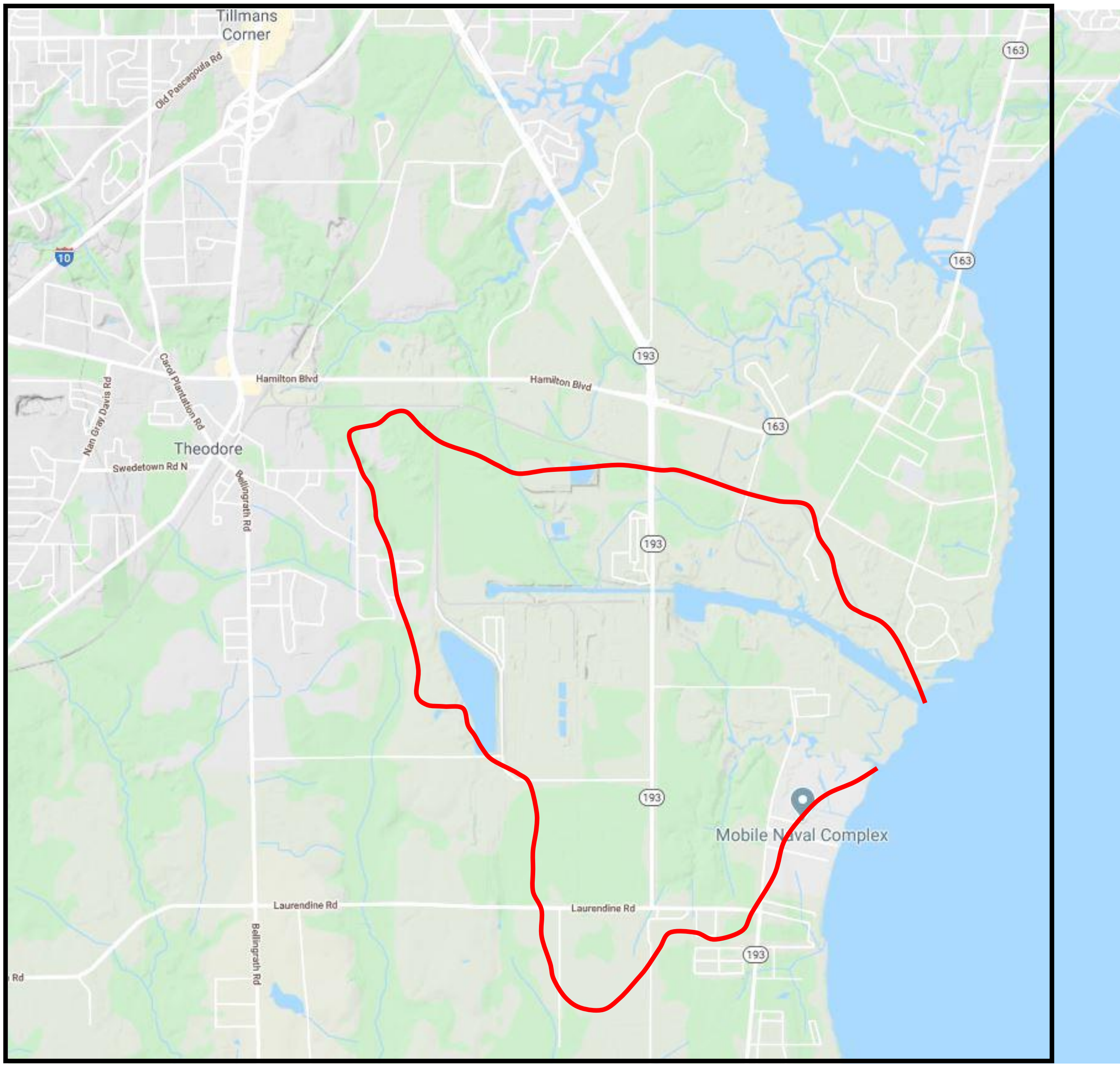
PRE-RESTORATION ANALYSIS OF DISCHARGE, SEDIMENT TRANSPORT RATES, AND WATER QUALITY IN THE DEER RIVER WATERSHED, MOBILE COUNTY, ALABAMA



PRERESTORATION ANALYSIS OF DISCHARGE, SEDIMENT TRANSPORT RATES, AND WATER QUALITY IN THE DEER RIVER WATERSHED, MOBILE COUNTY, ALABAMA

By

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TABLE OF CONTENTS

ILLUSTRATIONS

TABLES

.

INTRODUCTION

The Deer River watershed, in southeastern Mobile County flows into Mobile Bay about six miles (mi) south of the city of Mobile (fig. 1). Commonly, land-use and climate are major contributors to non-point source contaminants that impact surface-water quality. The Deer River watershed is rather unique, in that land use is dominated by industrial development with waterways used by the marine industry. Deer River was placed on the Alabama 303(d) list of impaired waters in 2006 and remains on the 2020 list (ADEM 2020). It is listed for organic enrichment due to collection system failures and urban runoff.

The purpose of this investigation is to assess general hydrogeologic and water-quality conditions, to estimate sediment loads, to measure nutrient and other contaminant concentrations, and evaluate land-use impacts for Deer River and its tributaries. These data will be used to quantify water-quality impacts and to support development of a watershed management plan, designed to preserve, protect, and restore the Deer River watershed.

PROJECT AREA

The Deer River watershed covers 5,825 acres (9.1 square miles (mi^2)) in southeastern Mobile County and includes three stream channels, North Fork, Middle Fork, and South Fork (US Geological Survey (USGS) StreamStats, 2020) (fig. 2). The North Fork channel is 1.7 mi long and flows into the Middle Fork one mi upstream from Mobile Bay (fig. 2). The Middle Fork is 3.5 mi long and flows into Mobile Bay seven mi south of the city of Mobile (fig. 2). Most of the Middle Fork is a man-made channel enlarged and deepened to accommodate ocean-going marine vessels. The South Fork is 3.0 mi long and flows into a large wetland prior to entering Mobile Bay, 0.5 mi south of the mouth of Middle Fork (fig. 2). The project area has one monitoring site on each channel and one monitoring site on an unnamed tributary to South Fork at Sunset Road (fig. 2). Elevations in the project area vary from 22 feet above mean sea level (ft MSL) to sea level (fig. 2).

PROJECT MONITORING STRATEGY AND SITE CHARACTERISTICS

The monitoring strategy employed for the Deer River project was to collect water samples at each site over a range of discharge for development of regression analysis of monitored water-quality parameters. Site accessibility, extensive wetlands and tidal

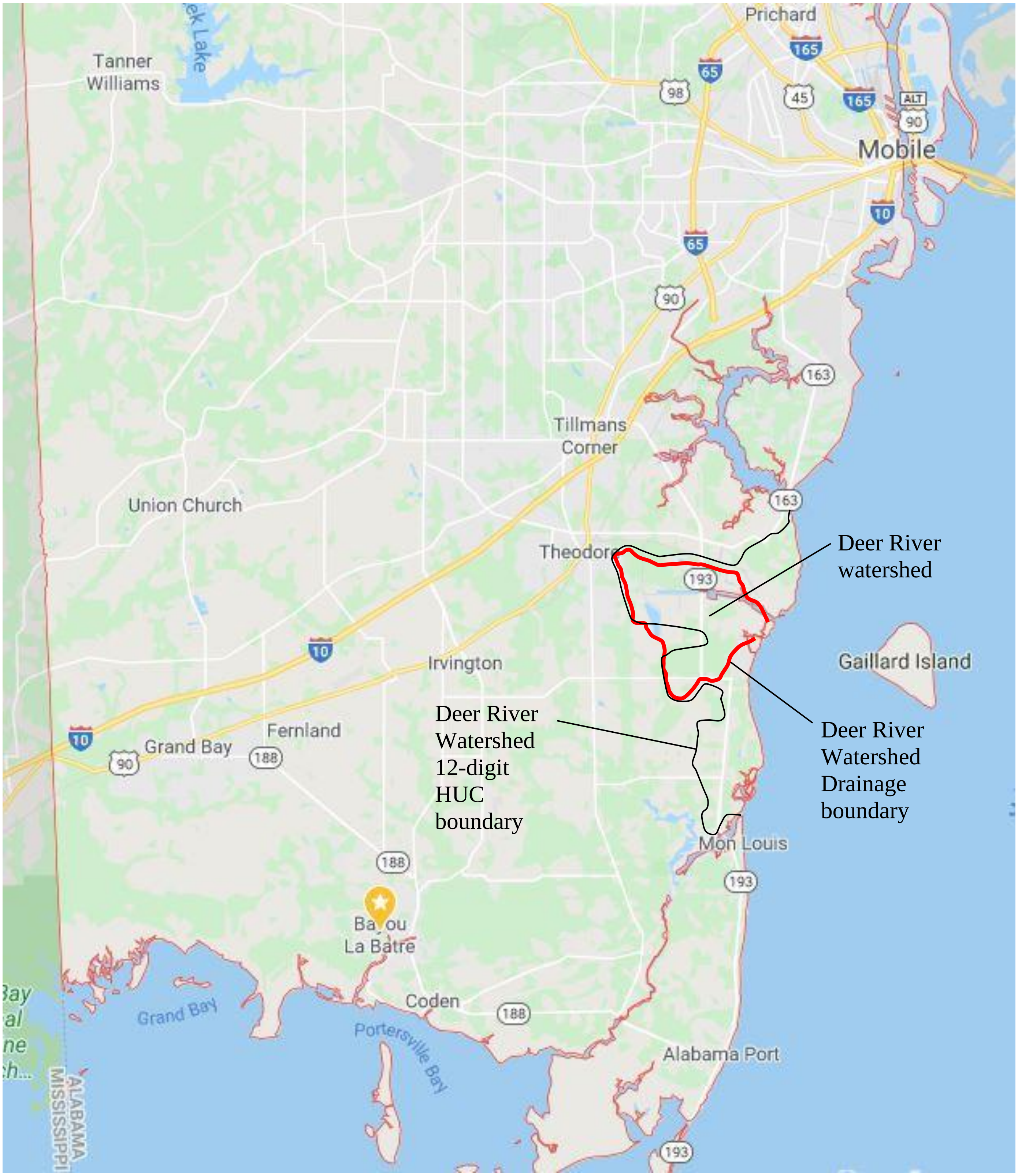


Figure 1.—Deer River watershed in southeastern Mobile County.

