
Copper	4.7	n/a	<8.0	<8.0	<8.0	<8.0
Cyanide	22.0	0	<0.003	<0.003	<0.003	<0.003
Iron	n/a	176	170.0	311.0	790.0	592.0
Lead	65.0	4.47	2.14	2.29	24.70	4.62
Mercury	1.4	0.8	0.065	0.005	0.008	0.007
Nickel	470.0	52.0	<10.0	<10.0	<10.0	<10.0
Selenium	n/a	5.0	<0.5	<0.5	<0.5	<0.5
Silver	3.2	n/a	<10.0	<10.0	<10.0	<10.0
Zinc	120.0	120.0	31.1	21.9	40.8	31.4
pH range	n/a	6.5-9.0	4.5-6.1	4.9-6.2	5.0-5.7	4.9-5.8

Metallic constituent	USEPA standards for protection of aquatic life (µg/L[a])		Maximum concentrations (µg/L)				
	Acute	Chronic	FR5	FR6	FR7	FR8	FR9
Aluminum	750.0	87.0	552.00	570.00	419.00	217.00	403.00
Arsenic	340.0	150.0	1.27	2.30	1.69	0.35	0.55
Cadmium	2.0	0.3	<0.1	<0.1	0.24	<0.1	1.7
Chromium (Cr_3)	570.0	74.0	2.65	<0.3	<0.3	<0.3	1.12
Copper	4.7	n/a	<8.0	11.0	<8.0	<8.0	<8.0
Cyanide	22.0	n/a	0.06	<0.003	<0.003	<0.003	<0.003
Iron	n/a	176	540.0	1,140.0	286.0	596.0	252.0
Lead	65.0	4.47	5.71	5.85	168.00	10.40	24.40
Mercury	1.4	0.8	0.054	<0.005	<0.005	<0.005	<0.005
Nickel	470.0	52.0	23	118	25	<10.0	20
Selenium	n/a	5.0	<0.5	<0.5	0.80	1.60	<0.5
Silver	3.2	n/a	<10.0	<10.0	10	<10.0	13
Zinc	120.0	120.0	83.9	52.7	36.3	52.9	36.6
pH range	n/a	6.5-9.0	3.9-6.2	4.4-6.5	3.8-6.5	4.2-6.2	4.2-5.9

[a] µg/L = micrograms per liter.
[b] < 0.1= below lower limit of detection.
[c] Chromium reported as total chromium and is assumed to be primarily Cr_3.

can be a good indicator of potential threats to a hydrologic system (USEPA, 2005). Typical TOC values for natural waters vary from 1 to 10 mg/L (Mays, 1996). Concentrations of TOC exceeded 10 mg/L at every site except FR2 and FR8 during high flow conditions and was exceeded at sites FR3, FR5, and FR7 during low flow conditions. The largest concentration (46.4 mg/L) was measured at site FR7, which occurred during low flow conditions (fig. 17). Pervasive, elevated TOC concentrations are normally related to contaminated urban runoff. However, land use in the Fowl River monitored watersheds does not support this conclusion.

Phenols are used in the production of phenolic resins, germicides, herbicides, fungicides, pharmaceuticals, dyes, plastics, and explosives (Bevans and others, 1998). They may occur in domestic and industrial wastewaters, natural waters, and potable water supplies. The USEPA water quality criterion states that phenols should be limited to 10,400 micrograms per liter (µg/L) (10.4 mg/L) in lakes and streams to protect humans from the possible harmful effects of exposure (USEPA, 2009). Phenols cause acute and

