EVALUATION OF PRE- AND POST-RESTORATION SEDIMENT LOADS IN JOES BRANCH, SPANISH FORT, BALDWIN COUNTY, ALABAMA

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By

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Funding for this project was provided by the
Mobile Bay National Estuary Program

2019

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INTRODUCTION

Joes Branch is a tributary of D'Olive Creek, with headwaters in Spanish Fort, west-central Baldwin County (fig. 1). The watershed contains about 0.9 square miles (mi^2) of drainage area, drains the western part of the city of Spanish Fort, and flows southwestward underneath Interstate Highway 10 where it joins D'Olive Creek immediately upstream from Mobile Bay.

The initial water-quality and sediment transport assessment in the Joes Branch watershed occurred in 2007 as a result of a severe erosion in the D'Olive Creek watershed. The assessment, *Analysis of Sediment Loading Rates and Impacts of Land-Use Change on the D'Olive and Tiawasee Creek Watersheds, Baldwin County, Alabama,* 2007 (Cook and others, 2007) resulted in quantification of water-quality impacts and listing of the Joes Branch watershed on the Alabama Department of Environmental Management Section 303 (d) list of impaired waters. The assessment also identified the need for major remediation to correct land-use based degradation of stream channels and water quality. A restoration plan was prepared in summer 2012, which included construction of step pool storm conveyance system (JB1) in an unnamed tributary of Joes Branch on the south side of US Highway 31, extending southwestward 1,000 feet (figs. 2, 3). The step pool storm conveyance system empties into a relatively broad wetland, which was restored as part of the implementation of the restoration plan (fig. 2). Construction was completed in April 2013. A second report, *Phase II Post-Restoration Analysis of Discharge and Sediment Transport Rates in Tributaries of Joes Branch in Spanish Fort, Baldwin County, Alabama* (Cook and others, 2014), documented the effectiveness of the restoration, in which sediment loads were reduced by more than 90 percent.

The restored waterway withstood a severe storm in April 2014 and sustained only minor damage, although severe headcutting began downstream from the restored reach. However, downstream headcutting advanced through the restored wetland to the base of the step pool conveyance system, resulting in a channel about 10 feet wide, four feet deep, and 700 feet long. About 1,600 feet of the unnamed tributary downstream of JB1 was impacted. Therefore, in April 2015 a second phase of restoration 9JB2) was initiated to repair the wetland and restore the downstream damage

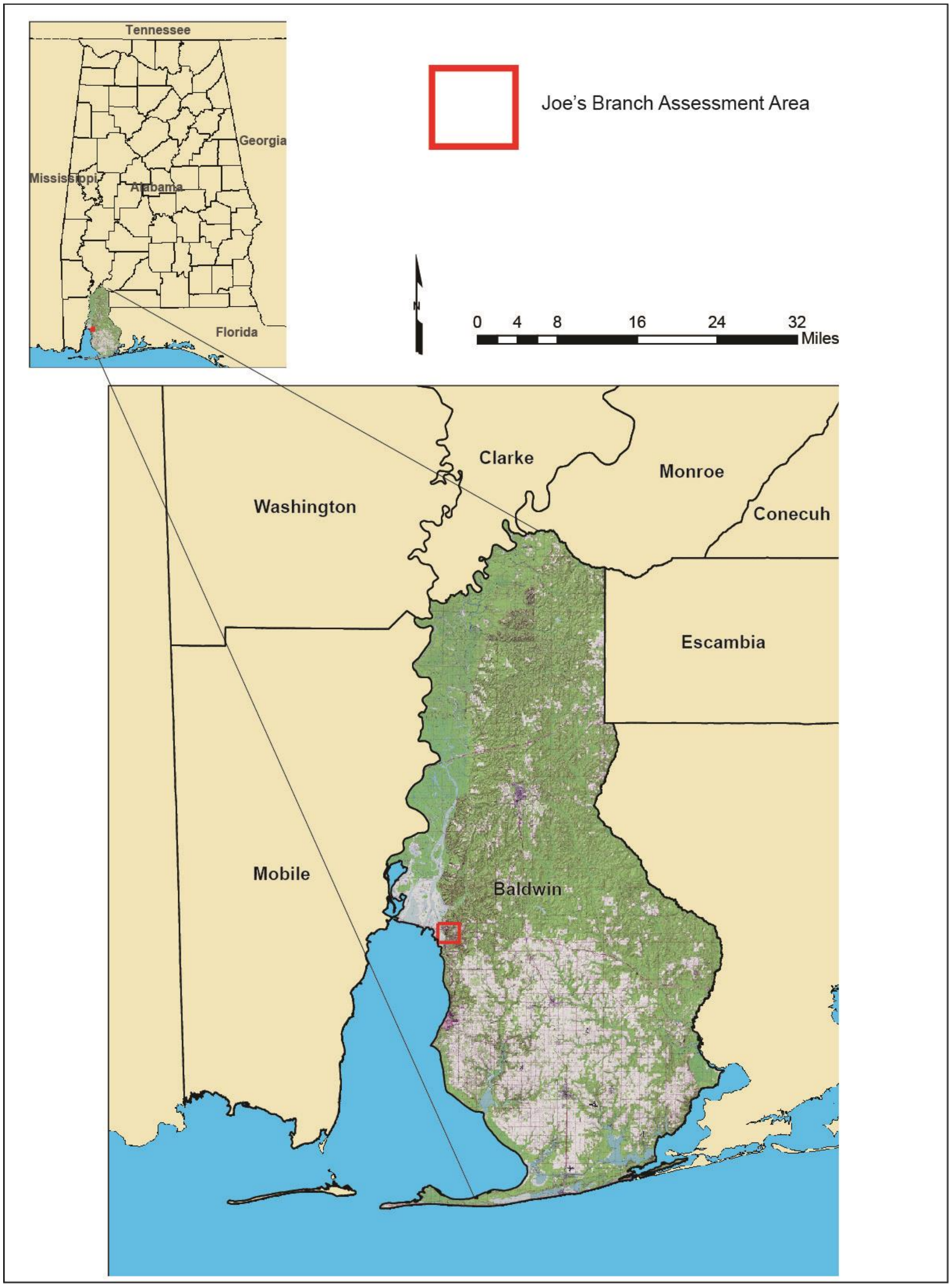


Figure 1.—Joes Branch watershed area in west-central Baldwin County.

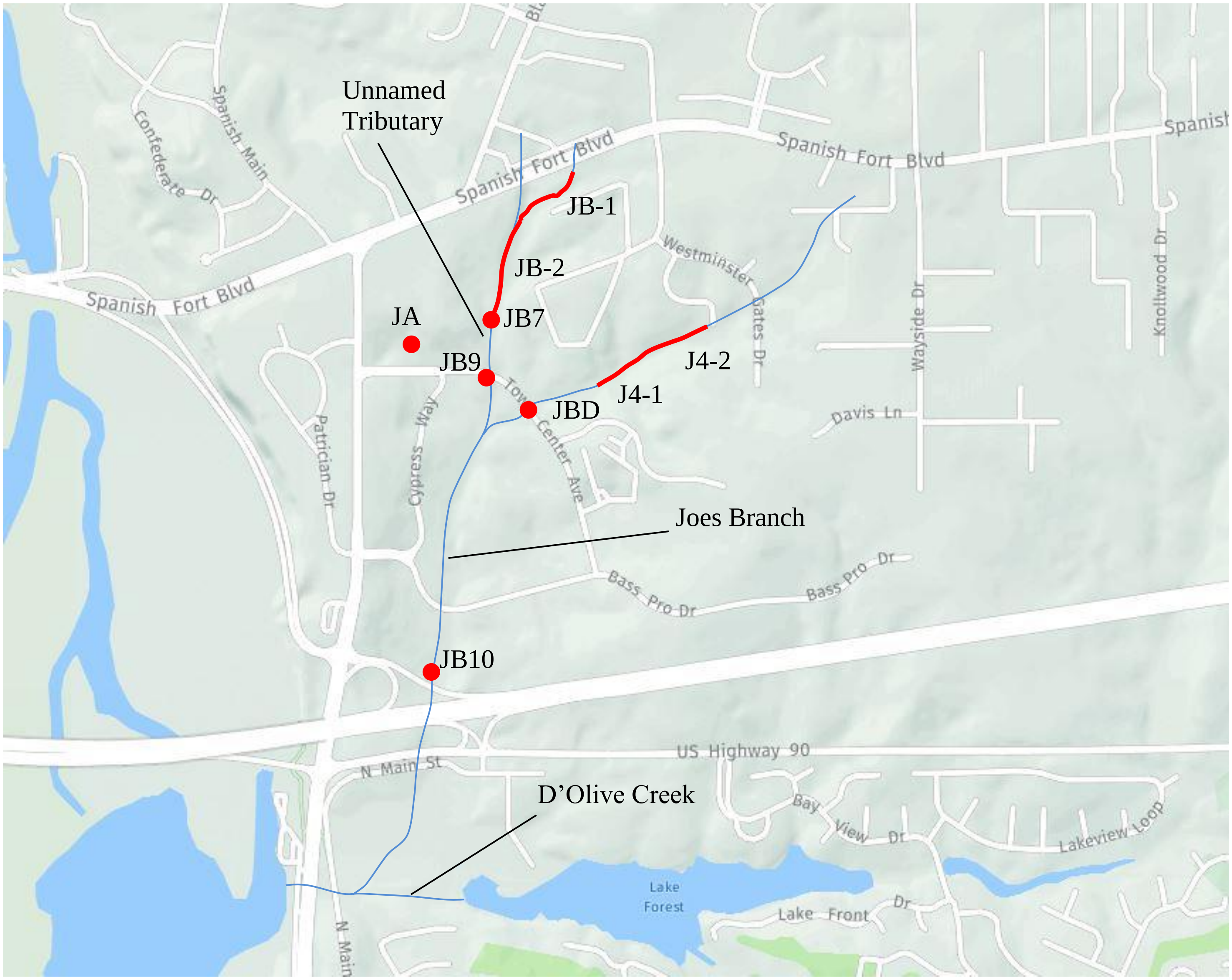


Figure 2.—Joes Branch watershed with restoration projects and monitoring sites.

caused by the headcut. This work was completed in August 2015 (fig. 4). A stormwater retention structure was also added on the north side of US Highway 31. Post-construction monitoring of the first phase of restoration was ongoing at site JB9, at the time of the second headcut. Therefore, monitoring continued during and after construction of the second phase of restoration.

