PHASE II POST-RESTORATION ANALYSIS OF DISCHARGE, SEDIMENT TRANSPORT RATES, AND WATER QUALITY IN TRIBUTARIES OF JOES BRANCH IN SPANISH FORT, BALDWIN COUNTY, ALABAMA

Mobile Bay National Estuary Program

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GEOLOGICAL SURVEY OF ALABAMA

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PHASE II POST-RESTORATION ANALYSIS OF DISCHARGE AND SEDIMENT TRANSPORT RATES IN TRIBUTARIES OF JOES BRANCH IN SPANISH FORT, BALDWIN COUNTY, ALABAMA

OPEN FILE REPORT 1408

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INTRODUCTION

Previous investigations of sedimentation and water-quality impacts by the Geological Survey of Alabama (GSA) have shown dramatic increases in sediment loading, degradation of water quality in streams, and loss of biological habitat downstream in areas affected by man's activities. These activities result in rapid runoff, increased stream discharge, erosion, and introduction of anthropogenic contaminants. Data from previous investigations are valuable in quantifying negative impacts so that limited regulatory and remedial resources may be focused where needs are greatest. Parts of Baldwin County, including Daphne and Spanish Fort, are among the fastest growing areas in Alabama. In many areas, especially along the eastern shore of Mobile Bay, agricultural and forested land is being converted to residential and commercial developments. Due to the geologic and hydrologic character of this area, activities associated with land-use change are particularly effective in eroding and transporting large volumes of sediment that eventually are deposited in Mobile Bay.

The Phase I assessment of an unnamed tributary to Joes Branch, 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. A stream restoration plan was prepared and construction of a step pool storm conveyance restoration system and other associated restoration strategies were initiated in summer 2012 and completed in late fall 2012 (fig. 1). The following report presents phase II post-restoration water quality and sediment transport data and documentation of the effectiveness of the stream restoration.

ACKNOWLEDGMENTS

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PROJECT AREA

The Joes Branch project is in the city of Spanish Fort in west-central Baldwin County (fig. 2). The project consists of monitoring sites on two unnamed tributaries that

Figure. 1—Step pool conveyance system constructed in the
unnamed tributary of Joes Branch in Spanish Fort.

drain the northwestern part of the Joes Branch watershed along U.S. Highway 31. The monitored tributaries join Joes Branch just upstream from the Town Center shopping area. Joes Branch flows through the Town Center and empties into D'Olive Creek immediately upstream from Mobile Bay (plate 1). The focus area for the project includes the step pool storm conveyance system on the south side of U.S. Highway 31 and extends southwestward about 1,000 feet where it empties into a relatively broad restored wetland (plate 1).

PROJECT MONITORING STRATEGY AND SITE CHARACTERISTICS

The monitoring strategy employed for the Joes Branch project is to measure contaminants immediately upstream and downstream from the step pool storm conveyance system and to monitor sediment loads downstream from the entire restoration area. The Joes Branch project monitoring design included three sites (plate 1).

Site JB1 is upstream from the step pool conveyance system (plate 1). Site JB1 (latitude 30.67099 north and longitude -87.90317 west) monitors a drainage area of 0.09