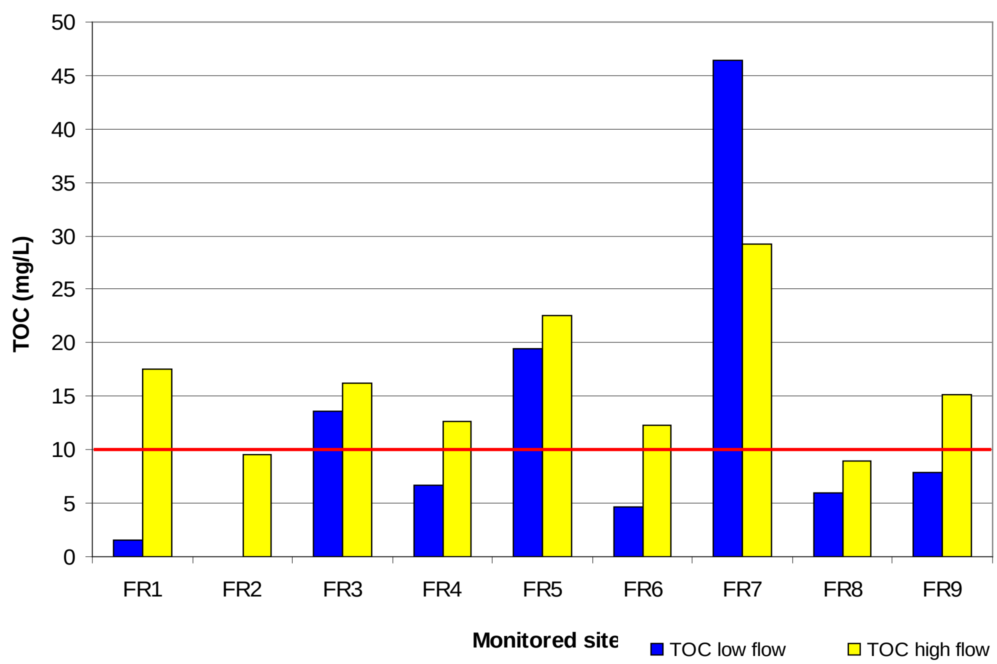

Figure 17.—Concentrations of TOC measured at monitored Fowl River sites for low and high flow events

chronic toxicity to freshwater aquatic life. Phenols were detected in 3 of 18 samples, with the largest concentration (5.2 mg/L) measured at sites FR3 and FR7.

Oil and grease includes fatty matter from animal and vegetable sources and from hydrocarbons of petroleum origin and are normally associated with urban runoff. Oil and grease was not detected in any samples.

SOURCES OF WATER-QUALITY IMPACTS

Evaluations of sediment loads, water-quality analyses, land-use data, and aerial imagery led to conclusions of probable sources of water quality and habitat impairments in the Fowl River watershed. Sites FR3 (unnamed tributary at Half Mile Road) and FR6 (Dykes Creek at Fowl River Road) had the largest sediment loads (303 and 271 t/mi^2/yr, respectively) and the largest percentages of agricultural land use (36.8 and 23.8 %, respectively). Samples collected at these sites in December 2014 and January 2015, had the largest turbidity values measured during the project period (fig. 4). Observations recorded during sampling noted that fields used for row crop agriculture upstream from site FR3 were bare and that rainfall and runoff were intense. Google Earth imagery from January 2015 shows bare fields upstream from site FR3 (fig. 18). Channelized field drainage with no vegetative buffers was also observed on January 2015, Google Earth