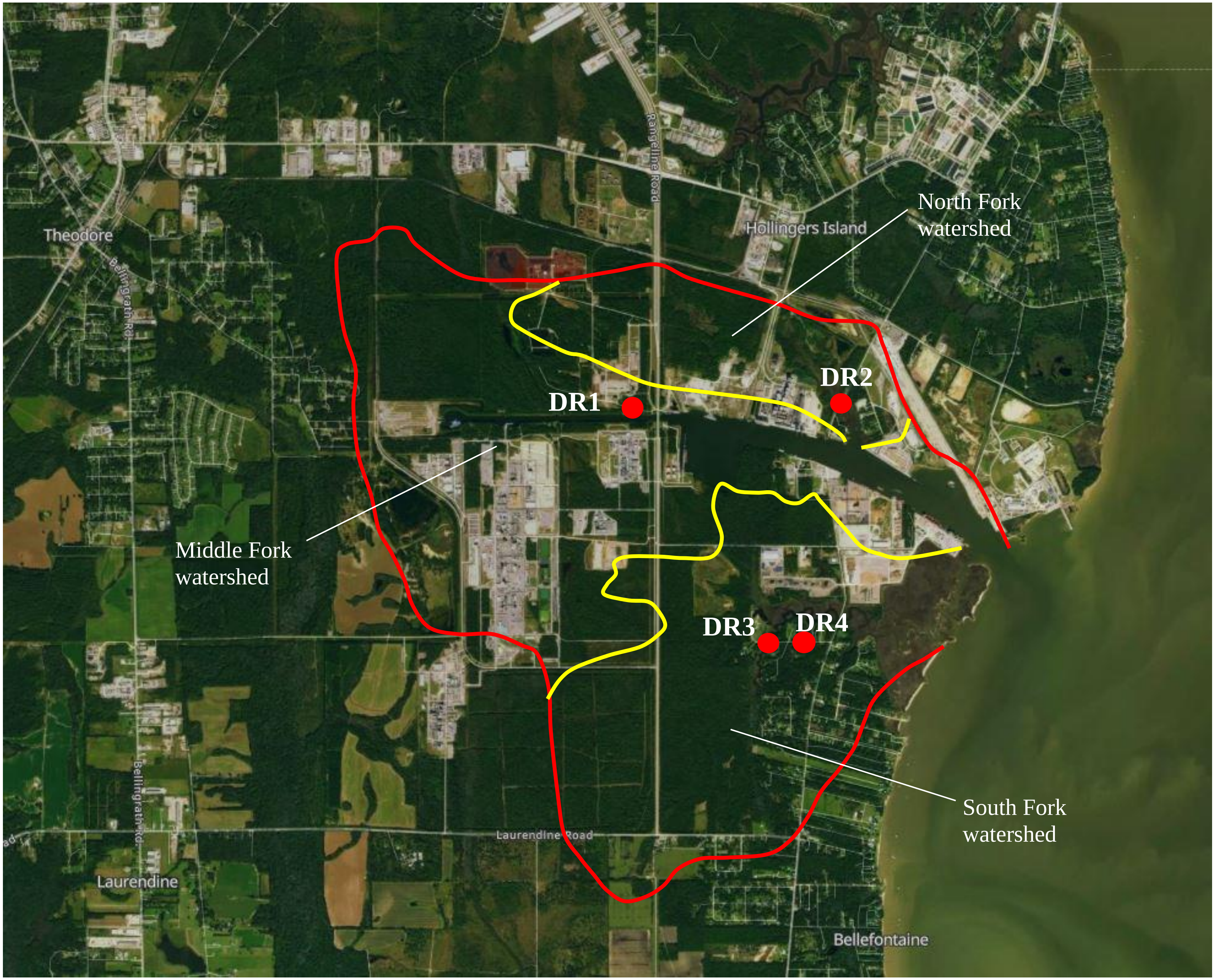


Figure 2.—Satellite image of the Deer River watershed with water-quality monitoring sites.

influence that constrains stream flow and impacts water chemical character, were limiting factors for selection of monitoring sites.

Site DR1 is on the man-made ship channel of Middle Fork (constructed in 1980), just west of the Rangeline Road western access road, 200 ft upstream from the Rangeline Road bridge and 2.1 mi upstream from the mouth at Mobile Bay (latitude (lat) 30.53377, longitude (long) -88.12449) (fig. 2). The watershed upstream from site DR1 covers 3.6 mi^2 (USGS StreamStats, 2020).

Site DR2 is on the North Fork at Dauphin Island Parkway (lat 30.53493, long -88.10708), 1,500 ft upstream from the confluence with Middle Fork (fig. 2). The watershed upstream from site DR2 covers 0.82 mi^2 (USGS StreamStats, 2020).

Site DR3 is on South Fork at Sunset Road (lat 30.51638, long -88.11360). The monitored site is 1.0 mi upstream from the mouth at Mobile Bay (fig. 2). The watershed upstream from site DR3 covers 1.9 mi^2 (USGS StreamStats, 2020).

Site DR4 is on an unnamed tributary at Sunset Road, 550 ft upstream from its confluence with the South Fork of Deer River (lat 30.51622, long -88.10993) (fig. 2). The watershed upstream from site DR4 covers 20 acres (0.03 mi^2).

LAND USE

Land use is directly correlated with water quality, hydrologic function, ecosystem health, biodiversity, and the integrity of streams and wetlands. Land use classification for the project area was determined 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). Land use/land cover in the project area was subdivided into six classified groups defined as developed, forested, agricultural, grassland/shrub/scrub, wetlands, and open water (fig. 3).

Dominant land use/land cover categories in the Deer River watershed are developed land and wetlands, composing about 35 and 30 percent (%), respectively (fig. 3). Developed land is primarily characterized as industrial, due to the dominance of maritime industries located along the Middle Fork ship channel (fig.3). Wetlands are distributed throughout the watershed but are concentrated along the North and South

Forks and along the Mobile Bay shore, south of the mouth of Middle Fork (fig. 3). Comparisons of 2013 land use/cover data and a 1982 topographic map (USGS, 1982) shows that a number of wetland areas were filled and industrial sites were developed, especially along the Mobile Bay shore on the north side of the mouth of Deer River, along the North Fork, and near the western perimeter of the watershed, along the Middle Fork ship channel (fig. 3). Loss of wetlands is critical, in that they provide important services such as: flood abatement, storm water management, water purification, shoreline stabilization, groundwater recharge, and streamflow maintenance.

Open water covers about 15% of the watershed, mostly in the Middle Fork ship channel. Agriculture composes about 10% of land use in the watershed, mostly along the western and southern perimeters (fig. 3).

Land-use/cover characteristics for monitored watersheds upstream from monitoring sites includes percentages of developed land (urban) and impervious surface (USGS StreamStats, 2020). The Middle Fork watershed upstream from site DR1 is 31% urban and 14% of the area is covered by impervious surfaces. The North Fork watershed upstream from site DR2 is 42% urban and 22% of the area is covered by impervious surfaces. The South Fork watershed upstream from site DR3 is 6% urban, with less than 1% of the area covered by impervious surfaces (USGS StreamStats, 2020).

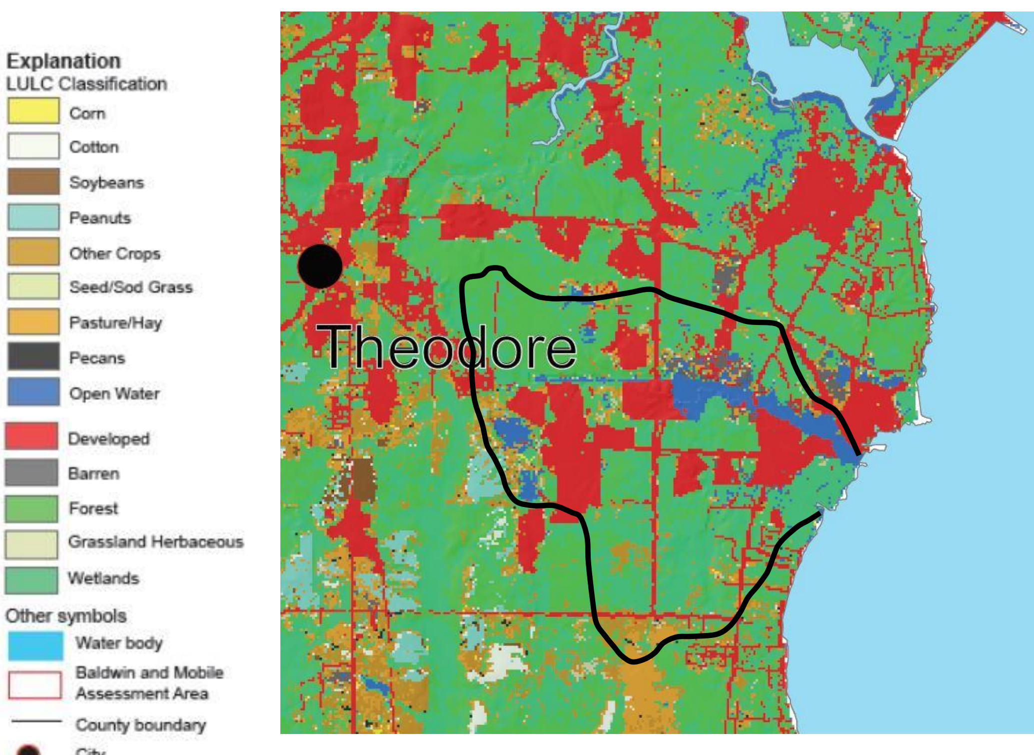


Figure 3.—Land use/cover in the Deer River watershed.

STREAM DISCHARGE

Streams in southern Mobile County are influenced by topography, land-use/cover, and Mobile Bay. Most streams in the metropolitan Mobile area are extremely flashy with relatively high velocities, due to channelization and urbanization. Most other streams in southern Mobile County are influenced by low gradients, extensive wetlands, limited urbanization, and tidal influence. However, streams in the Deer River watershed are influenced by a combination of natural characteristics, typical for south Mobile County, and urbanization related to the marine industry.

The character of stream flows in Deer River and its tributaries are influenced by natural characteristics including substantial groundwater contributions, relatively low topographic relief, extensive wetlands, salt marsh, and tidal effects. Middle and North Forks land use is about 40% urban (industrial) with about 20% impervious surface cover. However, flows are somewhat influenced by substantial coverage of wetlands that slow velocities and capture turbidity and contaminants. Land use/cover in the South Fork watershed is primarily forest and wetlands with a limited number of residences.

The average gradient for streams in the Dog River watershed, which adjoins the Deer River watershed on the north, is 48.0 ft/mi as compared to the Deer River Middle Fork watershed, which is 16 ft/mi, North Fork, 11 ft/mi, and South Fork, 10 ft/mi.

Measured discharge is not available for the Middle Fork due to tidal influence. However, discharge was measured during monitoring for the North and South Forks. Impacts of urbanization and impervious surfaces are clearly seen in North Fork discharge. Based on a limited number of measured discharge events, normalized discharge for North Fork is 154 cfs/mi^2 of drainage area, compared to 24 cfs/mi^2 in South Fork. Table 1 shows measured discharge and gradients for Deer River monitored streams.