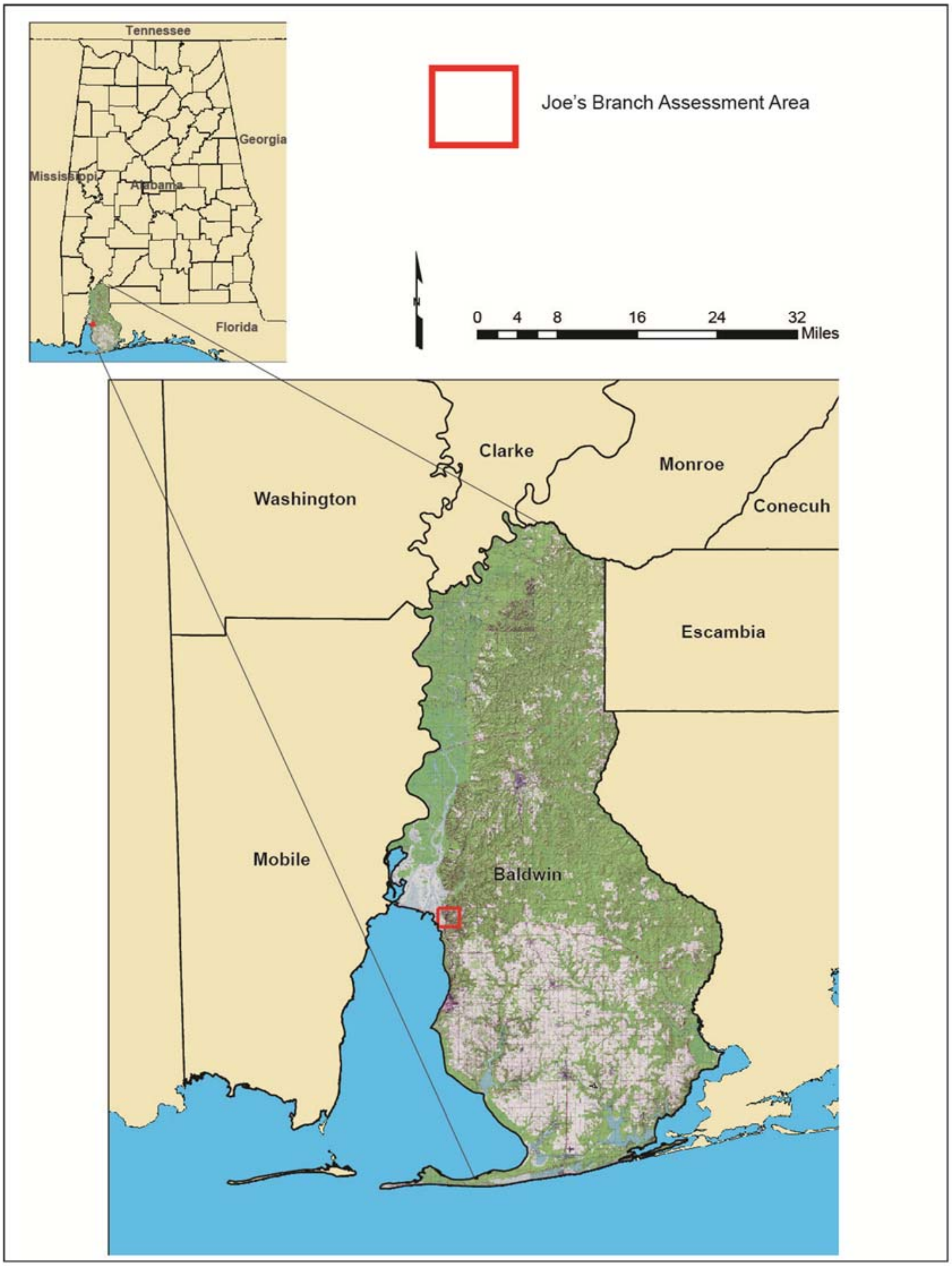

Figure 2.—Joes Branch project area in west-central Baldwin County.

square miles (mi^2) (58 acres) and is about 50 feet downstream from the south bound lane of U.S. Highway 31. The purpose of site JB1 is to monitor stream flow entering the step pool conveyance system.

Site JB6 (latitude 30.66966 north and longitude -87.90551 west) is located in the downstream pool of the step pool storm conveyance system and monitors a drainage area of 0.12 mi^2 (77 acres) (plate 1). The purpose of site JB6 is to monitor stream flow exiting the step pool conveyance system.

Site JB7 (latitude 30.66765 north and longitude -87.90627 west) monitors a drainage area of 0.22 mi^2 (141 acres) and is about 1,200 feet downstream from site JB6 (plate 1). The purpose of site JB7 is to monitor stream flow exiting the entire restoration area.

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. Water quality conditions in the Joes Branch watershed area are segregated by particular stream segments based on instream conditions that are influenced by topography and soils, impervious surfaces, construction activities, and associated erosion prevention and runoff management efforts. Estimates of sediment loads are based on measured sediment and stream discharge. Stream discharge at site JB1, in the headwaters, is intermittent and extremely flashy, resulting from the relatively small catchment, intensity of individual rainfall events, and large stream gradient. Discharge of groundwater into the step pool conveyance system down gradient from site JB1 results in perennial flow at the lower end of the restoration at site JB6.