An additional severe headcut was discovered on the main stem of Joes Branch, about 1,200 ft downstream from the headwaters, near the Westminster Gates subdivision (fig. 2). A second stream restoration system was constructed along with other remediation measures (J41 and J42) totaling about 1,100 ft of stream channel. This project also included stream stabilization of a 600-foot stream segment JA, east of JB0, downstream of the Piggly Wiggly shopping center. This phase of construction began in February 2016 and was completed in November 2016. Water quality and sediment transport monitoring, consisting of periodic measurements continued at site JBD from 2016 and ended in April, 2019. The resulting data set collected at sites JB7 (2012 predecessor to site JB9), JB9, JBD, and JB10 documents pre- and post-restoration conditions and effectiveness of remedial measures implemented in the Joes Branch watershed. The goal of this assessment is to provide data to the Alabama Department of Environmental Management, to be combined with future post-restoration monitoring data to determine the effectiveness of remediation and to determine if the stream can be removed from the Section 303 (d) list of impaired waters.

ACKNOWLEDGMENTS

Ms. Roberta Swann, Director; Mr. Jason Kadulis, Monitoring and Science Coordinator; and Mr. Tom Herder, Watershed Protection Coordinator, Mobile Bay National Estuary Program, provided coordination for the project. Ms. Ashley Campbell, Environmental Director, city of Daphne provided technical assistance; and Mr. Bruce Bradley, President, Poly, Inc. provided administrative assistance and laboratory support.

Figure. 3—Step pool conveyance system constructed in the unnamed tributary of Joes Branch in Spanish Fort.

PROJECT MONITORING STRATEGY AND SITE CHARACTERISTICS

The post-restoration monitoring strategy for Joes Branch was to measure discharge, field water-quality parameters, and sediment transport rates immediately downstream from the reaches where remedial measures were constructed and as near to the mouth of Joes Branch as possible. The Joes Branch project monitoring design included three sites. All discharge measurements, water sample collections, and field parameter measurements were made using ADEM Standard Operating Procedures. A copy of Standard Operating Procedures used for this project is available from the Mobile Bay National Estuary Program or Poly, Inc.

Site JB9 is at the Town Centre Boulevard crossing, about 200 ft upstream from the confluence of the unnamed tributary and Joes Branch (fig. 2). The site monitored a drainage area of 0.27 mi^2 and was downstream from all restoration activities on the unnamed tributary. The purpose of this site was to monitor general water quality,

Figure 4.—Phase II reconstruction downstream from the step pool conveyance (upper photo) and stream channel in 2015 immediately upstream from site JB9 (lower photo).

discharge, and sediment transport rates, and to determine the effectiveness of all remedial structures in the unnamed tributary, including the step pool storm conveyance system and the restored wetland.

Site JBD is on the main stem of Joes Branch at the Town Centre Boulevard crossing (fig. 2). The site monitored a drainage area of 0.26 mi^2, and was downstream from the J4-1, J4-2 stream restoration system and storm water detention structure near Westminster Gates subdivision. The purpose of site JBD was to monitor discharge, general water quality, and sediment transport rates, and to determine the effectiveness of stormwater detention and the stream restoration system on Joes Branch.

Site JB10 is downstream from all restoration projects in the Joes Branch watershed and monitored a drainage area of 0.78 mi^2 (fig. 2). The purpose of site JB10 was to monitor general water quality, discharge, and sediment transport rates to determine the effectiveness of all remedial measures employed in the Joes Branch watershed.

The total data set, including pre- and post-restoration data consists of data collected in 2006-2008, 2011-2012, 2014-2019. Post-restoration data was divided and analyzed in three groups (2015-2016, 2016-2017, and 2017-18), to determine annual sediment loads throughout the monitoring period and to distinguish construction period impacts.

STREAM FLOW AND PRECIPITATION

Precipitation, stream gradient, geology, and land use are all important factors that influence sediment transport characteristics and water quality of streams. Estimates of sediment transport rates and loads are based on measured sediment and stream discharge. Stream discharge at all monitoring sites is extremely flashy, due to relatively large topographic relief and resulting high stream gradient, impervious surfaces, and intense individual rainfall events.

Measured discharge ranged from 0.3 to 29.3 cubic feet per second (cfs) at site JB9, 2.4 to 98 cfs at site JBD, and 0.5 to 151 cfs at site JB10. Average daily discharge values required for sediment load estimations were obtained from ratios between measured discharge at each monitored site and data obtained from the USGS stream gaging site (02378500, Fish River near Silver Hill, Alabama), which is 9.9 miles southeast of the Joes Branch watershed.

Annual precipitation for 2016-2018 was obtained from the USGS Fish River gaging site to evaluate estimated annual discharge rates for each monitored site. Precipitation was 63.02 inches in 2016, 58.48 inches in 2017, and 61.85 inches in 2018.

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). Turbidity data may also be used to evaluate methods of treatment necessary to remove sediment from water.

The ADEM maximum criterion for turbidity in streams classified as Fish and Wildlife is ≤ 50 Nephelometer Turbidity Units (NTU) above natural background for a particular stream. The following was taken from the ADEM 2018 Alabama's Water Quality Assessment and Listing Methodology:

4.10 Minimum Sample Size and Allowable Number of Water Quality Criterion Exceedances

Table 17 *shows the allowable number of exceedances for various samples sizes up to 199 samples. The Department's annual sampling plans and available resources generally allow for at least eight samples per sampling location except in reservoirs where fewer samples (i.e. 3 samples) may be collected due to sample holding time and resource constraints. The number of exceedances in each range of sample sizes was calculated using the binomial distribution function. This number is the number of exceedances of a particular water quality criterion needed to say with 90% confidence that the criterion is exceeded in more than 10% of the population represented by the available samples. This table will be used to determine the number of exceedances of Alabama numeric water quality criteria listed in ADEM Administrative Code r. 335-6-10 (for dissolved oxygen, temperature, turbidity, pH, and bacteria), consistent with the assessment methodology for each use discussed earlier, necessary to establish that a waterbody segment is not fully supporting its designated uses. This approach is consistent with ADEM Administrative Code r. 335-6-10, which recognizes that natural conditions may cause sporadic excursions of numeric water quality criteria, and with EPA's 1997 305(b) guidance. For conventional water quality parameters, there must be at least eight temporally independent samples collected during the previous six-year period to be considered adequate for making use support determinations, except where fewer samples are determined to be adequate as discussed earlier. As used in this context, temporally independent means that the samples were collected at an interval appropriate to capture* *the expected variation in the parameter. For example, dissolved oxygen, temperature, and pH measurements should capture the normal diurnal variation that occurs in the parameters and temporal independence may occur in several hours (i.e. morning versus afternoon). Measurements for turbidity and bacteria should typically be at least 24 hours apart.*

Table 1.--Minimum Number of Samples Exceeding the Numeric Criterion Necessary for Listing*

Sample size	Number of exceedances
8 thru 11	2
12 thru 18	3
19 thru 25	4
26 thru 32	5
33 thru 40	6

*Table 1 modified from the ADEM 2018 Alabama's Water Quality Assessment and Listing Methodology Table 17.

Turbidity was measured downstream from major erosion and restoration activities during the pre-restoration period from February to July 2012 and during the construction and post-restoration periods from May 2014 to April 2019. The post-restoration assessment (Cook and others, 2016) documented that turbidity was reduced by an order of magnitude after construction of the JB1 step pool storm conveyance system and wetland restoration in 2012-2013. These upstream sediment load reductions resulted in increased stream flow energy downstream, resulting in downstream headward erosion, severe channel erosion, and damage to the wetland restoration, which led to a second phase of restoration in the unnamed tributary, downstream from the step pool storm conveyance system. Measurements made at site JB9 in 2015, after construction of the second phase of restoration (JB2) indicate an order of magnitude reduction in turbidity when compared to pre-phase II turbidity measurements made immediately upstream at site JB7 (fig. 5). Figures 6, 7, and 8 show turbidity values for pre-restoration/construction and post-restoration periods for sites JB9, JBD, and JB10, respectively.