A wide range of discharge events is required to adequately evaluate hydrologic conditions in Deer River. Figure 4 shows that sampling occurred in the Deer River watershed during a range of discharge events. Average daily discharge for each monitored stream is also required to adequately assess constituent loading. Discharge Data collected at the U.S. Geological Survey stream gaging site (02471078, Fowl River at Half Mile Road, near Laurendine, Alabama), 2.5 miles southwest of the Deer River watershed, was used as a basis for average daily discharge estimation for each monitored stream.

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

Monitored site	Average discharge (cfs)	Maximum discharge (cfs)	Minimum discharge (cfs)	Stream gradient (ft/mi)[2]
DR1	N/A[1]	N/A[1]	N/A[1]	16
DR2	126	332	30	11
DR3	45	137	19	10
DR4	N/A[3]	1.5	0.1	19

[1]TI- tidal influence
[2]ft/mi- feet per mile
[3]Intermittent discharge

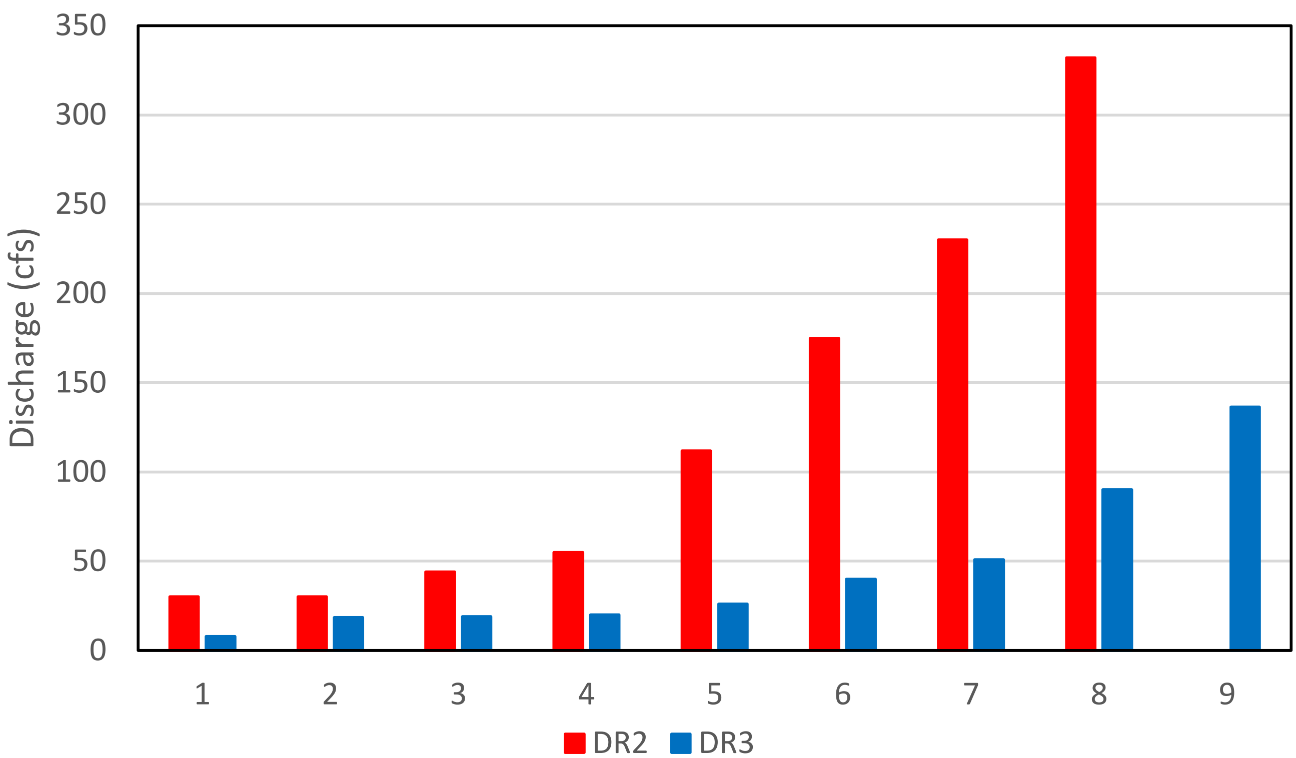


Figure 4.—Measured discharge at Deer River monitoring sites DR2 and DR3.

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 and soil conditions, and ionic influxes from nonpoint sources of pollution characteristic of urban runoff or from increased salinity in coastal streams influenced by tidal fluctuations. 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.

All water samples collected at Deer River monitoring sites DR1, DR2, and DR3 were impacted by tidal fluctuations (table 2). The highest SC was measured at the end of May, during a period of no rainfall and the lowest was measured during March and April, due to increased freshwater runoff during spring storms (table 2). Site DR4 was measured during one high flow event (103 µS/cm) and one low flow event (109 µS/cm).

Table 2.—Measured specific conductance in Deer River watershed samples.

Monitoring site	Maximum SC (µS/cm)	Minimum SC (µS/cm)	Average SC (µS/cm)
DR1	21,300	3,020	7,496
DR2	27,300	1,150	6,570
DR3	33,200	205	11,452

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).

Analyses of turbidity and stream discharge provide and insights into hydrologic, land-use, and general water-quality characteristics of a watershed. The water quality and sediment transport assessment of the Fowl River watershed (Cook and others, 2015) showed that land cover dominated by wetlands caused an inverse relationship between discharge and turbidity (higher discharge had lower turbidity). Unlike the nearby Fowl River watershed, which has a similar percentage of wetland cover, Deer River sites DR2 and DR3 have increasing turbidity with increased discharge, which indicates that as runoff increases, so does erosion and sediment transport (fig. 5). This is most likely caused by land disturbance related to the high percentage of developed land in the watershed. However, turbidity values in the Deer River watershed are relatively low, compared to Dog River and other watersheds in Baldwin County, due to buffering provided by extensive wetlands and marsh that detain and filter runoff prior to entering streams. Values of measured turbidity at Deer River monitoring sites are shown in table 3.

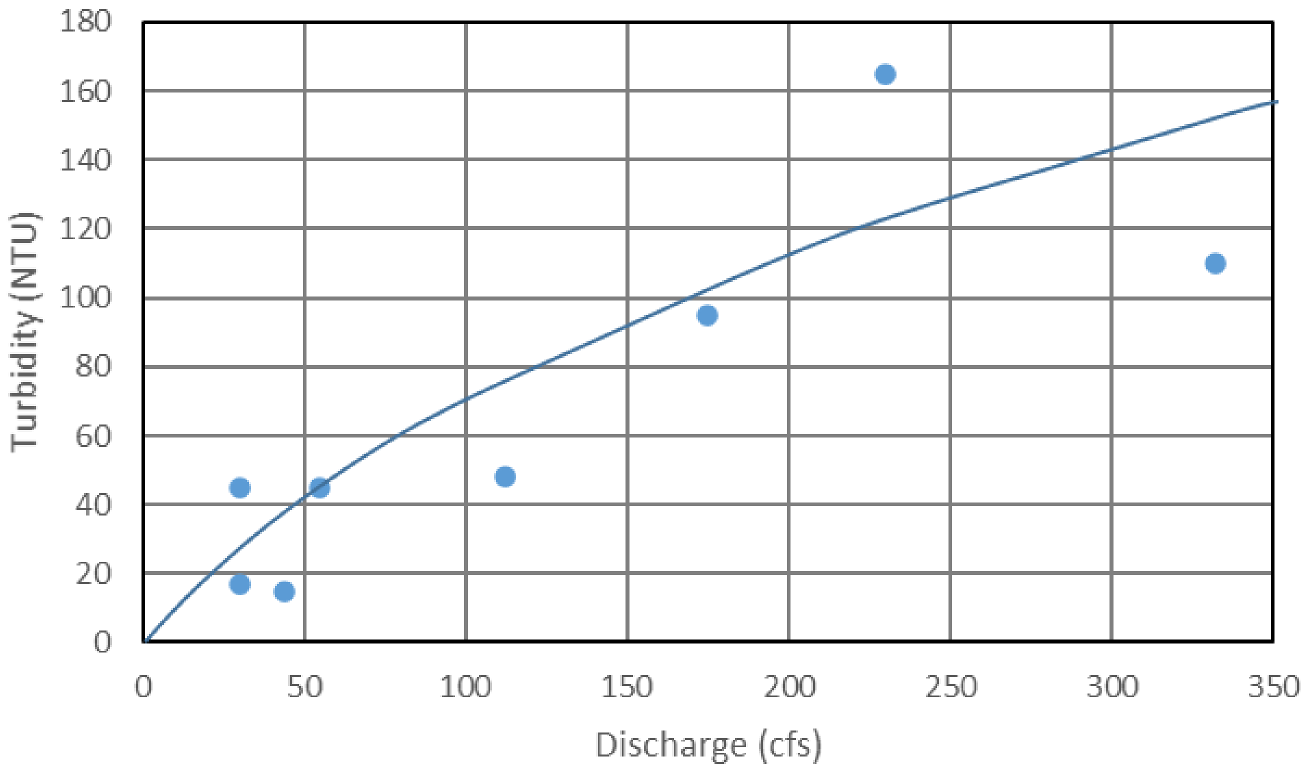
Turbidity values measured in nephlametric turbidity units (NTU) from water samples may be utilized to formulate a rough estimate of long-term trends of total suspended solids (TSS). Excellent correlations of turbidity and TSS are observed in sites DR1, DR2, and DR3 (fig. 6).

Table 3.—Measured turbidity in Deer River watershed samples.