Sites JB1 and JB6 each were outfitted with an American Sigma 900 Max automated sampler and data logger. The site JB1 American Sigma 900 Max also had a tipping bucket rain gauge (fig. 3). The 900 Max units measured water level and were programed to collect water samples based on specified water levels resulting from storm events. Both sites were rated for discharge so that stream water levels in inches and discharge in cubic feet per second (cfs) were recorded at 15-minute intervals. One of the design characteristics of the step pool conveyance system is to slow runoff velocities. During the pre-restoration period, the average stream flow velocity increased from 1.0 foot per second (ft/s) at site JB1 to 3.0 ft/s at site JB6. Discharge data collected during the post-restoration period, after installation of the step pool conveyance system, indicates that the average stream flow velocity decreased from 4.8 (ft/s) at site JB1 to 1.4 ft/s at site JB6. Average stream flow velocity at site JB7 was 1.1 ft/s during the pre-restoration monitoring period and was 1.3 ft/s during the post-restoration period. Stream flow characteristics for the pre- and post-restoration monitoring periods are shown in table 1.

Figure 3.—Installation of discharge and precipitation monitoring and sample collection equipment at Joes Branch site JB1.

Table 1. Monitored stream flow characteristics for the Joes Branch watershed during pre- and post-restoration monitoring periods.

Monitored site	Average discharge (cfs[1])	Maximum discharge (cfs)	Minimum discharge (cfs)	Average flow velocity (ft/s)	Maximum flow velocity (ft/s)	Minimum flow velocity (ft/s)
JB1—Pre	4.8	35.0	0.002	1.0	4.4	0.20
JB1—Post	9.5	44.7	0.210	4.8	14.2	0.75
JB6—Pre	13.6	31.6	0.060	3.0	5.5	0.50
JB6—Post	11.3	46.5	0.004	1.4	4.3	0.10
JB7—Pre	4.9	31.5	0.010	1.1	3.9	0.20
JB7—Post	2.4	5.4	0.130	1.3	1.9	0.70

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.

Turbidity values measured in stream at site JB1 shows that utility excavation upstream from the site during the post-restoration monitoring period caused increased turbidity during high flow events. Figure 4 shows impacts of sediment deposition in the step pool conveyance system cells. Except for this disturbance it was expected that turbidity values for the pre- and post-restoration monitoring periods would be similar (fig. 5). Values at site JB6 indicate decreased turbidities of more than an order of magnitude, demonstrating the effectiveness of the step pool conveyance system in preventing erosion and sediment transport in the area between sites JB1 and JB6 (fig. 6). Values at site JB7 also indicate a major reduction in turbidity during the post-restoration monitoring period (fig. 7).

Figure 4.—Sediment deposition in step pool conveyance system cells as a result of land disturbance upstream from site JB1.