Turbidity values for pre-construction and construction periods at site JB9 ranged from 42 to more than 1,000 NTU with a median value of 153 NTU (fig. 6). Discharge for the period ranged from 0.5 to 29.3 cfs with a median value of 4.6 cfs. Values for the post-construction period ranged from 5 to 145 NTU with a median value of 33 NTU and a

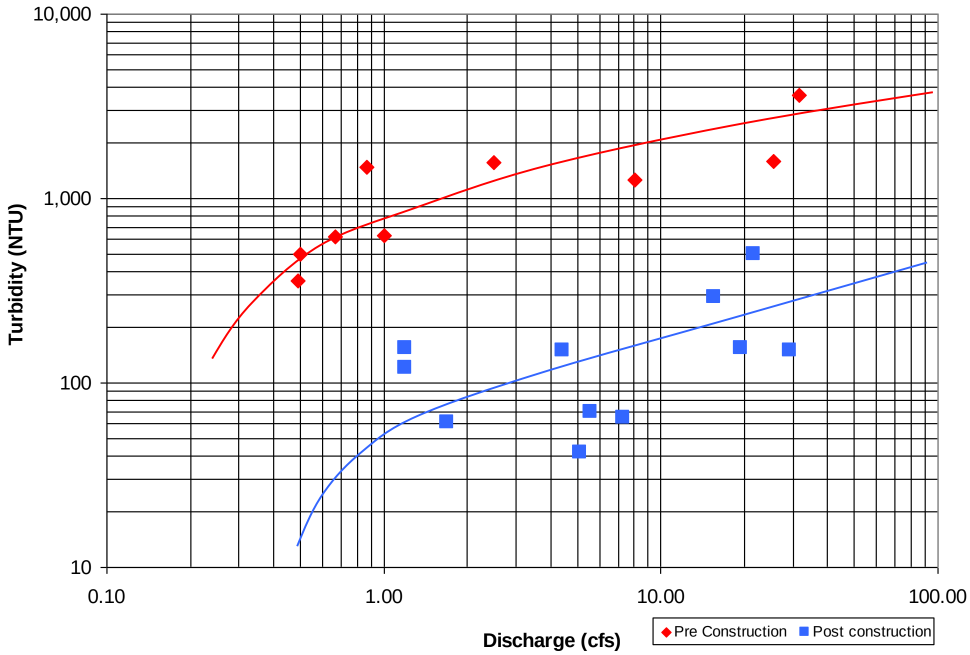
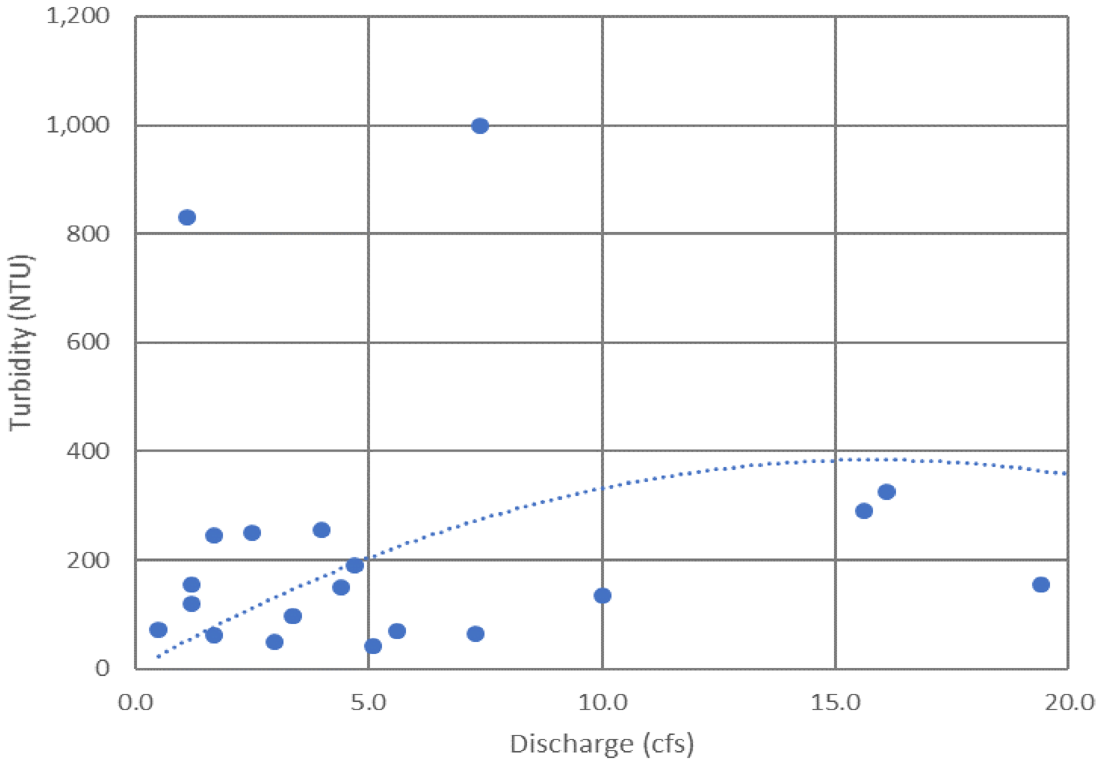


Figure 5.—Comparison of turbidity values for site JB7 during the phase II pre-construction period and site JB9 during the phase II post-construction period.

discharge range from .02 to 13.7 cfs with a median value of 0.8 cfs. Comparison of regression curves on graphs for pre- and post-construction periods at site JB9 show that turbidity decreased during the post-construction period by about 65 percent.

Turbidity values for pre-construction and construction periods at site JBD ranged from 15 to 542 NTU with a median value of 242 NTU (fig. 7). Discharge for the period ranged from 0.05 to 11.4 cfs with a median value of 4.0 cfs. Values for the post-construction period ranged from 28 to 245 NTU with a median value of 43 NTU and a discharge range from 2.4 to 98.0 cfs with a median value of 6.0 cfs. Comparison of regression curves on graphs for pre- and post-construction periods at site JB9 show that turbidity decreased during the post-construction period by about 80 percent.

Turbidity values for pre-construction and construction periods at site JB10 ranged from 40 to 260 NTU with a median value of 196 NTU (fig. 8). Discharge for the period ranged from 5.0 to 50.0 cfs with a median value of 16.5 cfs. Values for the post-construction period ranged from 14 to 250 NTU with a median value of 65.5 NTU and a discharge range from 0.5 to 151 cfs with a median value of 17.2 cfs. Comparison of regression curves on graphs for pre- and post-construction periods at site JB9 show that turbidity decreased during the post-construction period by about 60 percent.



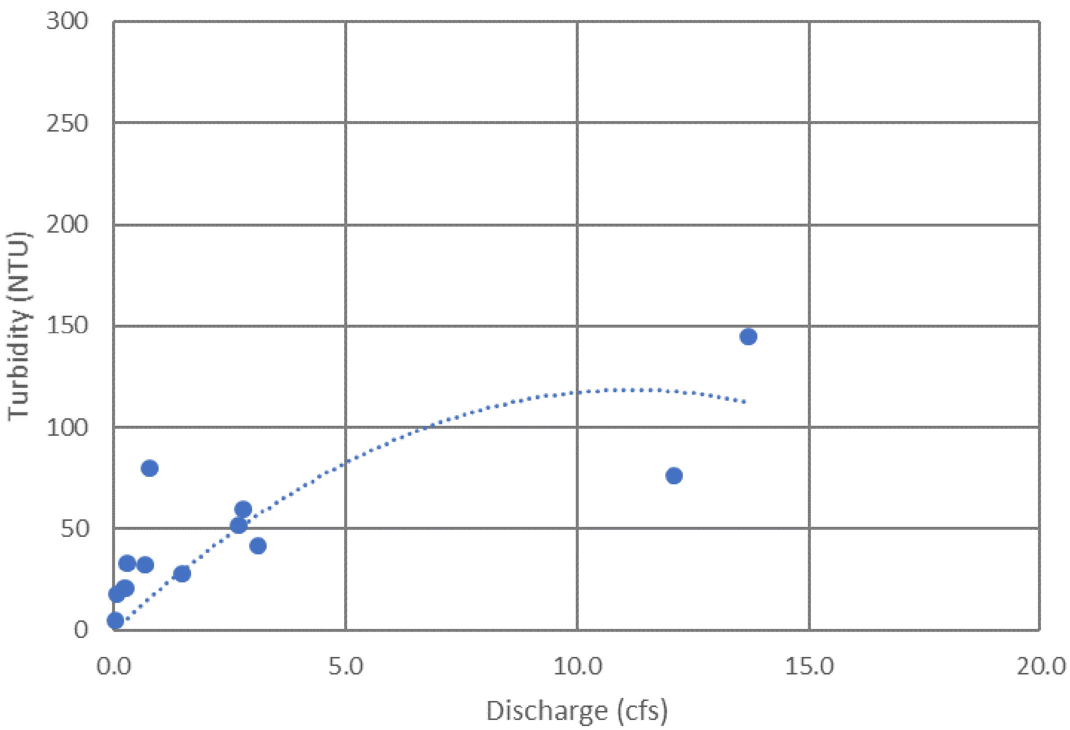
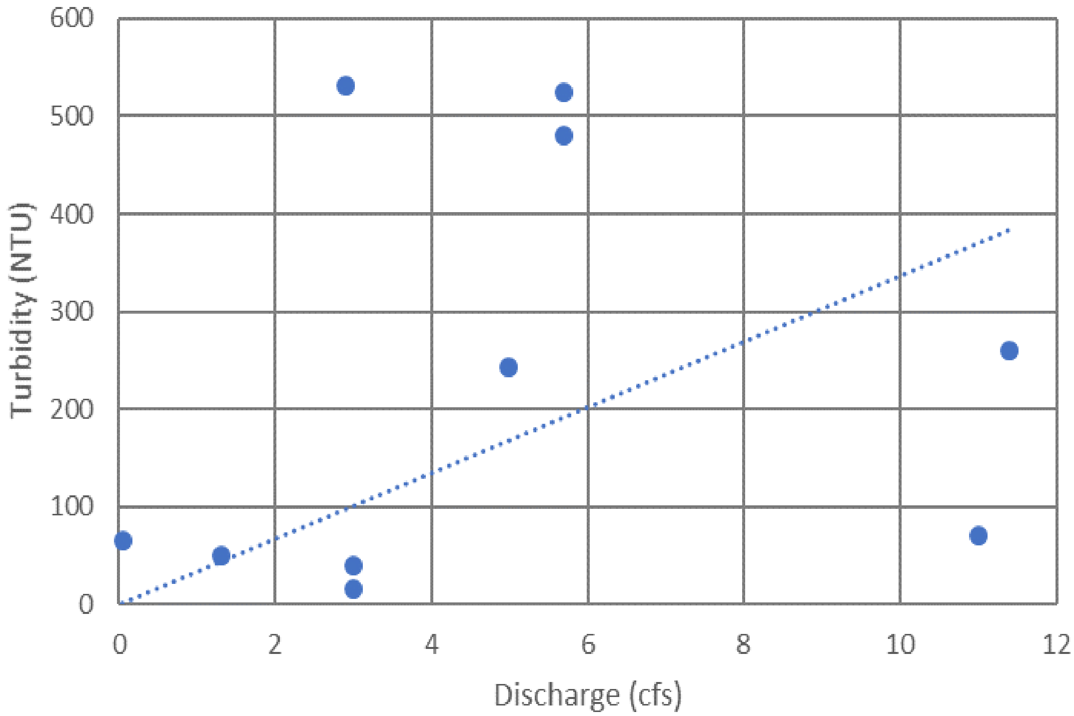


Figure 6.—Turbidity and stream discharge for pre-construction and construction (upper graph) and post-construction (lower graph) periods for Joes Branch unnamed tributary site JB9.