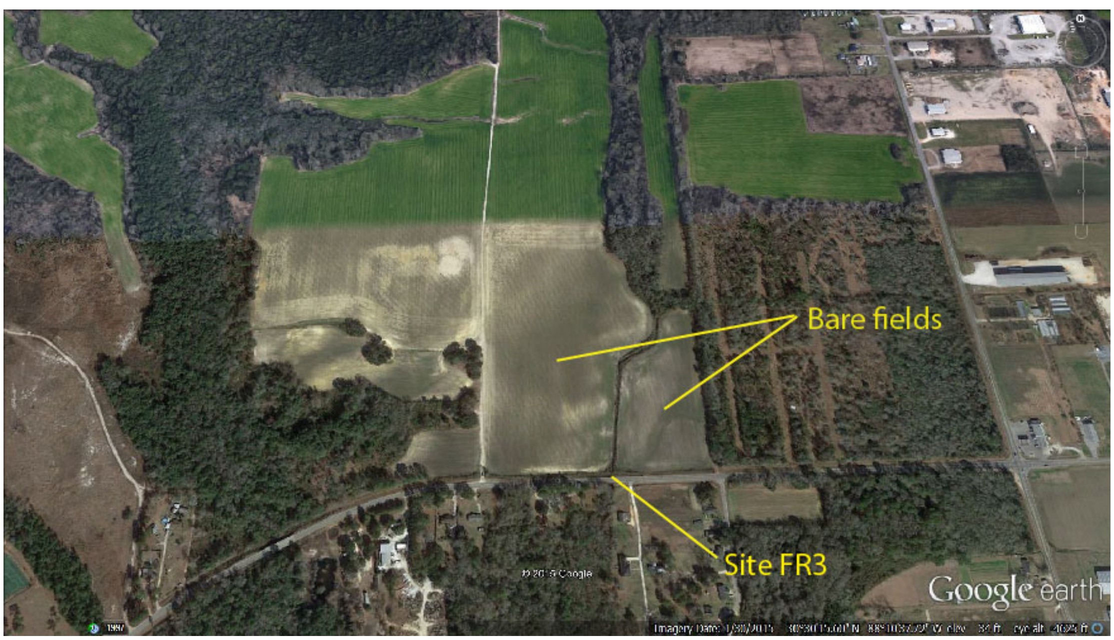

Figure 18.—Google Earth image (January 2015) showing bare fields near Fowl River site FR3.

imagery, along an unnamed tributary along the eastern margin of the Dykes Creek watershed, upstream from site FR6 (fig. 19). Although the largest percentage of land use in the Dykes Creek watershed is classified as forest, an evaluation of January 2015 Google Earth (2015) imagery indicates that much of the forest was recently clear cut, providing additional opportunities for increased runoff and erosion.

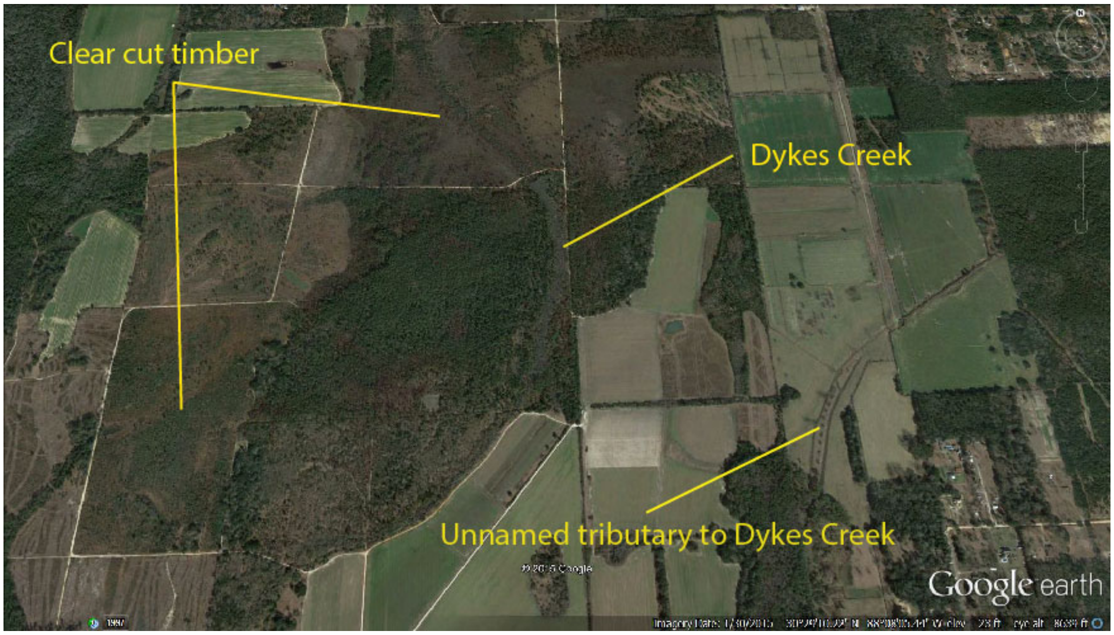

Figure 19.—Google Earth image (January 2015) showing channelized agricultural drainage and clear cut timber land in the Dykes Creek watershed, upstream from Fowl River site FR6.