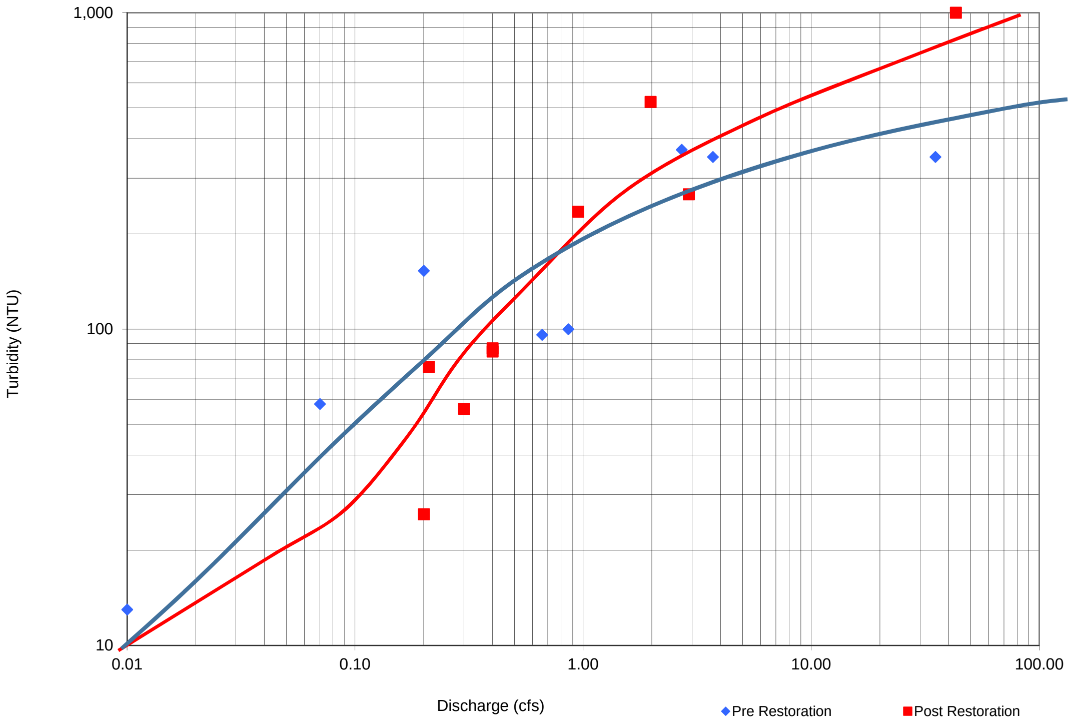

Figure 5.—Measured turbidity and stream discharge during pre- and post-restoration monitoring periods at Joes Branch site JB1.

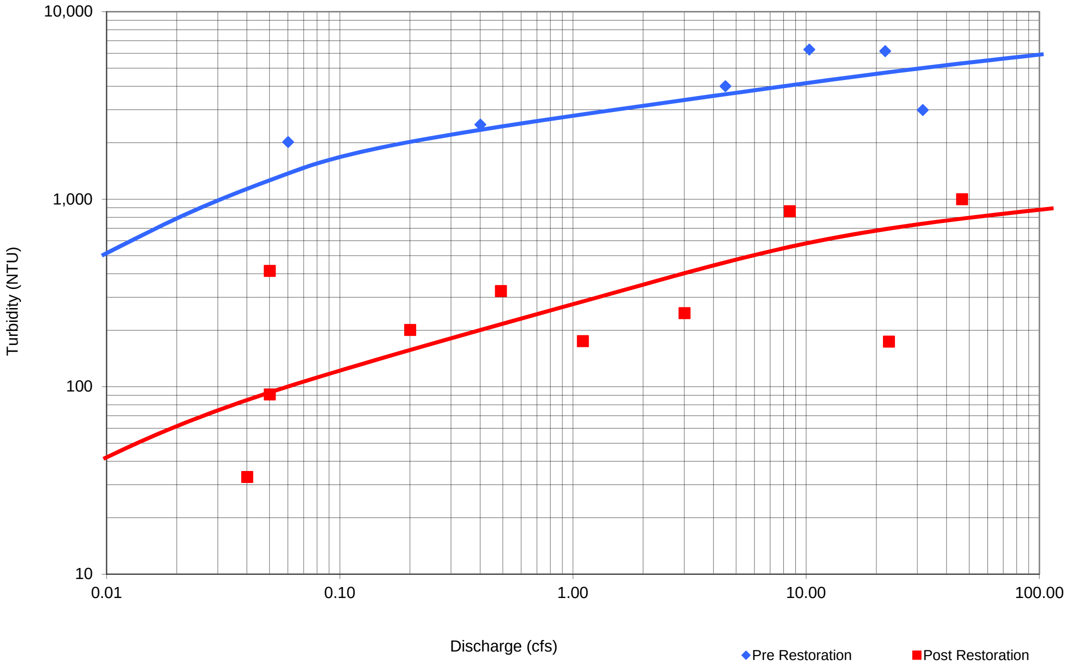

Figure 6.—Measured turbidity and stream discharge during the pre- and post-restoration monitoring periods at Joes Branch site JB6.