Monitoring site	Maximum turbidity (NTU)	Minimum turbidity (NTU)	Average turbidity (NTU)
DR1	63	19	40
DR2	165	15	68
DR3	48	10	24

SEDIMENTATION

Sedimentation is a process by which eroded particles of rock are transported primarily by moving water from areas of relatively high elevation to areas of relatively low elevation, where the particles are deposited. Upland sediment transport is primarily accomplished by overland flow and rill and gully development. Lowland or flood plain transport occurs in streams of varying order, where upland sediment joins sediment eroded from flood plains, stream banks, and stream beds. Erosion rates are accelerated by human activity related to agriculture, construction, timber harvesting, unimproved roadways, or any activity where soils or geologic units are exposed or disturbed. Excessive sedimentation is detrimental to water quality, destroys biological habitat,



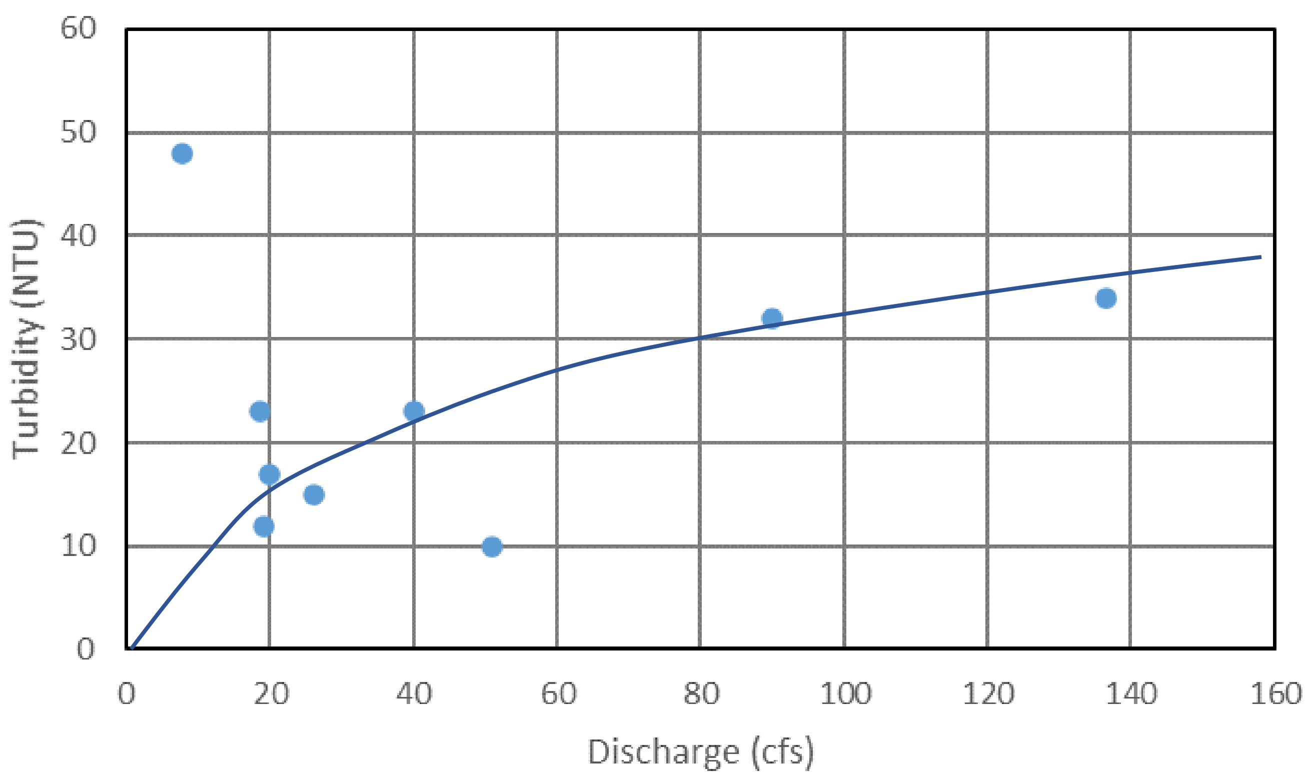


Figure 5.—Measured discharge and turbidity at Deer River monitoring sites DR2 (above) and DR3.

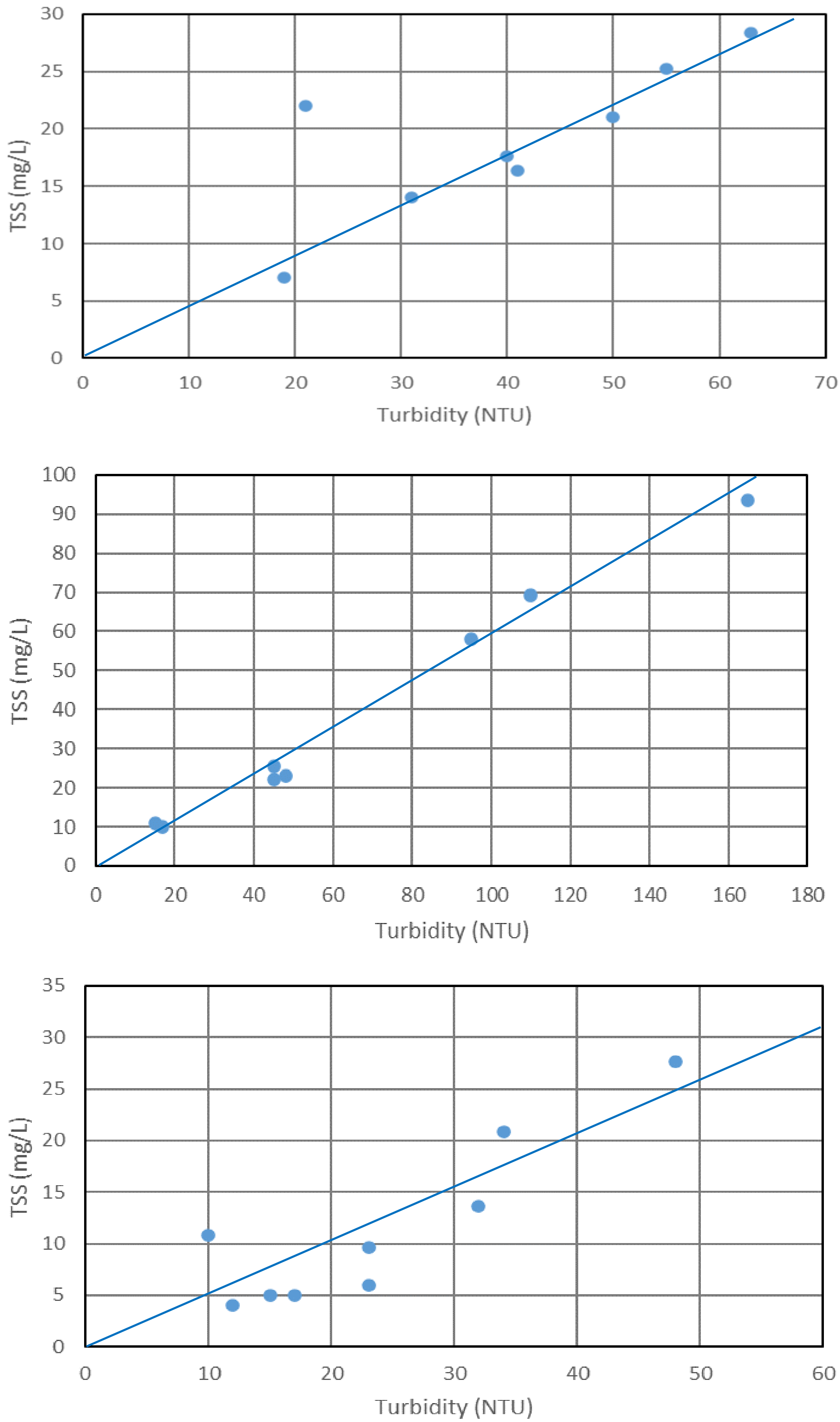


Figure 6.—Measured turbidity and TSS at Deer River monitoring sites DR1 (above), DR2 (middle), and DR3 (below).

reduces storage volumes 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. In addition to commonly observed factors 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 high flow is desirable. Measured stream discharge values for sites DR2 and DR3 are shown in figure 4.

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). Evaluation of hydrologic characteristics of the Deer River watershed indicate that relatively little bed sediment transport occurs in the streams at selected Deer River monitoring sites. Therefore, total sediment loads were assumed to be primarily suspended.

SEDIMENT LOADS TRANSPORTED BY PROJECT STREAMS

The rate of transport of sediment is a complex process controlled by a number of factors primarily related to land use, precipitation runoff, erosion, stream discharge and flow velocity, stream base level, and physical properties of the transported sediment.

In much of Baldwin County and in parts of Mobile County, 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, 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 constructed features to promote infiltration of precipitation and to store and slow runoff.

Streams in the Deer River watershed, like most other streams in southern Mobile County, have relatively low gradients and extensive wetlands and marsh that limit erosion and excessive sediment transport. However, these positive impacts are negated in the North Fork watershed by large percentages of impervious surface, development activity, and tidal impacts. High tides, from one to two ft at Deer River, cause increased hydraulic head, which restricts downstream flow. Fresh water, held upstream during high tide is released as the tide falls, causing relatively high stream flow velocities, which transport relatively large volumes of suspended sediment in the North Fork. Another mechanism for sediment transport related to tidal influence was documented in Bayou La Batre (Cook, 2016), where alternating upstream and downstream flow during rising and falling tides resuspends fine-grained bottom sediment causing unusually high turbidity and sediment transport. This occurs in the lower reaches of Deer River, especially in the Middle and North Forks, where average turbidity was 40 and 68 NTU, respectively.

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 6 shows that turbidity and suspended sediment are closely related in the Deer River watershed.

Annual suspended sediment loads were estimated for Deer River 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 Deer 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 the U.S. Geological Survey 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 (1/1/19-12/31/19). Sites DR2 (North Fork) and DR3 (South Fork), suspended sediment loads were 3,229 and 316 tons per year (t/yr), respectively (table 3). Turbidity, TSS, suspended sediment loads, and discharge values for all monitoring sites are shown in table 3.

For comparison, the largest suspended sediment loads in the Dog River watershed were Eslava Creek, Spencer Branch, and Spring Creek (sites 10, 7, and 2) with 10,803, 5,970, and 5,198 tons per year (t/yr), respectively (Cook, 2012). Discharge and land-use/cover are two of the primary factors that influence sediment transport rates in the Deer River watershed. Figure 7 depicts discharge, suspended sediment loads, and percentage of impervious surface.

Table 3.—Measured sediment transport characteristics and estimated suspended sediment loads at Deer River monitored sites.