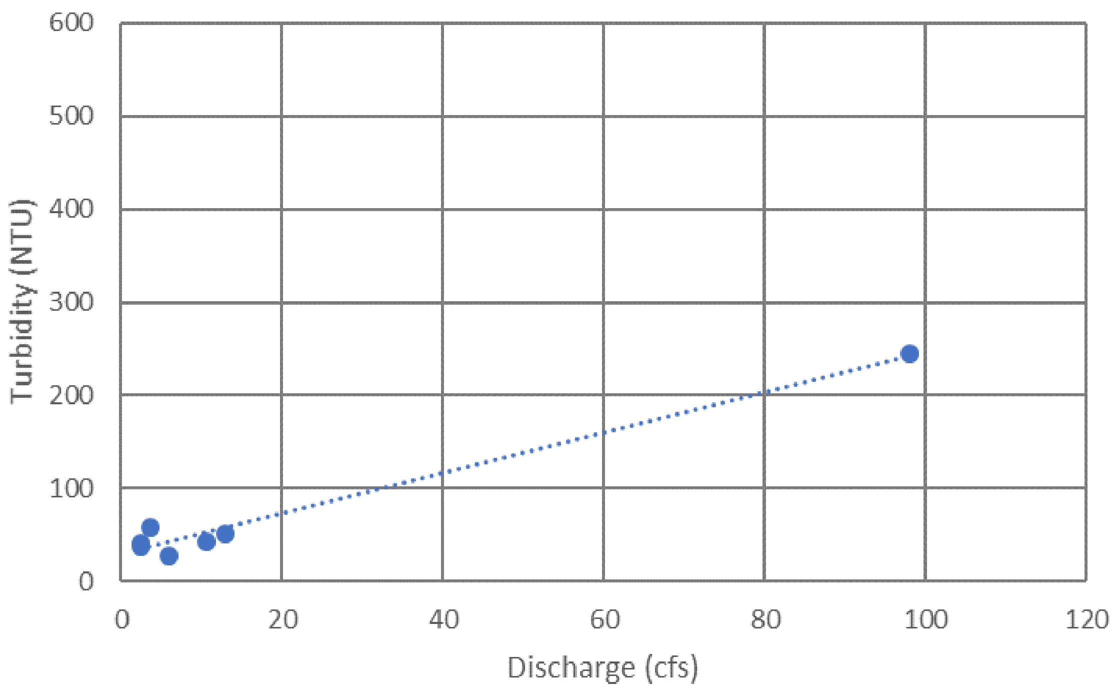
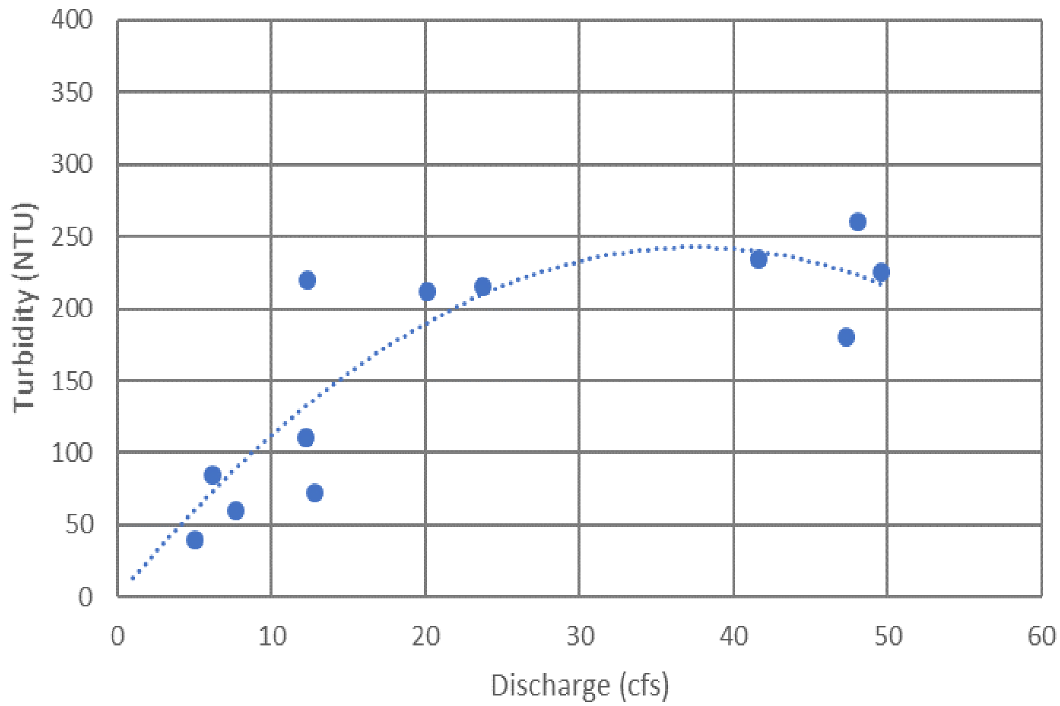


Figure 7.—Turbidity and stream discharge for pre-construction and construction (upper graph) and post-construction (lower graph) periods for Joes Branch site JBD.



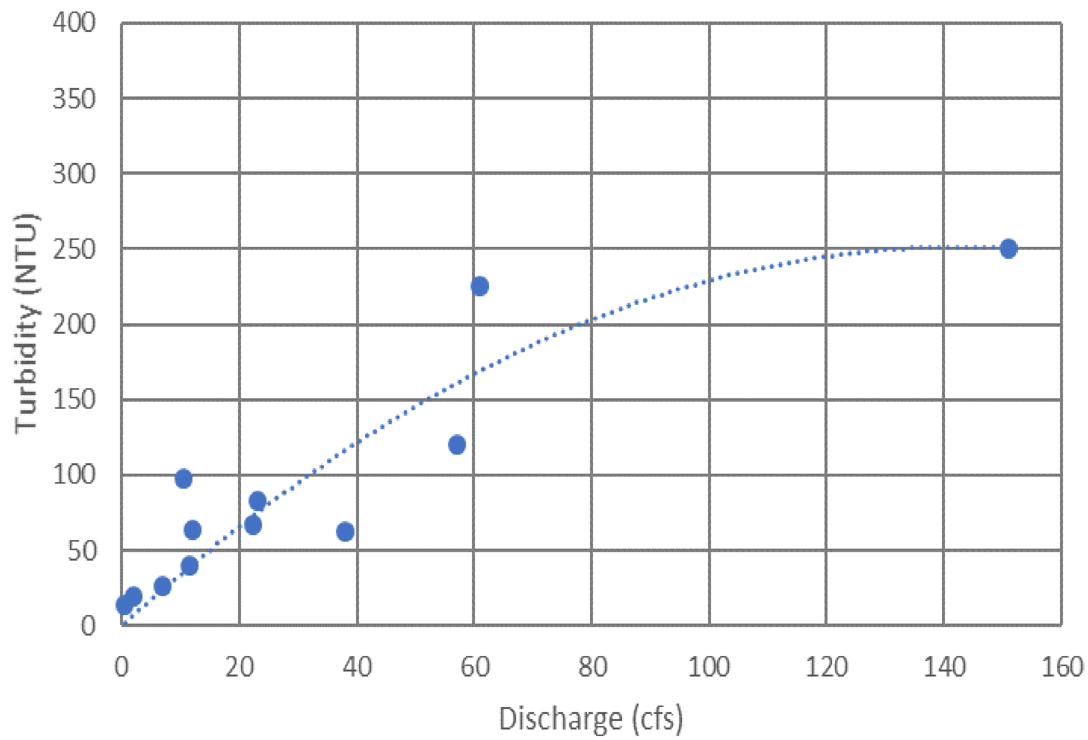


Figure 8.—Turbidity and stream discharge for pre-construction and construction (upper graph) and post-construction (lower graph) periods for Joes Branch site JB10.

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, reduces storage volume of water impoundments, impedes the usability of aquatic recreational areas, and causes damage to structures. Streams with excessive sediment loads that discharge into estuaries, damage estuarine habitats including aquatic vegetation, fish and shellfish, and limit boating and recreational access.

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 sediment).

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. Highly erodible soils formed from sand, clayey sand, and sandy clay of the undifferentiated Miocene Series and the Citronelle Formation, combined with relatively high topographic relief related to the formation of Mobile Bay, is a major contributing factor to high rates of erosion and sedimentation. This situation can be aggravated in watersheds dominated by urban development, such as Joes Branch, where upland areas are covered with impervious surfaces, such as roofs, driveways, streets and highways, and parking lots that increase runoff and cause accelerated stream flow velocities, flashy flows, and flooding.

Monitoring of the unnamed tributary to Joes Branch included bed and suspended sediment, which were measured in the stream channel at site JB6 (downstream terminus of the step pool storm conveyance system) prior to the first phase of restoration and was measured on hard surfaces after installation of the step pool conveyance system so that all sediment was assumed to be suspended. Bed and suspended sediment were measured at the downstream end of the wetland at site JB7 until the downstream headward erosion occurred. At that time, downstream monitoring was shifted to site JB9 at the Town Center Boulevard crossing where bed and suspended sediment were measured until February 2016 when bed sediment volumes were reduced to the point that it could not be measured.

SUSPENDED SEDIMENT

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 9 shows the correlation between turbidity and total suspended solids for sites JB9, JBD, and JB10. Figure 10 shows the temporal context of monitoring at site JB9 from May 2014 through December 2015, where after the second phase of restoration in the unnamed tributary was completed, suspended solids values returned to those measured after the first phase of restoration.