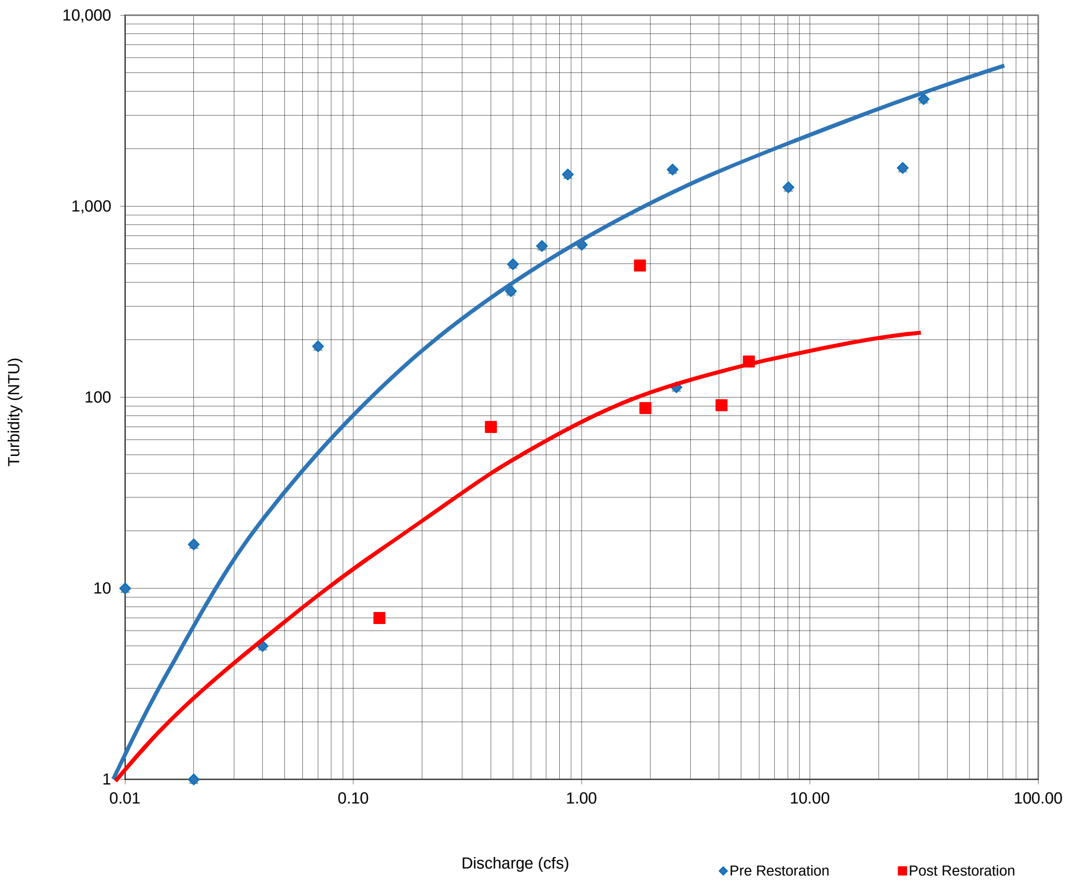

Figure 7.—Measured turbidity and discharge during pre- and post-restoration monitoring periods at Joes Branch site JB7.

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. 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). Sediment at site JB1 was measured during the pre- and post-restoration monitoring periods on hard surfaces where all sediment was suspended or saltating so that water samples contained representative concentrations of all grain sizes transported downstream. Therefore, the total sediment loads at site JB1 were assumed to be suspended. Bed sediment and suspended sediment were measured at site JB6 during the pre-restoration monitoring period but was measured on hard surfaces after installation of the step pool conveyance system so that all sediment measured at site JB6 during the post-restoration period is assumed to be suspended. Bed sediment and suspended sediment were measured at site JB7 during the pre- and post-restoration monitoring periods.

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.

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. Graphical comparisons of pre- and post-restoration suspended solids concentrations at sites JB1, JB6, and JB7 are shown in figures 8, 9, and 10 and turbidity values and total suspended solids concentrations for the sites are shown in table 2.