Monitored site	Average Discharge (cfs)	Average turbidity (NTU)	Maximum turbidity (NTU)	Average TSS (mg/L)	Maximum TSS (mg/L)	Estimated suspended sediment load (t/yr)	Estimated normalized suspended sediment load ($t/mi^2/yr$)
DR1	N/A	40	63	19	28	N/A	N/A
DR2	126	68	165	39	69	3,229	3,938
DR3	45	24	48	11	35	316	167

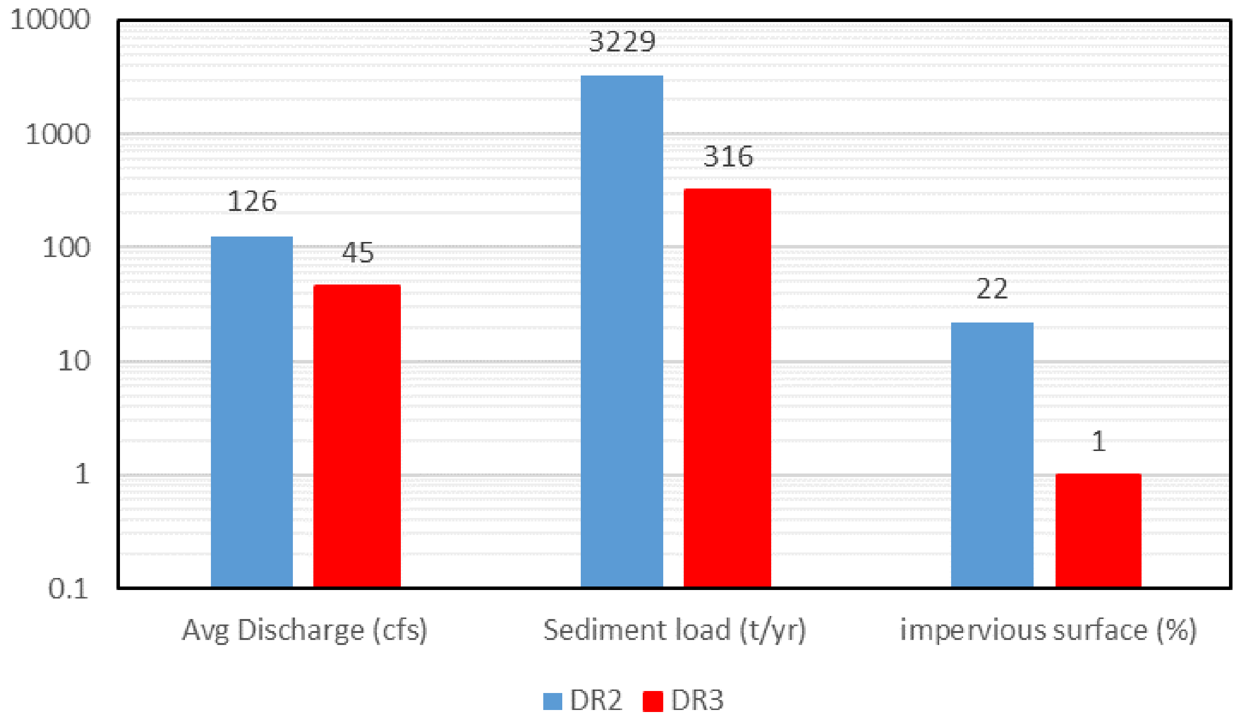


Figure 7.—Average measured discharge, sediment loads, and impervious surface cover in Deer River watersheds, upstream from monitoring sites DR2 and DR3.

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 suspended sediment loads at sites DR2 and DR3 were 3,938 and 167 t/mi^2/yr, respectively. For comparison, the largest normalized suspended sediment loads in the Dog River watershed (urban 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, 2012).

Comparisons of sediment loads from other watersheds, estimated using similar methodologies, are helpful in determining the severity of erosion problems in a watershed of interest. Figure 8 shows comparisons of estimates of normalized sediment loads from the North and South Deer River Forks with sites in eight previously monitored watersheds in Mobile and Baldwin Counties, including Fowl River site FR2 (Half-Mile Road) (Cook and others, 2015); Dog River tributary, Spencer Branch site DR2 (Cottage Hill Road city of Mobile) (Cook and Moss, 2012); Magnolia River site FR4 (U.S.

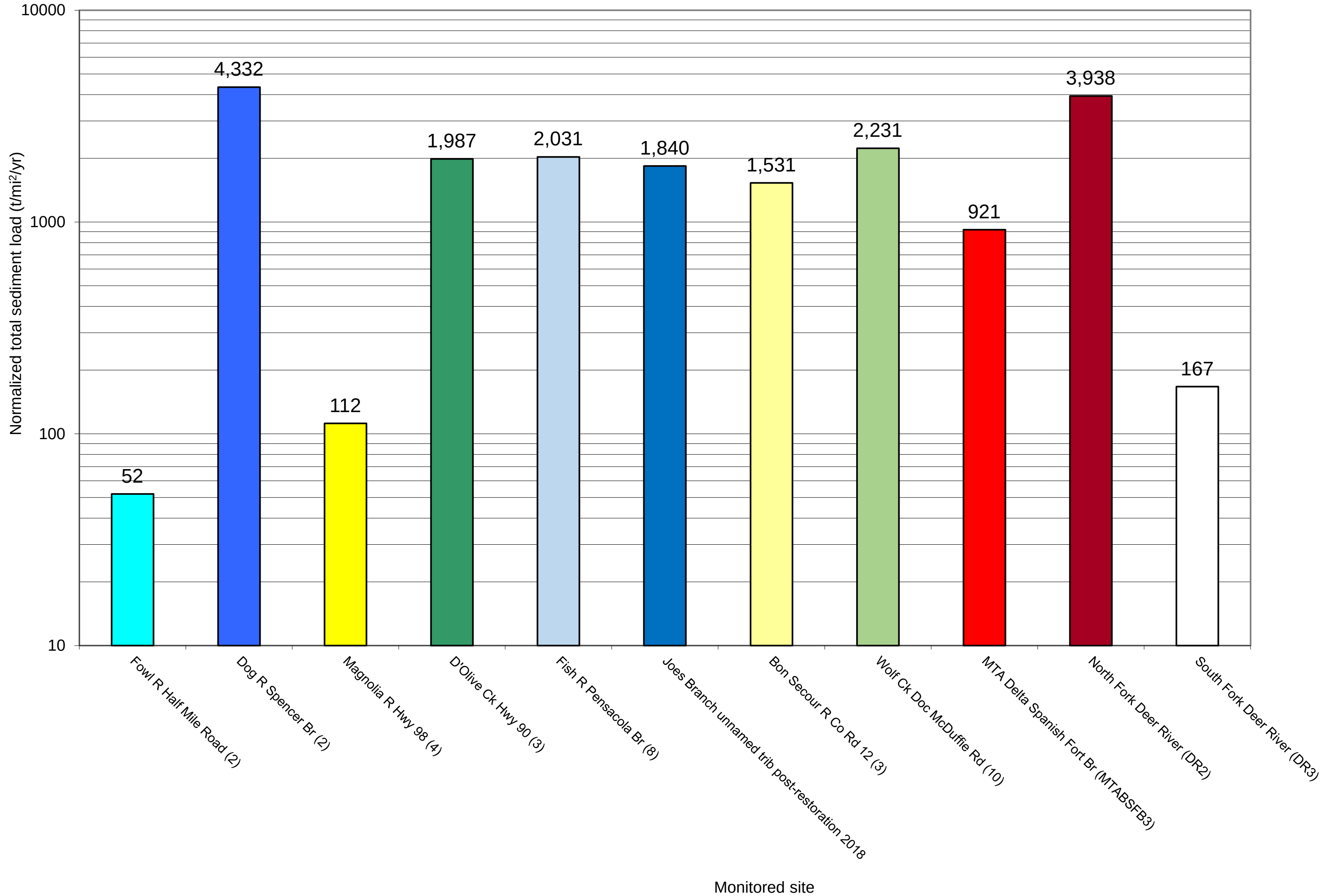


Figure 8.—Comparisons of sediment loads for Deer River sites DR2 and DR3 with selected watersheds in Baldwin and Mobile Counties.

Highway 98) (Cook and others, 2009); D’Olive Creek site DC3 (U.S. Highway 90 Daphne) (Cook and others, 2008); Pensacola Branch site FR8 tributary to Fish River (Cook, 2016); D’Olive Creek tributary Joes Branch site JB9 (Town Center Blvd. Spanish Fort) (Cook, 2019); Bon Secour River site BSR3 (County Road 12 Foley) (Cook and others, 2014); Wolf Creek site WC10 (Doc McDuffie Road Foley) (Cook, 2017) and Mobile-Tensaw-Apalachee Delta site MTABSFB3 (Spanish Fort Branch).

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 to euthrophic levels. Toxins also can be produced during blooms of particular algal species. Nutrient-impaired water can dramatically increase treatment costs required to meet drinking water standards. Nutrients discussed in this report are nitrate (NO_3-N) 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). The critical nitrate concentration in surface water for excessive algae growth is 0.5 mg/L (Maidment, 1993).

A total of 24 samples were collected from January 2018 through May 2018 at Deer River watershed monitoring sites DR1, DR2, and DR3 for discharge events from base flow to bank full. Deer River samples were compared to the ADEM reference concentration of 0.3258 mg/L nitrate+nitrite nitrogen, which equals the 90th percentile for Ecoregion 65f. Nitrate was detected in one sample at site DR2 and one sample at site

DR3 and the 0.5 mg/L nitrate criterion was not exceeded. The ADEM reference concentration was exceeded at site DR3 (0.496 mg/L).

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 (total P) 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 of 0.04 mg/L for total P for level IV ecoregion 65f. In many streams phosphorus is the primary nutrient that influences excessive biological activity. These streams are termed “phosphorus limited.”

Eight samples were collected at each Deer River site and analyzed for total P, which was detected in five samples at site DR1, four samples at site DR2, and four samples at site DR3. The 0.04 mg/L ADEM phosphorus reference standard was exceeded in all 13 samples, with the highest concentration (1.3 mg/L) at site DR1 on March 28, 2018 (fig. 9). Commonly, total P exhibits a positive correlation with discharge, but concentrations at Deer River sites have no recognizable correlation. However, detections only occurred during the winter and spring when fresh-water flow were highest. Also, total P has good negative correlations at site DR1 and DR3 with specific conductance, where total P decreases as salinity increases (fig. 10).