Annual suspended sediment loads for the post-restoration monitoring period were estimated at the monitored sites 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

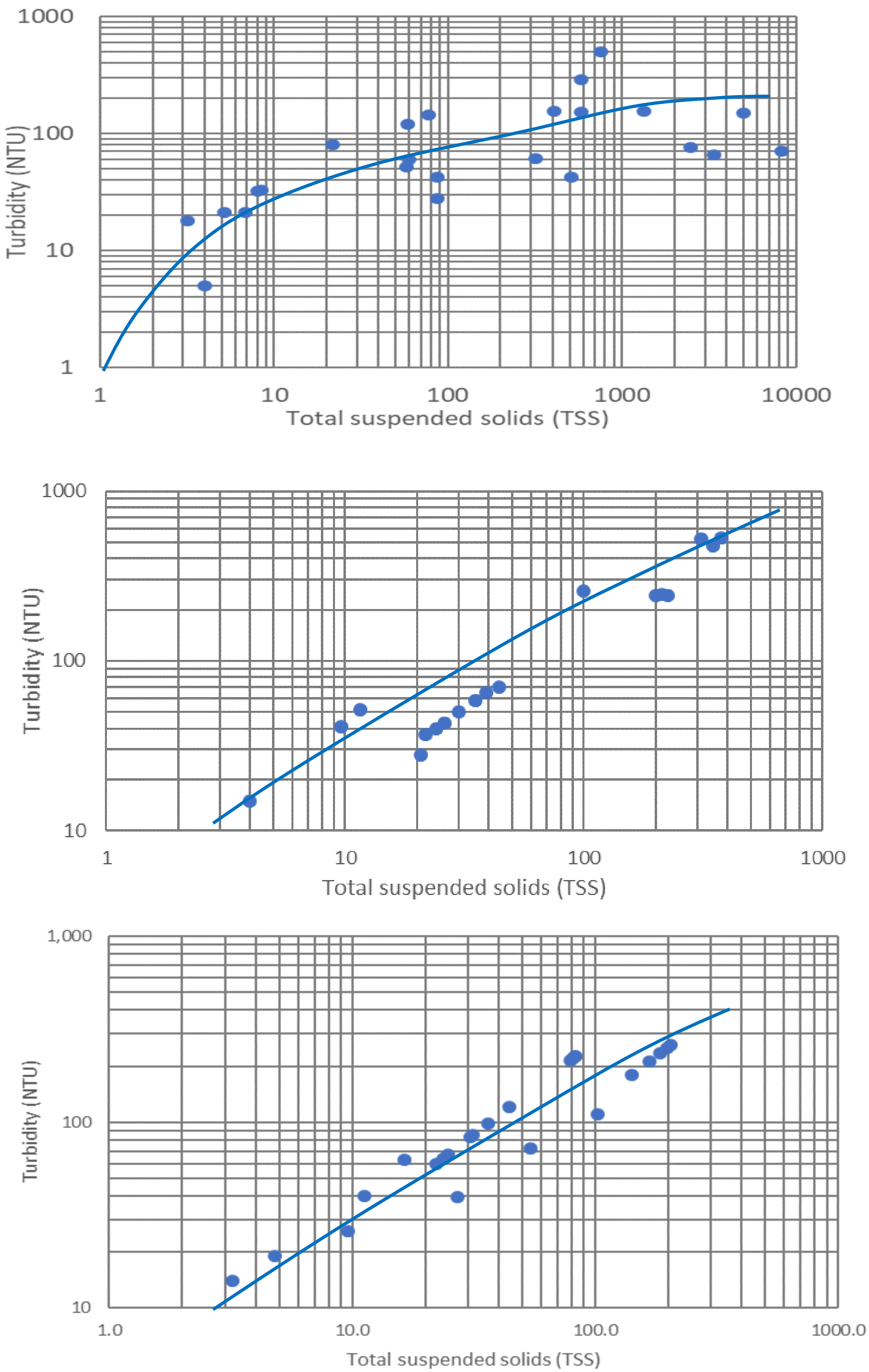


Figure 9.—Correlation of TSS and turbidity for pre- and post-construction water samples collected at Joes Branch sites JB9 (upper graph), JBD (middle graph), and JB10 (lower graph).

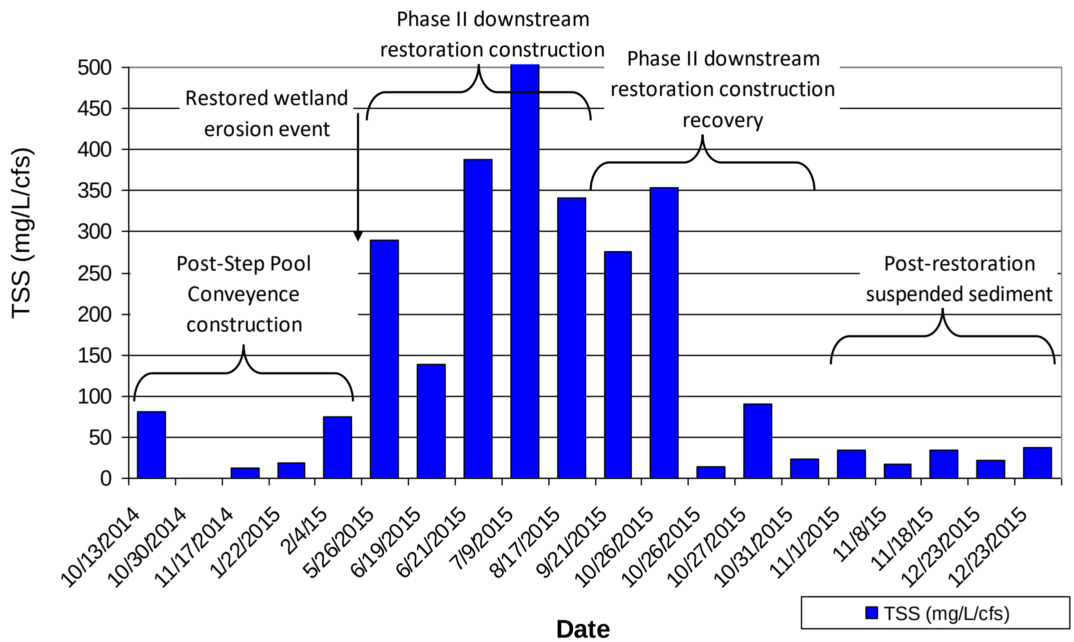


Figure 10.—Site JB9 showing the temporal context of restoration activities and corresponding normalized TSS values.

perennial streams (Cohn and others, 1992). The regression with centering program (*Regression with Centering*) (Richards, 1999) requires total suspended solids concentrations and average daily stream discharge to estimate annual loads. Concentrations of TSS in mg/L were determined by laboratory analysis of periodic water grab samples.

Annual suspended sediment loads were estimated for sites JB7, during pre- and post-phase I restoration periods and JB9, during pre- and post-phase II restoration periods. The estimated annual suspended sediment load for site JB7 (downstream from the step pool storm conveyance system and wetland area) during the post-phase I restoration monitoring period was 1,034 t/yr, which indicates a reduction of about 94 percent when compared to the pre-phase I restoration load (18,236 t/yr). Therefore, the suspended sediment load estimated at site JB7, eventually transported to Mobile Bay, was reduced from 33,770 cubic yards or 20.9 acre-feet per year to 1,915 cubic yards or about 1.2 acre-feet per year.

Additional data were added to the data set from 2016 to 2019. Suspended sediment loads were estimated, using the additional data, for each year to determine changes in suspended sediment loads since the phase II construction in 2015. Loading estimates for these periods are 5,764 t/yr for the 2015-2016, 12-month period and 497 t/yr for the 2017-2018, 12-month period, which indicates continual reductions since the phase II construction and an overall reduction of about 97 percent from the 2012 pre-construction period. Normalized suspended sediment loads are 21,347 t/mi^2/yr for the 2015-2016, 12-month period and 1,840 t/mi^2/yr for the 2017-2018, 12-month period. Figure 11 shows suspended sediment loads estimated for all annual monitoring periods.