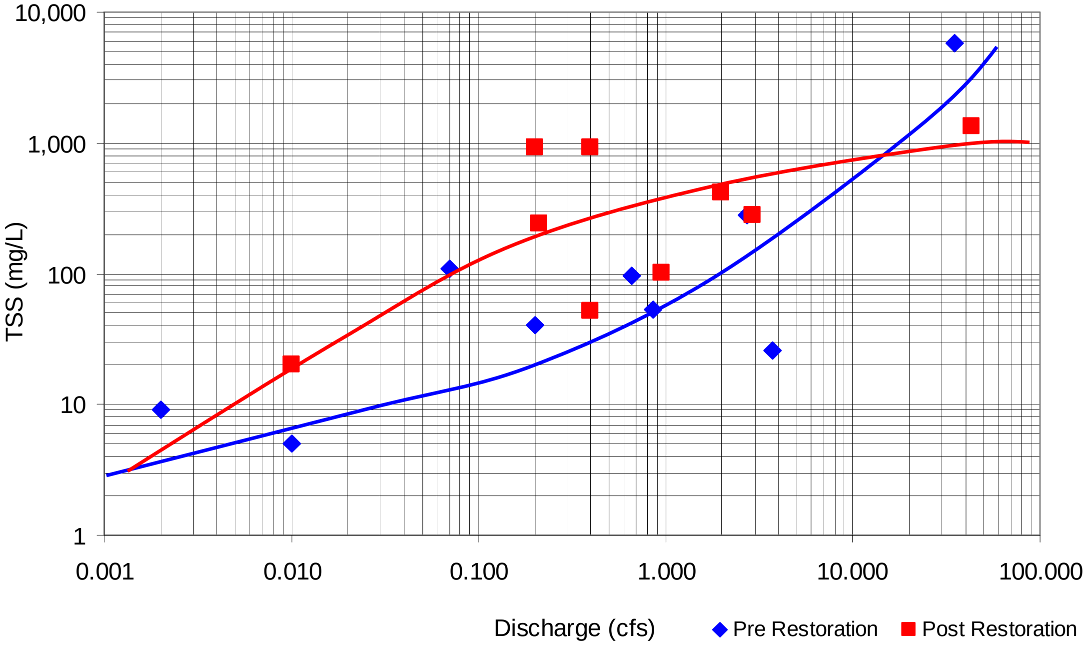

Figure 8.—Measured total suspended solids and stream discharge during the pre-and post-restoration monitoring periods at Joes Branch site JB1.

Annual suspended sediment loads for the post-restoration monitoring period were estimated at sites JB6 and JB7 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

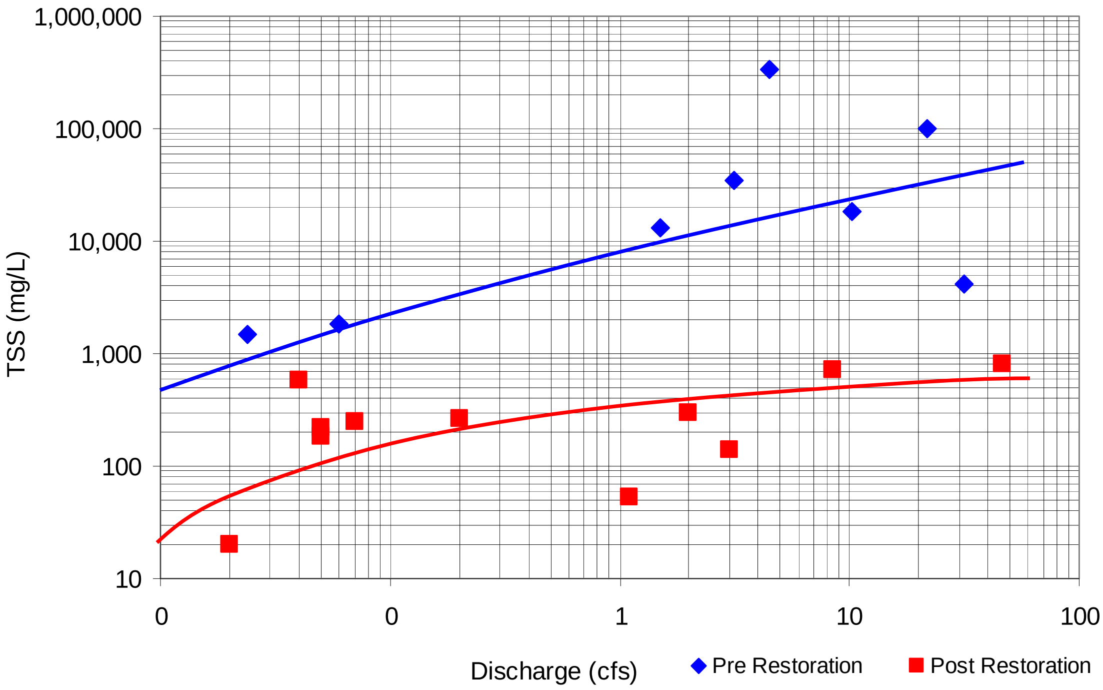

Figure 9.—Measured total suspended solids and stream discharge during the pre- and post-restoration monitoring period at Joes Branch site JB6.

requires total suspended solids concentrations and average daily stream discharge to estimate annual loads.

Sediment is transported by overland flow related to storm-water runoff to stream channels. In intermittent streams, suspended sediment for individual stream discharge events is quantified by the formula:

$$Q_s = Q_w \ C_s \ k,$$

where

Q_s is the sediment discharge, in tons per day (t/d)
Q_w is the water discharge, in cubic feet per second (cfs)
C_s is the concentration of suspended sediment, in milligrams per liter (mg/L)

and

k is a coefficient based on the unit of measurement of water discharge and assumes a specific weight of 2.65 for sediment (Porterfield, 1972).