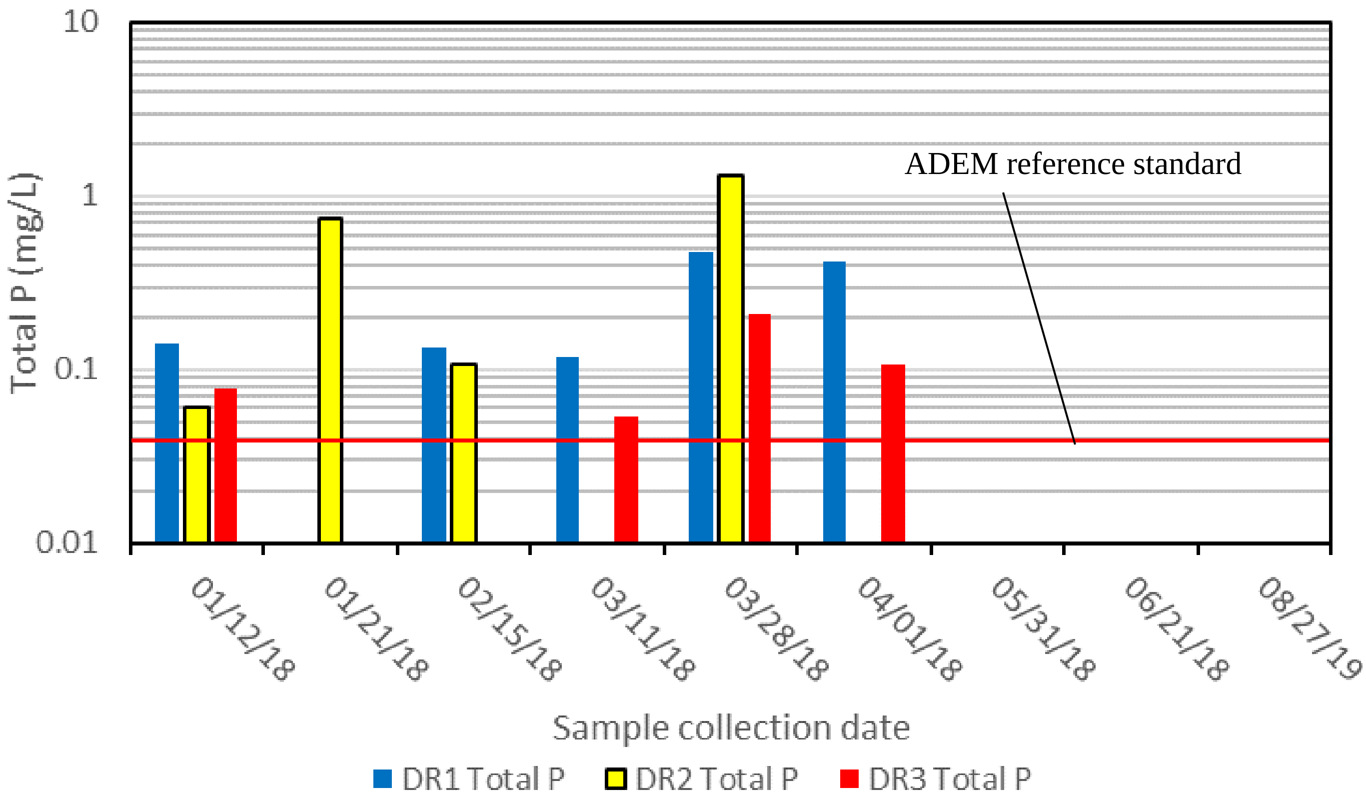


Figure 9.—Total phosphorus concentrations at Deer River monitoring sites DR1, DR2, and DR3, compared to the ADEM reference standard.

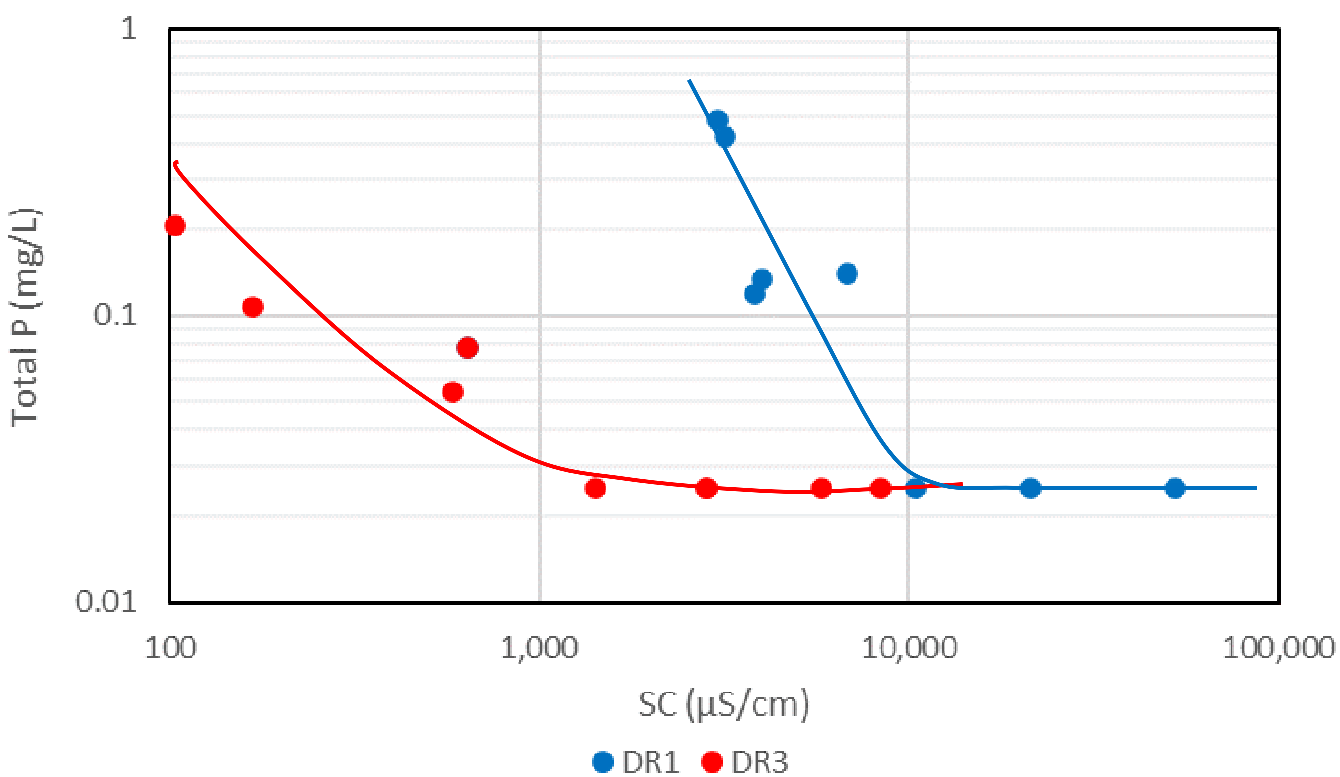


Figure 10.—Specific conductance and total phosphorus at Deer River monitoring sites DR1 and DR3.

PREVIOUS INVESTIGATIONS OF WATER-QUALITY

Previous investigations in the Deer River watershed yielded water quality data that may be compared to data collected during this investigation to determine changes in water quality that have occurred over time. In 1977, the Ideal Corporation proposed to construct a cement plant in the Deer River watershed. The proposed plant site borders Dauphin Island Parkway on the east and Middle Fork Deer River on the south. The North Fork Deer River flows through the proposed site. The US Environmental Protection Agency and US Army Corps of Engineers required an environmental impact statement (EIS) prior to construction. The Ideal Corporation contracted Environmental Science and Engineering, Inc. (ESEI) to prepare the EIS, which included water-quality monitoring and constituent load estimations (Environmental Science and Engineering, Inc. 1977). ESEI collected water samples at five sites, including two sites (P1 and P2) that are at the same locations as DR1 (Middle Fork near Rangeline Road) and DR2 (North Fork at Dauphin Island Parkway) (fig. 11).

Vintage aerial photography shows that less than 10% of the current development in the watershed occurred before 1967 (fig. 12). By 1993, 75% of the current development was in place (fig. 12). Development was tied to dredging of the ship channel, which occurred between 1967 and 1993.

The 1978 EIS stated that previous water quality investigations documented degraded water quality in Deer River and adjacent freshwater wetlands and marshes, caused by point source industrial discharges and stormwater runoff from industrial sites. Previous studies cited industrial discharges of phenol, oil and grease, nitrogen and phosphorus compounds, and toxic metals.

Eight samples were collected at sites P1 and P2 from April to August 1977. Twenty-eight constituents were measured, including temperature, pH, turbidity, specific conductance, dissolved oxygen, TSS, nutrients, pathogens, and selected metals. Analytical results show that the USEPA standards for protection of aquatic life criteria for lead was exceeded in 2 of 8 samples at site P1 and 1 of 8 samples at site P2. The criteria for mercury was exceeded in 3 of 8 samples at site P1 and 4 of 8 samples at site P2.

Table __ shows selected constituent average values compared to average values measured during this investigation. Differences in average constituent values are

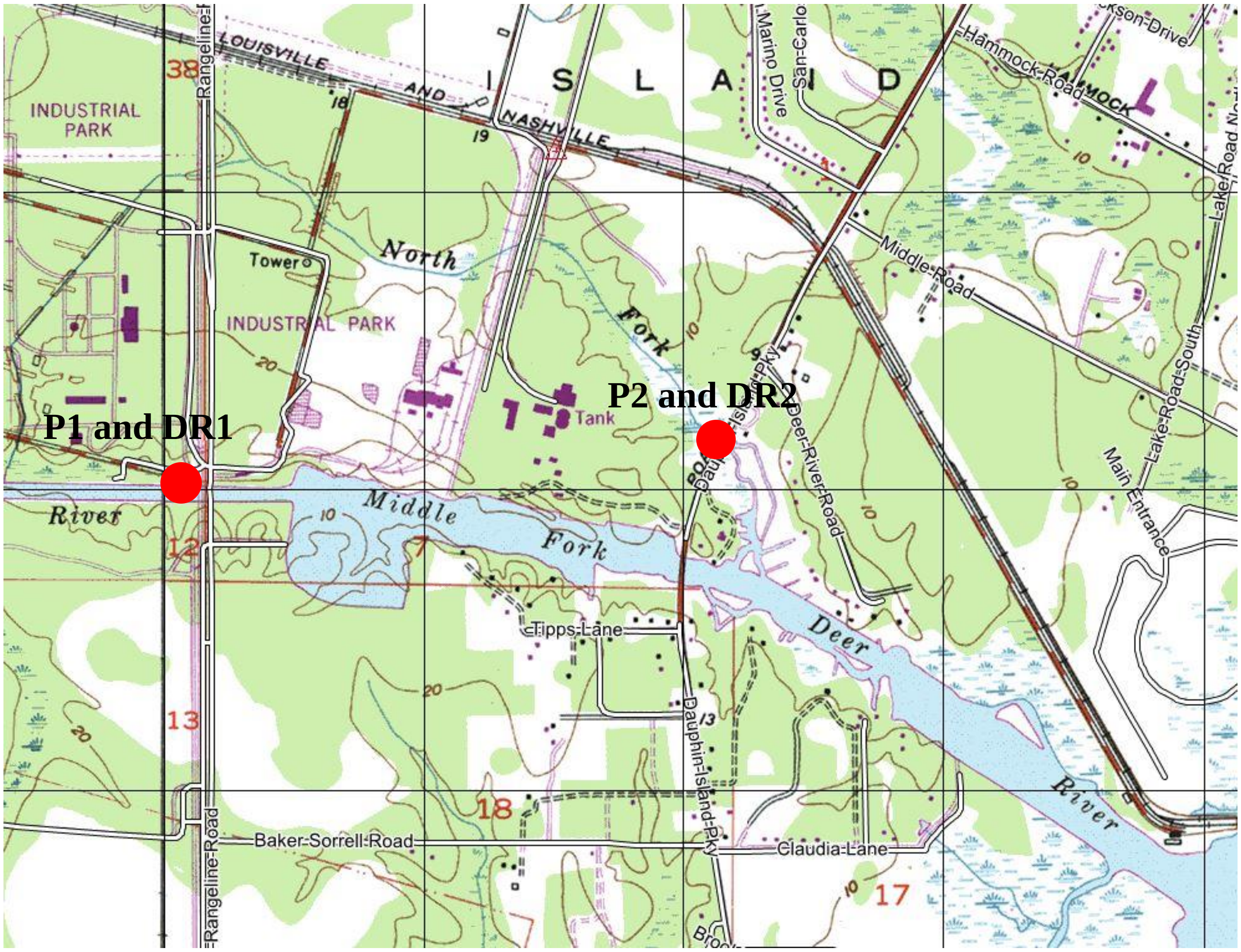


Figure 11.—Monitoring sites for 1977 and 2018 sampling.