Figure 15 shows that sites FR1, FR2, and FR9 had nitrate concentrations in excess of the 0.5 mg/L criteria for excessive algae growth. This is expected for site FR2 (Fowl River at Half Mile Road), due to the cumulative volume of nitrate from this relatively large watershed. An evaluation of January 2015 Google Earth imagery indicates that site FR1 (unnamed tributary at Half Mile Road) has a large complex of greenhouses just upstream from the site along with some row crop agriculture and several residential areas (Google Earth, 2015) (fig. 20). Site FR9 (East Fowl River at Rebel Road) has several natural gas processing plants along the southern perimeter of the watershed on Rock Road. Also, there is a large area of clear cut forest in the watershed. A recent study by the

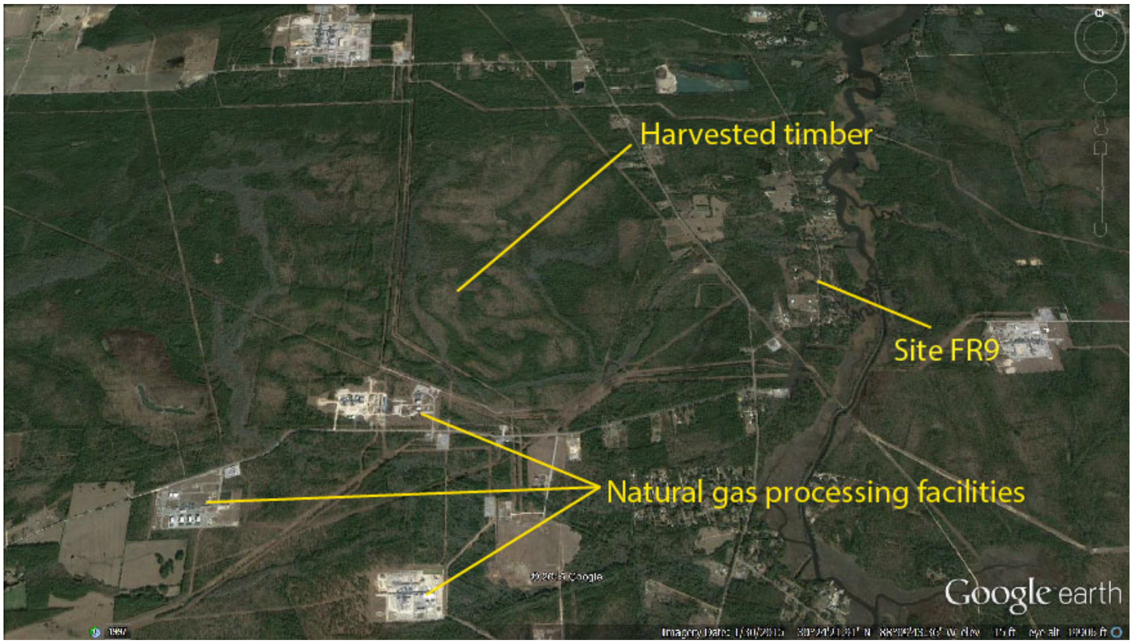

Figure 20.—Google Earth image (January 2015) showing the East Fowl River watershed, Fowl River site FR9, natural gas processing facilities, and areas of harvested timber.

State University of New York found that streams in areas of harvested timber contain significantly more nitrate than streams in non-harvested forests. The source of the nitrate is from shallow groundwater due to a number of factors including increased precipitation infiltration and soil saturation, increased soil temperature, and increased microbial activity (Golden, 2015). This is likely occurring in the monitored Fowl River sites with significant recent timber harvesting, since all excessive nitrate concentrations occurred during base flow conditions where the source of stream flow was from shallow groundwater.

Figures 16 and 17 show that the watershed upstream from site FR7 had the highest phosphorus and TOC concentrations. Although the headwaters are forested, row crop agriculture and a major plant nursery operation dominate land use immediately upstream from the monitoring site (Google Earth, 2015) (fig. 21).