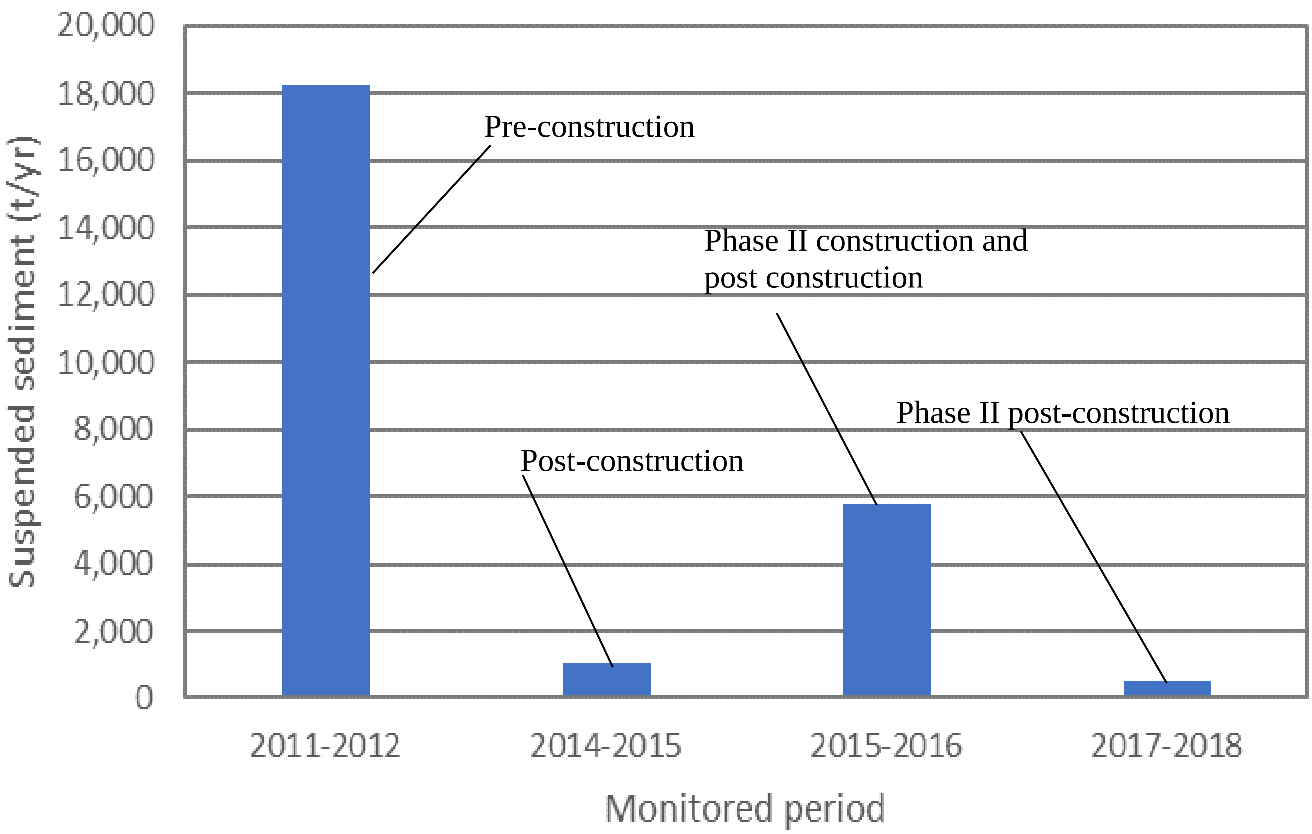


Figure 11.—Annual estimated suspended sediment loads for the unnamed tributary to Joes Branch at sites JB7 and JB9.

Suspended sediment loads were also estimated for site JBD, to evaluate remedial measures constructed near the headwaters of Joes Branch and for site JB10 to demonstrate changes in sediment transport throughout the entire watershed. Discharge and TSS measurements were made at site JBD during the pre-construction period from June 2014 to April 2015. The estimated annual suspended load for the pre-construction period was 2,594 t/yr and the normalized load with respect to unit drainage area was 9,978 t/mi^2/yr. Post-construction monitoring occurred from June 2017 to April 2019. Post-construction estimated annual loads for the post-construction period are 39.7 t/yr and 153 t/mi^2/yr (normalized). This is a reduction in suspended sediment of about 98 percent.

The first sediment load estimated for site JB10 in 2006-2008 was 303 t/yr. However, this was not a meaningful value, since much of the data that the load was estimated from were collected during severe drought conditions in 2007. Additional data were collected from May 2014 to April 2015, after construction of Phase I but before Phase II construction in the unnamed tributary or before J4-1 and J4-2 construction in Joes Branch. Suspended sediment loads for this period were 32,948 t/yr and 35,813 t/mi^2/yr (normalized). Post-construction data were collected from February 2016 to April 2019. Annual loads for the 2016-2017 post-construction period were 1,687 t/yr and 2,183 t/mi^2/yr (normalized), a reduction of 95 percent. Post-construction loads for the 2017-2018 period were 158 t/yr and 203 t/mi^2/yr (normalized). This is a reduction of more than percent 99. Figure 12 shows suspended sediment loads for all monitored periods for sites JBD and JB10.

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

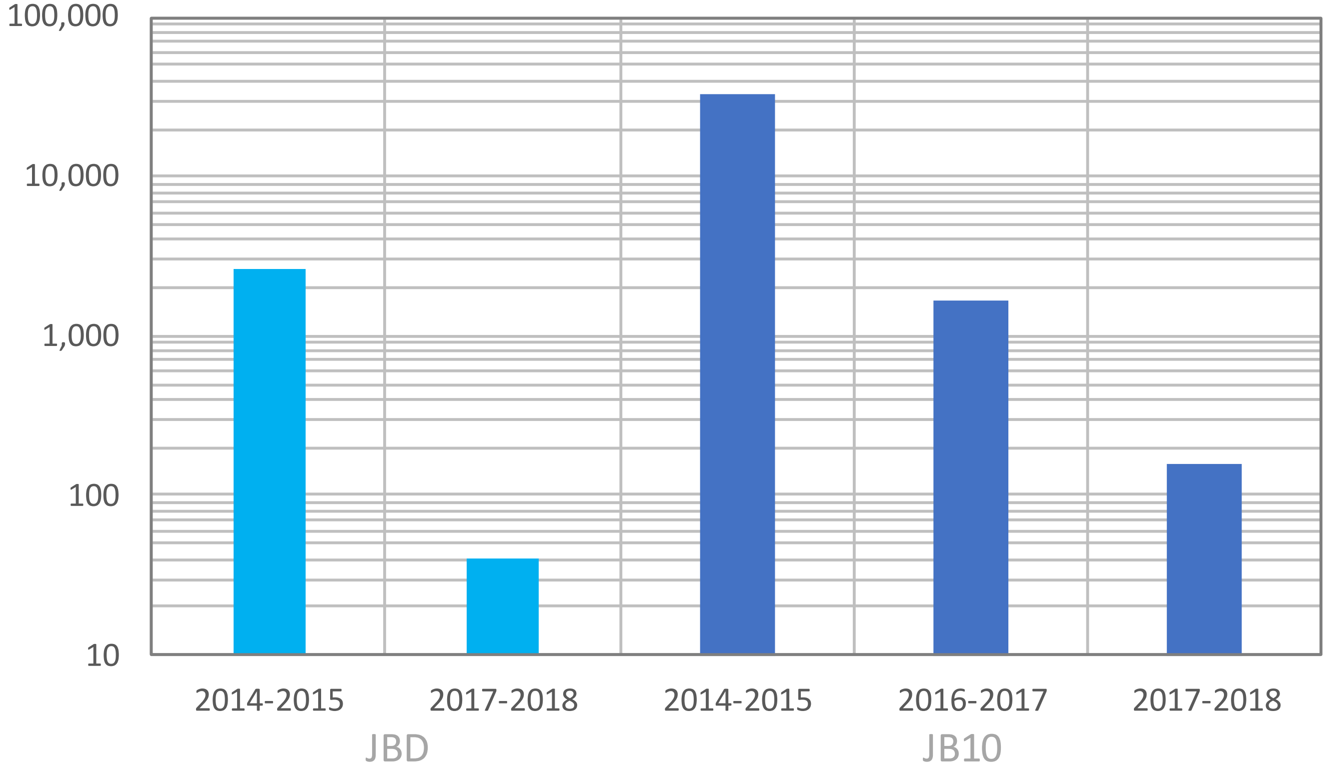


Figure 12.—Annual estimated suspended sediment loads for Joes Branch at sites JBD and JB10.

caused by changing precipitation rates, and/or land use practices that promote excessive erosion in the floodplain or upland areas of the watershed. Bed sediment 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.

Bed sediment was monitored at sites JB7 and JB9 in the unnamed tributary and at site JB10 in Joes Branch. All water samples at site JBD were collected on a concrete surface, therefore, all sediment was considered suspended.

Pre-construction bed sediment loads in the unnamed tributary during 2011-2012 were 3,948 t/yr and 17,946 t/mi ^{2}/yr (normalized). Subsequent to the Phase I construction during 2014 and 2015, loads were reduced to 1,113 t/yr and 5,059 t/mi ^{2}/yr (normalized), a reduction of 72 percent. A bed sediment measurement on February 22, 2016 yielded a load of 0.2 tons per day. Eight additional measurement were attempted during 2016, 2017, and 2018, all yielding no measurable bed sediment.

Bed sediment data were collected from May 2014 to April 2015, after construction of Phase I but before Phase II construction in the unnamed tributary or before J4-1 and J4-2 construction in Joes Branch. Bed sediment loads for this period were 3,413 t/yr and 3,710 t/mi^2/yr (normalized). Post-construction bed sediment loads for the 2017-2018 period were 239 t/yr and 260 t/mi^2/yr (normalized). This is a reduction of 93 percent. Figure 13 shows bed sediment loads for all monitored periods for sites JB7, JB9, and JB10.

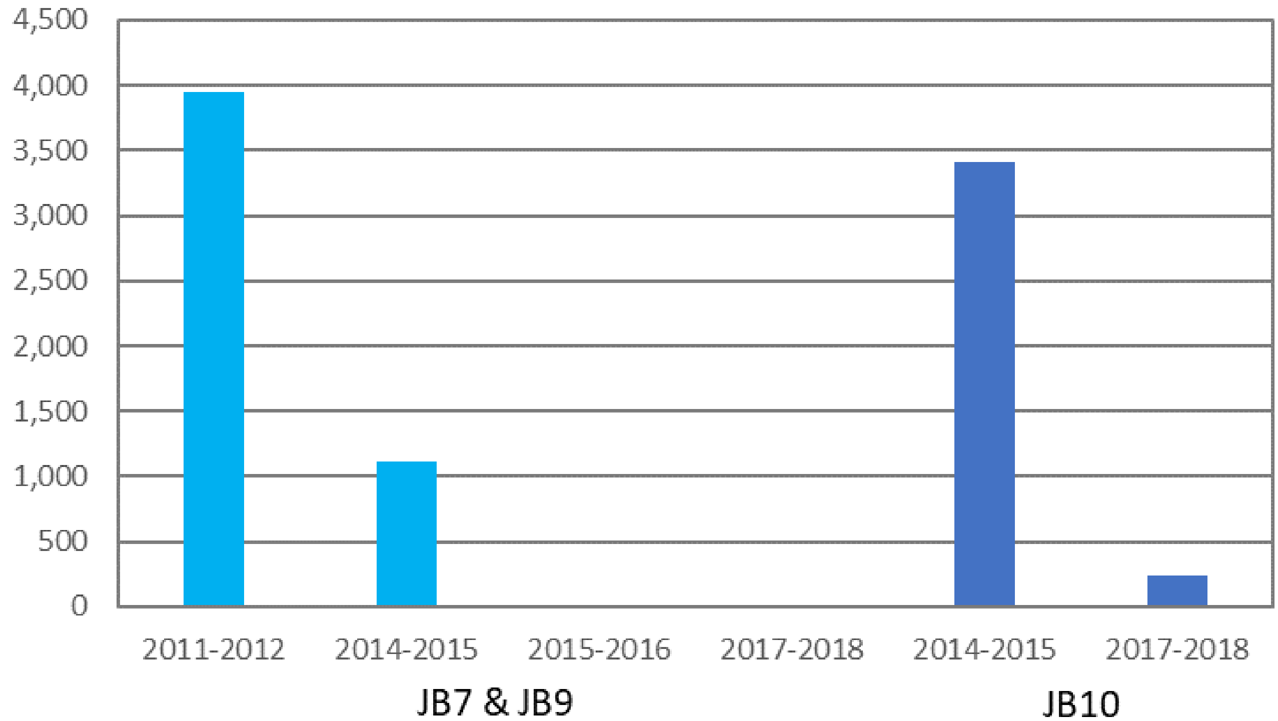


Figure 13.—Annual estimated bed sediment loads for Joes Branch at sites JBD and JB10.