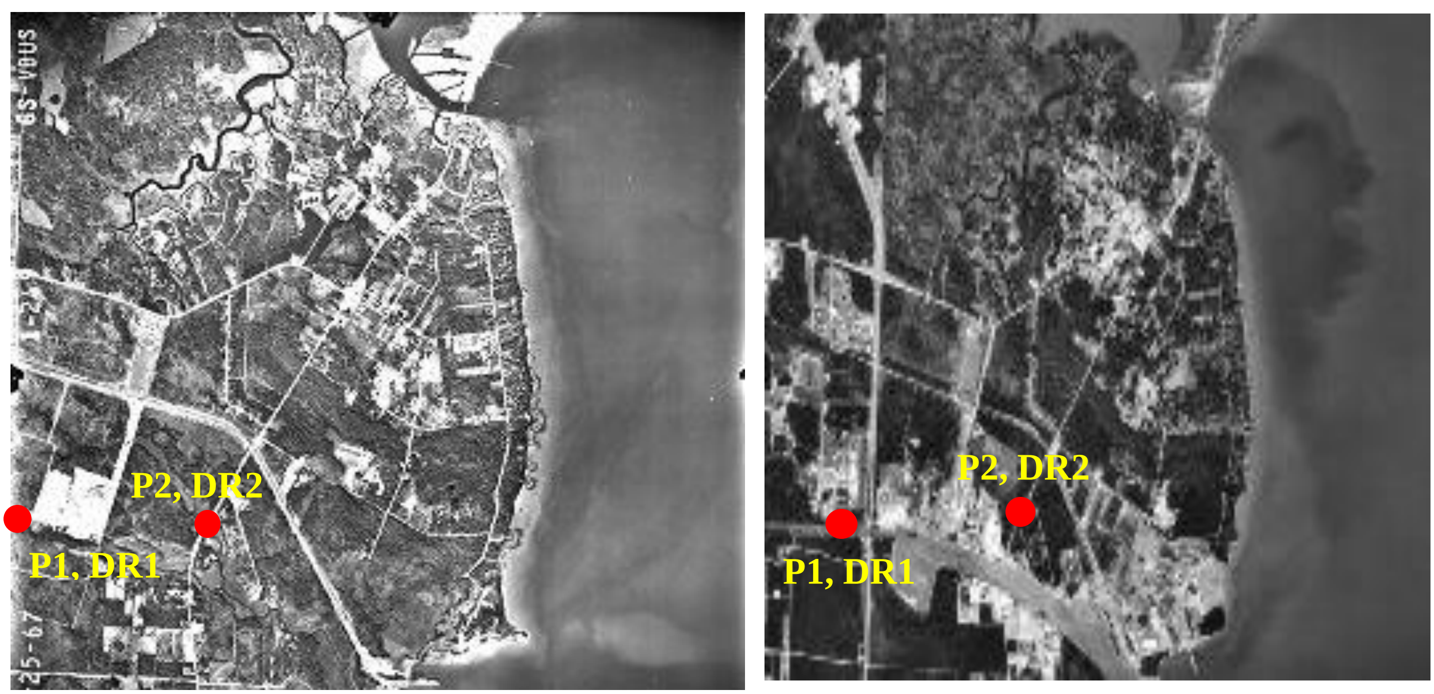


Figure 12.—Aerial photographs of the northern part of the Deer River watershed in 1967 (left) and 1993 (right), showing monitoring sites P1, DR1 and P2, DR2.

probably related to stream discharge at the time of sample collection or land-use changes between 1977 and 2018. No discharge was reported with the 1977 data, while most samples collected in 2018 were during rainfall events, which could explain lower SC, higher turbidity, and higher phosphorus in the 2018 samples. Another explanation is that 1977 samples were collected primarily during high tide, when saline conditions at sample collection sites were maximized and SC was highest. Higher turbidity and phosphorus in 2018 samples could be related to increased land disturbance and impervious surfaces and greater discharge of phosphorus from industrial processes and wastewater from industrial sites in the watershed.

Table 4.—Average constituent values for Deer River monitoring site water samples collected in 1977 and 2018.

	P1	DR1	P2	DR2
Specific conductance	12,158	7,496	12,403	6,570
Turbidity	8	40	7	68
TSS	17	17	13	39
Nitrate	<0.3	<0.3	<0.3	.170
Phosphorus	0.10	0.17	0.12	0.28

An EIS prepared in 1979 by the South Alabama Regional Planning Commission for a proposed wastewater discharge pipeline from the Theodore Industrial Park in the Deer River watershed to Mobile Bay contained sediment transport estimates for the watershed. These estimates were for major industrial sites, open areas, and suburban developments in the Deer River watershed. Input data were taken from other similar sites throughout the United States. The estimate for total annual sediment loads entering the Theodore Industrial Canal (Middle Fork) are 20,615 tons per year, which compares to the sediment load from the North and South Forks estimated during this assessment of 3,545 t/yr.

SUMMARY AND CONCLUSIONS

The Deer River watershed is rather unique, in that land use is dominated by industrial development with waterways used by the marine industry. Deer River was placed on the Alabama 303(d) list of impaired waters in 2006 and remains on the 2020 list. It is listed for organic enrichment due to collection system failures and urban runoff and storm sewers.

The Deer River watershed covers 5,825 acres (9.1 mi^2) in southeastern Mobile County and includes three stream channels, North Fork, Middle Fork, and South Fork. Site DR1 is on the man-made ship channel of Middle Fork (constructed in 1980), just west of the Rangeline Road western access road, 5,100 ft upstream from the Rangeline Road bridge, and 2.1 mi upstream from the mouth at Mobile Bay. The watershed upstream from site DR1 covers 3.6 mi^2. Site DR2 is on the North Fork at the Dauphin Island Parkway crossing, 1,500 ft upstream from the confluence with Middle Fork. The watershed upstream from site DR2 covers 0.82 mi^2. Site DR3 is on South Fork at the Sunset Road crossing. The monitored site is 1.0 mi upstream from the mouth at Mobile Bay. The watershed upstream from site DR3 covers 1.9 mi^2. Site DR4 is on an unnamed tributary at the Sunset Road crossing, 550 ft upstream from its confluence with the South Fork of Deer River. The watershed upstream from site DR4 covers 20 acres.

Dominant land use/land cover categories in the Deer River watershed are developed land and wetlands, composing about 35 and 30 percent (%), respectively. Developed land is primarily characterized as industrial, due to the dominance of maritime industries located along the man-made Middle Fork channel. Wetlands are distributed throughout the watershed but are concentrated along the North and South Forks and along the Mobile Bay shore, south of the mouth of Deer River. Open water covers about 15% of the watershed, mostly in the Middle Fork channel. Agriculture composes about 10% of land use in the watershed, mostly along the western and southern perimeters

The Middle Fork watershed upstream from site DR1 is 31% urban, with 14% of the area covered by impervious surfaces. The North Fork watershed upstream from site DR2 is 42% urban and 22% of the area is covered by impervious surfaces. The South Fork watershed upstream from site DR3 is 6% urban, with less than 1% of the area covered by impervious surfaces.

The average gradient for streams in the Dog River watershed, which adjoins the Deer River watershed on the north, is 48.0 ft/mi as compared to the Deer River Middle Fork watershed, which is 16 ft/mi, North Fork, 11 ft/mi, and South Fork, 10 ft/mi. Measured discharge is not available for the Middle Fork due to tidal influence. However, measured discharge for the North and South Forks shows the impact of urbanization and impervious surfaces on North Fork discharge. Based on a limited number of measured discharge events, normalized discharge for North Fork is 154 cfs/mi^2 of drainage area, compared to 24 cfs/mi^2 in South Fork.

Surface water in each project watershed is characterized by a unique specific conductance profile based on physical and chemical properties. All water samples collected at Deer River monitoring sites DR1, DR2, and DR3 were impacted by tidal fluctuations, with average SC values 7,496, 6,570, and 11,452 μS/cm at sites DR1, DR2, and DR3, respectively.

Analyses of turbidity and stream discharge provide and insights into hydrologic, land-use, and general water-quality characteristics of a watershed. Deer River sites DR2 and DR3 have increasing turbidity with increased discharge, which indicates that as runoff increases, so does erosion and sediment transport. However, North Fork turbidity is 2.8 time higher than the South Fork, which is most likely caused by land disturbance related to the high percentage of developed land and impervious surface in the North Fork watershed. Generally, turbidity values in the Deer River watershed are relatively low, compared to Dog River and other watersheds in Baldwin County, due to buffering provided by extensive wetlands and marsh that detain and filter runoff prior to entering streams. Average turbidity values are 40, 68, and 24 NTU at sites DR1, DR2, and DR3, respectively.

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.

Sites DR2 (North Fork) and DR3 (South Fork), suspended sediment loads were 3,229 and 316 tons per year (t/yr), respectively. For comparison, the largest suspended sediment loads in the Dog River watershed were Eslava Creek, Spencer Branch, and Spring Creek (sites 10, 7, and 2) with 10,803, 5,970, and 5,198 tons per year (t/yr), respectively. Normalized suspended sediment loads at sites DR2 and DR3 were 3,938 and 167 t/mi^2/yr, respectively. For comparison, the largest normalized suspended sediment loads in the Dog River watershed (urban 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.

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. 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.

A total of 24 samples were collected from January 2018 through May 2018 at Deer River watershed monitoring sites DR1, DR2, and DR3 for discharge events from base flow to bank full. Nitrate was detected in one sample at site DR2 and one sample at site DR3 and the 0.5 mg/L nitrate criterion was not exceeded. The ADEM reference concentration was exceeded in one sample at site DR3 (0.496 mg/L).

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. Eight samples were collected at each Deer River site and analyzed for total P, which was detected in five samples at site DR1, four samples at site DR2, and four samples at site DR3. The 0.05 mg/L phosphorus criterion was exceeded in all 13 samples, with the highest concentration (1.3 mg/L) at site DR1 on March 28, 2018.

Previous investigations in the Deer River watershed yielded water quality data that may be compared to data collected during this investigation to determine changes in water quality that have occurred over time. In 1977, the Ideal Corporation proposed to construct a cement plant in the Deer River watershed. The proposed plant site borders Dauphin Island Parkway on the east and Middle Fork Deer River on the south. The North Fork Deer River flows through the proposed site. The US Environmental Protection Agency and US Army Corps of Engineers required an EIS prior to construction, which required a relatively comprehensive water quality assessment.