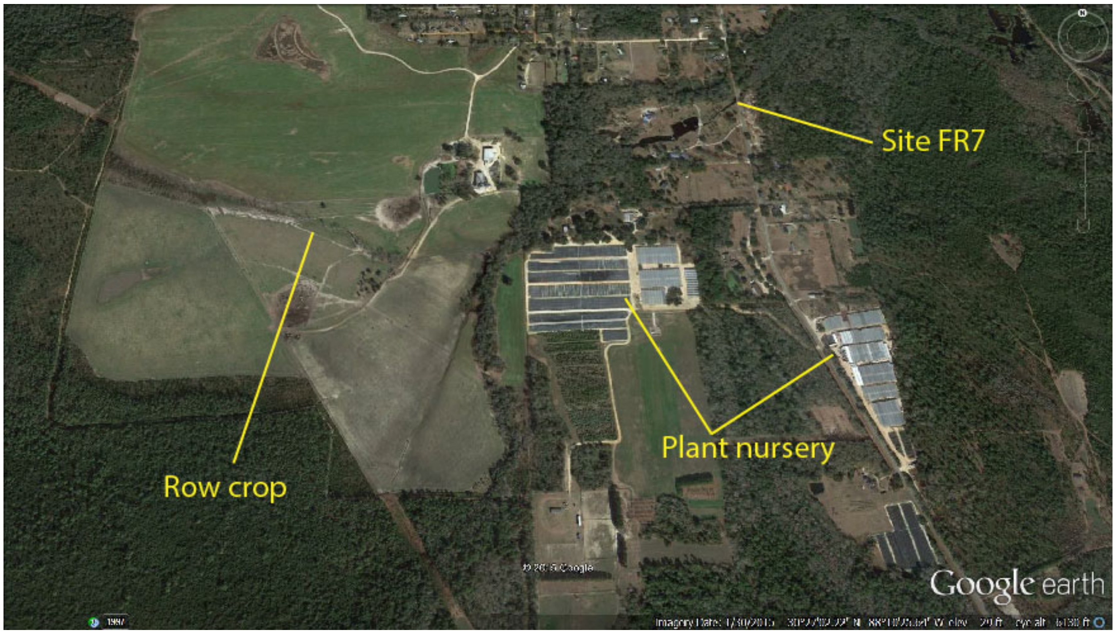

Figure 21.-- Google Earth image (January 2015) showing Fowl River site FR7, plant nursery facilities, and areas of row crop agriculture.

All metals listed on the USEPA list for protection of aquatic life were detected at Fowl River monitoring sites (table 3). A number of these metals are known to be naturally occurring. However, cadmium, chromium, copper, lead, mercury, nickel, selenium, and silver were detected in relatively small concentrations during the GSA assessment and are normally of anthropogenic origin in Alabama streams (table 3). Fowl River is currently on the ADEM 303(d) list for impairment by atmospheric deposition of mercury. Stream sediment samples were collected and analyzed for toxic metals during the ADEM water-quality assessment of Fowl River (Woods, 2006). Results revealed the pervasive nature of these metals with increasing concentrations from upstream to downstream. However, all detected metals were in relatively small concentrations. Regular sampling and analyses of streams in the Fowl River watershed should be conducted to monitor any changes in distribution and concentration.

At least six sand mining operations were identified in the headwaters of Fowl River. No direct impacts were observed in sediment or water-quality data. However, this mining activity should be monitored to determine any negative effects in the future.

CONCLUSIONS AND RECOMMENDATIONS

Comparisons of sediment transport rates and water-quality data in watersheds in Baldwin and Mobile Counties indicate that Fowl River has relatively small sediment loads and good water quality. This is attributed to the relatively rural setting, extensive wetlands and forests, and use of winter cover crops on agricultural fields. However, water quality and habitats could be improved and protected for the future by employing best management practices that prevent destruction of wetlands, prevent erosion and sediment transport from areas of timber harvesting and row crop agriculture, and control runoff from construction sites and areas with significant impervious surfaces.

The GSA assessment indicates that water quality in the Fowl River watershed is relatively good, due primarily to the rural character of the watershed. However, steps should be taken to correct current impairments and to protect the watershed from future negative impacts that are common in streams in Alabama's coastal region.

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