TOTAL SEDIMENT LOADS

Total sediment loads are composed of suspended and bed sediment. As noted previously, much of the erosion in the project watersheds is caused by human activity. Without human impact, erosion rates and resulting sediment transport rate in the watershed, termed the geologic erosion rate, would be 64 t/mi^2/yr (Maidment, 1993). Therefore, the geologic erosion rate for the Joes Branch unnamed tributary watershed, upstream from site JB9 (drainage area 0.27 mi^2), is 17 t/yr. The geologic erosion rate for the watershed upstream from Joes Branch site JBD (drainage area 0.26 mi^2), is 16.6 t/yr and the watershed upstream from site JB10 (drainage area 0.78 mi^2) is 50 t/yr.

Total sediment loads at site JB7 were 22,184 t/yr (100,836 t/mi^2/yr) during the Phase I pre-construction monitoring period (2011-2012). Total loads during the post-construction monitoring period (2015-2016) were 5,764 t/yr (21,347 t/mi^2/yr) and 497 t/yr (1,840 t/mi^2/yr) during 2017-2018. This represents a 98 percent reduction in total sediment load transported from the unnamed tributary at site JB9.

Total sediment loads at site JBD were 2,594 t/yr (9,978 t/mi^2/yr) for the pre-construction period (2014-2015). Post-construction (2017-2018) estimated annual loads were 39.7 t/yr (153 t/mi^2/yr). This is a reduction in sediment transported from the Joes Branch watershed upstream from site JBD of about 98 percent.

Total sediment loads at site JB10 were 36,361 t/yr (39,523 t/mi^2/yr) after construction of Phase I but before Phase II construction (2014-2015) in the unnamed tributary or before J4-1 and J4-2 construction in Joes Branch. Total loads during the post-construction monitoring period (2015-2016) were 1,687 t/yr (2,183 t/mi^2/yr) and 397 t/yr (463 t/mi^2/yr) during 2017-2018. This represents a 99 percent reduction in total sediment load transported from Joes Branch at site JB10.

SUMMARY

Joes Branch is a tributary of D'Olive Creek, with headwaters in Spanish Fort, west-central Baldwin County. The watershed contains about 0.9 mi^2 of drainage area, drains the western part of the city of Spanish Fort, and flows southwestward underneath Interstate Highway 10 where it joins D'Olive Creek immediately upstream from Mobile Bay.

Due to the geologic and hydrologic character of the eastern shore of Mobile Bay, activities associated with land-use change are particularly effective in eroding and transporting large volumes of sediment that are eventually deposited in Mobile Bay. The Phase I assessment of an unnamed tributary to Joes Branch in 2011 and 2012, immediately downstream from U.S. Highway 31 in Spanish Fort, resulted in quantification of water-quality impacts and identified the need for major remediation to correct land-use based degradation of the stream channel and water quality.

Four primary monitoring sites were established for assessment of the Joes Branch watershed. Site JB7 was established near the downstream end of the impacted reach of the unnamed tributary to Joes Branch. The purpose of the site was for collection of data to determine the degree of impairment of the impacted reach.

Site JB9 is at the Town Centre Boulevard crossing, about 200 ft upstream from the confluence of the unnamed tributary and Joes Branch. The site monitored a drainage area of 0.27 mi^2 and was downstream from all restoration activities on the unnamed tributary. The purpose of this site was to monitor general water quality, discharge, and sediment transport rates, and to determine the effectiveness of all remedial structures in the unnamed tributary.

Site JBD is on the main stem of Joes Branch at the Town Centre Boulevard crossing. The site monitored a drainage area of 0.26 mi^2 and was downstream from the stream restoration system and storm water detention structure near Westminster Gates subdivision. The purpose of site JBD was to monitor discharge, general water quality, and sediment transport rates, and to determine the effectiveness of stormwater detention and the stream restoration system.

Site JB10 is downstream from all restoration projects on Joes Branch and monitored a drainage area of 0.78 mi^2. The purpose of site JB10 was to monitor general water quality, discharge, and sediment transport rates to determine the effectiveness of all remedial measures employed in the Joes Branch watershed.

The total data set, including pre- and post-restoration data consists of data collected in 2006-2008, 2011-2012, 2014-2019. Post-restoration data was divided and analyzed in three groups (2015-2016, 2016-2017, and 2017-18), to determine annual sediment loads and to distinguish construction period impacts.

Turbidity is used by the ADEM as a primary indicator of erosion and sediment transport in surface-water bodies. The ADEM maximum criterion for turbidity in streams classified as Fish and Wildlife is ≤ 50 Nephelometer Turbidity Units (NTU) above natural background for a specified stream. The ADEM guidance for turbidity sample collection is that there must be at least eight temporally independent samples collected during the previous six-year period to be considered adequate for making use support determinations. The definition for "temporally independent" is that samples were collected at an interval appropriate to capture the expected variation in the parameter. For example, measurements for turbidity should typically be at least 24 hours apart. There is no specific guidance for discharge conditions during sample collection.

Turbidity values for pre-construction and construction periods at site JB9 ranged from 42 to more than 1,000 NTU with a median value of 153 NTU (fig. 5). Discharge for the period ranged from 0.5 to 29.3 cfs with a median value of 4.6 cfs. Values for the post-construction period ranged from 5 to 145 NTU with a median value of 33 NTU and a discharge range from .02 to 13.7 cfs with a median value of 0.8 cfs. Comparison of regression curves on graphs for pre- and post-construction periods at site JB9 show that turbidity decreased during the post-construction period by about 65 percent.

Turbidity values for pre-construction and construction periods at site JBD ranged from 15 to 542 NTU with a median value of 242 NTU (fig. 7). Discharge for the period ranged from 0.05 to 11.4 cfs with a median value of 4.0 cfs. Values for the post-construction period ranged from 28 to 245 NTU with a median value of 43 NTU and a discharge range from 2.4 to 98.0 cfs with a median value of 6.0 cfs. Comparison of regression curves on graphs for pre- and post-construction periods at site JB9 show that turbidity decreased during the post-construction period by about 80 percent.

Turbidity values for pre-construction and construction periods at site JB10 ranged from 40 to 260 NTU with a median value of 196 NTU (fig. 8). Discharge for the period ranged from 5.0 to 50.0 cfs with a median value of 16.5 cfs. Values for the post-construction period ranged from 14 to 250 NTU with a median value of 65.5 NTU and a discharge range from 0.5 to 151 cfs with a median value of 17.2 cfs. Comparison of regression curves on graphs for pre- and post-construction periods at site JB9 show that turbidity decreased during the post-construction period by about 60 percent.

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. Annual suspended sediment loads were estimated at the monitored sites using the computer regression model Regr_Cntr.xls (*Regression with Centering*). The program is an Excel adaptation of the USGS seven-parameter regression model for load estimation in perennial streams.

The regression with centering program requires total suspended solids concentrations and average daily stream discharge to estimate annual loads. Concentrations of TSS in mg/L were determined by laboratory analysis of periodic water grab samples.

Bed sediment is composed of particles that are too large or too dense to be carried in suspension by stream flow. Total sediment loads are composed of suspended and bed sediment. Total estimated sediment loads downstream from the impacted reach in the Joes Branch unnamed tributary during 2011-2012 were 22,184 t/yr (100,836 t/mi^2/yr). Without human impact, erosion rates and the resulting sediment transport rate in an average watershed, called the geologic erosion rate, would be 64 t/mi^2/yr. Therefore, the estimated geologic erosion rate for the Joes Branch unnamed tributary watershed (upstream from site JB9) is 14 t/yr. Results of pre-restoration assessments resulted in Joes Branch being listed on ADEMs 303-d list of impaired water bodies.

A stream restoration plan was prepared and construction of a step pool storm conveyance system and other associated restoration strategies were initiated in summer 2012 and completed in April 3013. Intense rainfall events in April 2013 and early 2015 caused headward erosion in a restored wetland and anastimosing reach of the stream downstream from the step pool conveyance system. These events prompted a to repair the wetland and restore the downstream reach. Additional monitoring was initiated to determine the effectiveness of the phase I restoration to evaluate phase II remedial structures. Total post-construction monitoring period loads were 5,764 t/yr (21,347 t/mi^2/yr) during 2015-2016 and 497 t/yr (1,840 t/mi^2/yr) during 2017-2018. This represents a 98 percent reduction in total sediment load transported from the unnamed tributary at site JB9.

An additional monitoring site (JBD) was established in 2014 on the main stem of Joes Branch at the Town Center Boulevard crossing. This site was used to collect baseline data on the Joes Branch main channel. An additional severe headcut was discovered on the main stem of Joes Branch, about 1,200 ft downstream from the headwaters, near the Westminster Gates subdivision. A second stream restoration system (J41 and J42) was constructed along with other remediation measures (JA) totaling about 1,100 ft of stream channel. This phase of construction began in February 2016 and was completed in November 2016. Water quality and sediment transport monitoring, consisting of periodic measurements at site JBD from 2016 and ended in April 2019.