Eight samples were collected at sites DR1 and DR2 from April to August 1977. Twenty-eight constituents were measured, including temperature, pH, turbidity, specific conductance, dissolved oxygen, TSS, nutrients, pathogens, and selected metals. Analytical results show that the USEPA standards for protection of aquatic life criteria for lead was exceeded in 2 of 8 samples at site DR1 and 1 of 8 samples at site DR2. The criteria for mercury was exceeded in 3 of 8 samples at site DR1 and 4 of 8 samples at site DR2.

Comparisons of 1977 and 2018 turbidity values indicate that average turbidity was 5 times higher in 2018 samples at site DR1 and almost 10 times higher at site DR2. Average phosphorus concentrations were 59% higher in 2018 samples at site DR1 and 233% higher at site DR2. Since no discharge was reported for the 1977 sampling, it is difficult to determine the actual magnitude of change in turbidity and phosphorus between 1977 and 2018, but changes in land use and runoff are most likely responsible.

An EIS prepared in 1979 by the South Alabama Regional Planning Commission for a proposed wastewater discharge pipeline from the Theodore Industrial Park in the Deer River watershed to Mobile Bay contained sediment transport estimates for the watershed. These estimates were for major industrial sites, open areas, and suburban developments in the Deer River watershed. Input data were taken from other similar sites throughout the United States. The estimate for total annual sediment loads entering the Theodore Industrial Canal (Middle Fork) are 20,615 tons per year, which compares to the sediment load from the North and South Forks estimated during this assessment of 3,545 t/yr. Evaluation of estimation methods indicates that the 1979 estimates were based on data from other watersheds around the United States and may be grossly inaccurate.

REFERENCES CITED

ADEM, 2018, Clean Water Act 303-d list for Alabama, URL http://216.226.179.150/programs/water/wquality/2020AL303dList.pdf, accessed May 20, 2020.

Cohn, T. A., Caulder D. L., Gilroy E. J., Zynjuk L. D., and Summers, R. M., 1992, The validity of a simple statistical model for estimating fluvial constituent loads: an empirical study involving nutrient loads entering Chesapeake Bay: Water Resources Research, v. 28, p. 2353-2363.

Cook, M. R., and Moss, N. E., 2008, Analysis of water quality, sediment loading, biological resources, and impacts of land-use change on the D'Olive and

Tiawasee Creek watersheds, Baldwin County, Alabama, 2008: Geological Survey of Alabama Open-file Report 0811, 140 p.

Cook, M. R., Moss, N. E., and Murgulet, Dorina, 2009, Analysis of sediment loading for the Magnolia River watershed, Baldwin County, Alabama, 2009: Geological Survey of Alabama Open-file Report 0914, 22 p.

Cook, M. R., and Moss, N. E., 2012, Analysis of discharge and sediment loading rates in tributaries of Dog River in the Mobile metropolitan area: Geological Survey of Alabama Open-file Report 1214, 24 p.

Cook, M. R., Moss, N. E., and Rogers, A. L, 2013, Analysis of sediment loading for the Bon Secour River watershed, Baldwin County, Alabama, 2013: Geological Survey of Alabama Open-file Report 1409, 34 p.

Cook, M. R., Moss, N. E., and Rogers, A. L, 2015, Pre-restoration analysis of discharge and sediment transport rates in tributaries of Fowl River, Mobile County, Alabama, 2015: Geological Survey of Alabama Open-file Report, 34 p.

Cook, M. R, 2016, Pre-restoration analysis of discharge, sediment transport Rates, water quality, and land-use impacts in the Bayou La Batre watershed, Mobile County, Alabama: Polyengineering Inc., 33 p.

Cook, M.R., 2016, Pre-restoration analysis of discharge, sediment transport rates, water quality, and land-use impacts in the Fish River watershed, Baldwin County, Alabama: Polyengineering, Inc., 48 p.

Cook, M.R., 2017, Pre-restoration analysis of discharge, sediment transport rates, water quality, and land-use impacts in the Wolf Bay watershed, Baldwin County, Alabama: Polyengineering, Inc., 48 p.

Cook, M.R., 2017, Analysis of discharge, sediment transport rates, water quality, and land-use impacts in tributaries of the Mobile-Tensaw-Apalachee Delta watershed, Baldwin and Mobile Counties, Alabama: Polyengineering, Inc., 39 p.

Eaton, A. D., Clesceri, L. S., and Greenberg, A. E., 1995, Standard methods for the examination of water and wastewater, 19th edition: Washington, D. C., American Public Health Association, p. 9-53—9-72.

Ideal Basic Industries, 1977, Draft Environmental Impact Statement for a proposed cement plant in the Theodore Industrial Park, pp 120-147.

Maidment, D. R., ed., 1993, Handbook of hydrology: New York, Mcgraw-Hill Inc., p. 11.37-11.54.

Mays, L. W., ed., 1996, Water resources handbook: New York, McGraw-Hill, p. 8.3-8.49.

Richards, R. P., 1999, Estimation of pollutant loads in rivers and streams: a guidance document for NPS programs: Heidelberg College.

South Alabama Regional Planning Commission, 1979, Draft Environmental impact statement for a proposed pipeline and wastewater outfall in Mobile Bay, Alabama from the Theodore Industrial Park, https://books.google.com/books?id=vSw0AQAAMAAJ&pg=RA6-SA8-PA15&lpg=RA6-SA8-PA15&dq=south+alabama+regional+planning+commission+mobile+alabama+1976&source=bl&ots=80aeGJ1Nx1&sig=ACfU3U2nEyfoY2CDUTA5LDNa_-J8JYA5jg&hl=en&sa=X&ved=2ahUKEwiC9a3yqdnpAhXQdN8KHZ1nCkoQ6AEwAXoECB0QAg#v=onepage&q=south%20alabama%20regional%20planning%20commission%20mobile%20alabama%201976&f=false, accessed May 29, 2020.

USDA National Agricultural Statistics Service Cropland Data Layer, 2013, Published crop-specific data layer. http://nassgeodata.gmu.edu/CropScape/.html accessed May 20, 2013. USDA-NASS, Washington, DC.

U.S. Environmental Protection Agency, 2020, National recommended water-quality criteria-aquatic life criteria table, https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table#table, accessed May 29, 2020.

U.S. Geological Survey, 2003, Total mercury and methylmercury in fish fillets, water, and bed sediments from selected streams in the Delaware River Basin, New Jersey, New York, and Pennsylvania, 1998-2001, Water Investigations Report 03-4183, 30 p.

U.S. Geological Survey, 2017, StreamStats watershed mapping and statistics, southeast Mobile County, Alabama, URL http:// http://water.usgs.gov/osw/streamstats/ accessed May 22, 2020.

APPENDIX A

FIELD AND ANALYTICAL DATA

Middle Fork Deer River at Rangeline Road											
Site	Date	Time	Discharge	Temperature	SC	Turbidity	pH	DO	TSS	NO_3	Total P
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
DR1	1/12/18	14:20	N/A	13.2	6,770	31	6.5	8.3	14.0	<0.3	0.14
DR1	1/21/18	20:40	N/A	13.8	10,400	21	6.0	8.0	22.0	<0.3	<0.05
DR1	2/15/18	19:00	N/A	14.1	4,000	63	7.6	8.2	28.4	<0.3	0.134
DR1	3/11/18	12:30	N/A	19.7	3,810	55	7.7	8.0	25.2	<0.3	0.119
DR1	3/28/18	9:20	N/A	20.6	3,020	41	7.3	8.2	16.4	<0.3	0.479
DR1	4/1/18	12:45	N/A	22.0	3,170	40	7.4	7.1	17.6	<0.3	0.419
DR1	5/31/18	16:15	N/A	30.8	21,000	19	5.2	7.6	7.0	<0.3	<0.05
DR1	6/14/18	9:50	N/A	29.2	7,496	50	5.0	6.8	21.0	<0.3	<0.05

North Fork Deer River at Dauphin Island Parkway											
Site	Date	Time	Discharge	Temperature	SC	Turbidity	pH	DO	TSS	NO_3	Total P
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
DR2	1/12/18	14:00	30	12.8	5,650	45	6.3	8.8	25.6	<0.3	0.061
DR2	1/21/18	20:15	44	12.6	3,100	15	6.3	8.6	10.8	<0.3	0.749
DR2	2/15/18	18:30	332	14.2	2,960	110	7.1	8.5	69.2	0.307	0.108
DR2	3/11/18	12:10	230	19.9	1,150	165	7	8.0	93.6	<0.3	<0.05
DR2	3/28/18	9:00	55	20.1	3,110	45	7.5	8.1	22.0	<0.3	1.3
DR2	4/1/18	12:15	112	22.2	2,720	48	6.8	8.6	23.2	<0.3	<0.05
DR2	5/31/18	15:45	30	31.4	27,300	17	4.6	6.9	10.0	<0.3	<0.05
DR2	6/14/18	9:20	175	29.8	6,570	95	4.7	6.8	58.0	<0.3	<0.05

South Fork Deer River at Sunset Road

Site	Date	Time	Discharge	Temperature	SC	Turbidity	pH	DO	TSS	NO_3	Total P
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
DR3	01/12/16	15:00	8	12.9	639	48	6.8	8.7	27.6	<0.3	0.078
DR3	01/21/16	20:50	51	13.2	8,330	10	6.1	8.9	10.8	<0.3	<0.05
DR3	02/15/16	19:20	90	14.8	2,830	32	7.4	9.1	13.6	<0.3	0.054
DR3	03/11/16	13:00	137	19.9	586	34	6.9	6.8	20.8	<0.3	0.208
DR3	03/28/16	9:35	19	20.0	104	23	6.3	7.6	6	0.496	0.107
DR3	04/01/16	13:00	40	21.9	168	23	6.6	8.8	9.6	<0.3	<0.05
DR3	05/31/16	16:30	20	31.1	5,760	17	4.9	7.5	5	<0.3	<0.05
DR3	08/27/19	12:30	19	27.5	2,830	12	6.2	3.1	4.0	<0.3	<0.05
DR3	09/01/19	9:20	26	27.7	1,410	15	6.1	2.8	5.0	<0.3	<0.05

South Fork Deer River Unnamed Tributary at Sunset Road

Site	Date	Time	Discharge	Temperature	SC	Turbidity	pH	DO	TSS	NO_3	Total P
			cfs	°C	mS/cm	NTU		mg/L	mg/L	mg/L	mg/L
DR4	08/27/19	16:00	1.5	27.5	103	>1,000	6.8	3.2	N/A	N/A	N/A
DR4	09/01/19	9:50	0.1	27.1	109	25	6.0	0.7	N/A	N/A	N/A