Total sediment loads at site JBD were 2,594 t/yr (9,978 t/mi^2/yr) for the pre-construction period (2014-2015). Post-construction (2017-2018) estimated annual loads were 39.7 t/yr (153 t/mi^2/yr). This is a reduction in sediment transported from the Joes Branch watershed upstream from site JBD of about 98 percent.

Site JB10 was established near the confluence of Joes Branch with D'Olive Creek during the first D'Olive Creek assessment in 2006. Discharge, water quality, and sediment transport data were collected from 2006 to 2008 and sediment loads were estimated for the watershed upstream from the site. However, much of the data were collected during a period of extreme drought and the resulting sediment loads were not representative of normal conditions. Additional data were collected at the site from May 2014 to April 2019.

The total sediment loads at site JB10 were 36,361 t/yr (39,523 t/mi^2/yr) after construction of Phase I but before Phase II construction (2014-2015) in the unnamed tributary or J4-1 and J4-2 construction in Joes Branch. Total loads during the post-construction monitoring period (2015-2016) were 1,687 t/yr (2,183 t/mi^2/yr) and 397 t/yr (463 t/mi^2/yr) during 2017-2018. This represents a 99 percent reduction in total sediment load transported from Joes Branch at site JB10.

CONCLUSIONS

The purpose of this hydrogeologic assessment was to document the impacts of land uses and major erosion on sediment transport rates and to evaluate potential improvements resulting from three phases of restoration implementation in the Joes Branch watershed.

Although restoration efforts did not reduce sediment loads in the streams to geologic erosion rate levels, improvements were substantial with estimated total sediment loads reduced by 98 to 99 percent from pre-restoration levels. Therefore, the primary conclusion drawn from this assessment is that restoration structures installed in the watershed averted catastrophic infrastructure damage and improved water quality dramatically. However, it must be noted that the Joes Branch watershed is in an increasingly urban environment where comparisons of habitat and water quality with rural or reference streams are unrealistic. However, efforts to reduce and slow runoff discharge and to protect stream channels and remaining wetlands, as seen in the Joes Branch watershed will preserve habitat and riparian characteristics that will enhance quality of life in coastal Alabama.

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Appendix A

Physical and analytical data collected during pre- and post-restoration construction periods at monitoring sites in Joes Branch.

Site	Discharge	Date	TSS	Bed Sediment	Turbidity	Temp	pH	Conductivity
			mg/L	t/d	NTU	°C		µS/cm
JB7	0.04	2/24/12	4	0.006	5	17	6.4	181
JB7	0.49	3/9/12	25	6.4	360	19	6.5	140
JB7	0.02	3/22/12	12	0.003	1	20	6.3	187
JB7	2.60	3/23/12	127	9.0	113	22	6.1	86
JB7	8.04	4/17/12	1,270	3.6	1,260	21	5.6	38
JB7	0.87	5/31/12	2,400	31	1,470	24	5.5	60
JB7	2.50	6/1/12	1,500	85	1,560	24	4.9	89
JB7	0.50	6/9/12	2,180	27	498	24	6.3	114
JB7	31.50	6/9/12	10,200	399	3,640	23	6.8	41
JB7	0.07	6/13/12	123		185	24	6.7	399
JB7	0.01	7/11/12	36	0.0001	10	28	6.3	378
JB7	0.67	7/12/12	1,370	4.600	620	24	6.0	78
JB7	0.02	7/18/12	87	0.040	17	27	6.8	291
JB7	1.00	7/18/12	371	7.200	630	27	7.2	79
JB7	25.5	7/19/12	8,210	249.00	1,590		6.4	35
JB7	1.8	2/25/13	747	7.3	490	15	7	76
JB7	1.9	4/3/13	65	3.1	88	26	6.8	131
JB7	0.13	7/8/13	9	0.03	7			194
JB7	1.30	8/21/13		8.5		12	5.6	
JB7	5.4	11/26/13	234	19.2	154	16	6.6	85
JB7	4.1	1/13/14	259	2.1				42
JB7	22.1	10/13/14		12.5				
JB7	0.02	10/30/14		0.007				
JB7	8.8	11/17/14		4.9				
JB7	3.7	1/22/15		1.08				
JB7	1.5	2/4/15		0.03				
JB9	3.0	5/29/14	13		50	23	6.9	111
JB9	0.5	7/10/14	25		72	26	6.9	90
JB9	16.1	10/13/14	1300		327	23.7	5.6	43
JB9	1.7	10/30/14	1			19	5.9	53
JB9	10	11/17/14	120		245	11.7	5.7	33
JB9	3.4	1/22/15	65		135	11	5.5	44
JB9	4.7	2/4/15	350		98	21.3	6	47
JB9		4/13/15			190			
JB9	1.1	5/26/15	318	0.24	830		6.3	154
JB9	4.0	6/19/15	555		255		6.2	173
JB9	7.4	6/21/15	2870		1000	27.5	5.6	47
JB9	2.5	7/9/15	1270	6.1	250			
JB9	1.2	8/17/15	410	7.3	155	26.9	6.1	55
JB9	1.2	9/21/15	330	3.3	120	20.4	5.9	52
JB9	1.7	10/26/15	600	0.65	61	19.2	5.9	31
JB9	29.3	10/26/15	400	12.7	151		5.4	201

JB9	4.4	10/27/15	400		150		5.8	93
Site	**Discharge**	**Date**	**TSS**	**Bed Sediment**	**Turbidity**	**Temp**	**pH**	**Conductivity**
JB9	7.3	10/31/15	170		65		6	85
JB9	5.6	11/1/15	190		70		6.5	60
JB9	5.1	11/8/15	87		42	22	6.6	45
JB9	21.6	11/18/15	750		498			
JB9	19.4	12/23/15	410		155			
JB9	15.6	12/23/15	580		290			
JB9	1.5	2/2/2016	87		28		7.2	113
JB9	3.1	2/22/2016	509	0.2	42	19.2	7.2	111
JB9	12.1	3/11/2016	2500	0	76	19.9	7	46
JB9	0.3	6/22/2017	5.2	0	21	28.1	6	87
JB9	0.3	8/4/2017	8.4	0	33	25.8	7.3	53
JB9	0.02	8/10/2017	4	0	5	26.9	7	163
JB9	0.76	8/30/2017	21.6	0	80	24.7	7	42
JB9	0.05	3/6/2018	3.2	0	18	20.2	7.2	57
JB9	0.24	2/11/2018	6.8	0	21		6.4	59
JB9	13.70	4/14/2018	77.3	0	145	19.4	6.7	34
JB9	2.80	9/5/2018	60		60			
JB9	0.68	10/25/2018	8		32	19.8	5.9	77
JB9	2.70	4/4/2019	58		52	17.8	6.7	35
JBD	1.3	6/13/2014	24		40			
JBD	3	9/3/2014	39		65	25	5.4	98
JBD	0.05	9/8/2014	4		15		15	
JBD	3	9/16/2014						
JBD	10.5	10/13/2014	375		532	24	5.4	63
JBD	2.9	11/17/2014	100		260	18.4	5.8	172
JBD	11.4	1/23/2015	349		480	11.6	5.6	50
JBD	4.98	2/4/15	225		242	20.9	5.5	44
JBD	5.7	2/13/2015	44		70	11	5.4	69
JBD	11	2/25/2015	310		525		5.5	75
JBD	5.7	4/15/2015	200		242	20.9	5.5	44
JBD	2.4	6/22/2017	21.6		37	28.2	7.0	130
JBD	2.5	8/4/2017	9.6		41	25.6	6.9	79
JBD	13	8/30/2017	11.6		52	25	6.9	54
JBD	6	2/11/2018	20.8		28	17	6.5	82
JBD	98	4/14/2018	212		245		6.8	43
JBD	10.6	9/5/2018	26		43			
JBD	3.7	4/4/2019	35		58	17.4	6.6	58
JB10	5	5/29/2014	27.0		40	24	7.2	58
JB10	12.2	7/10/2014	103.0		111	26	6.6	72
JB10	41.6	10/13/2014	184.9		234	24.6	5.7	84
JB10	20.1	11/17/2014	167.5		212	18	5.9	79
JB10	48.1	1/23/2015	205.4		260	11.9	5.5	61
JB10	12.86	2/4/2015	54.0		72	11	5.8	95
JB10	47.3	4/13/2015	142.2		180	22	6.1	61

Site	Discharge	Date	TSS	Bed Sediment	Turbidity	Temp	pH	Conductivity
JB10	12.3	5/26/2015	81.4	1.7	220	24.3	5.9	82
JB10	23.7	7/9/2015	79.6	39.0	215	27.0	5.6	63
JB10	7.7	8/17/15	22.2	1.2	60	27.2	5.8	104
JB10	6.13	9/21/2015	31.5		85	23.7	5.4	137
JB10	49.6	10/26/2015	83.3	60.9	225	20.2	5.7	50
JB10	12	2/2/2016	23.7		64		7.5	148
JB10	61	2/15/2016	83.3		225	16.1	6.5	70
JB10	10.5	2/22/2016	36.3		98	18.5	7.1	152
JB10	57	3/11/2016	44.4		120	19.9	7.3	59
JB10	6.9	6/22/2017	9.6	0.5	26	26.8	6.7	90
JB10	11.6	8/4/2017	11.2		40	25.8	6.9	68
JB10	0.5	8/10/2017	3.2		14	27.2	6.5	115
JB10	38.1	8/30/2017	16.4	2.7	63	24.5	6.9	45
JB10	2.1	3/6/2018	4.8		19	20.2	6.9	96
JB10	151	4/14/2018	199.0		250	19.8	6.5	53
JB10	23.2	9/5/2018	30.7	1.2	83			
JB10	22.4	4/4/2019	24.8		67	17.5	6.5	59