Concentrations of TSS in mg/L were determined by laboratory analysis of periodic water grab samples. Annual suspended sediment loads could not be estimated for sites JB1 and JB6 during the pre-restoration period due to the intermittent flow character of the stream at these sites. However, suspended loads were estimated in pounds per minute (lbs/min) using discharge, flow duration, and total suspended solids

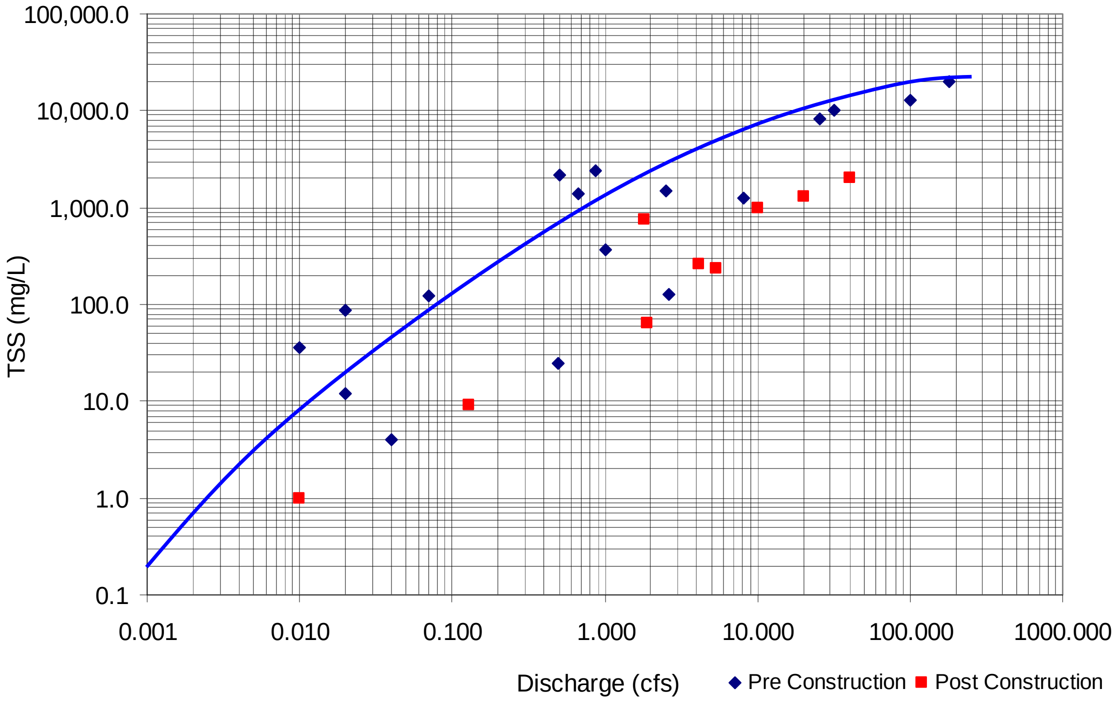

Figure 10.—Measured total suspended solids and stream discharge during the pre- and post-restoration monitoring period at Joes Branch site JB7.

concentrations with the Porterfield formula. Normalization of loads with respect to discharge facilitate comparisons of pre- and post-restoration suspended sediment loads.

Due to hard surfaces in the stream channel at site JB1, all sediment transported at this site during the pre- and post-restoration monitoring periods was assumed to be suspended. Due to hard surfaces installed with the step pool conveyance system, all sediment transported at site JB6 during the post-restoration monitoring period was assumed to be suspended.

The average suspended sediment load estimated during the post-restoration monitoring period at site JB1 (upstream from the step pool conveyance system restoration) is comparable to the pre-restoration period load (table 2). Table 2 shows that during the pre-restoration monitoring period, the estimated suspended sediment load at site JB6 (downstream from the step pool conveyance system restoration) was more than 300 times higher than site JB1. However, the suspended sediment load estimated during the post-restoration monitoring period at site JB6 is comparable to the site JB1 and indicates a reduction of 97 percent when compared to the suspended load estimated for site JB6 during the pre-restoration monitoring period (table 2). Figure 11 is a photograph of the step pool conveyance system with a 43 cfs flow on July 11, 2013.

The estimated annual suspended sediment load for site JB7 (downstream from site JB6 and the wetland area) during the post-restoration monitoring period is 1,034 t/yr, which indicates a reduction of about 94 percent when compared to the pre-restoration load (table 2). Therefore, the suspended sediment load estimated at site JB7, eventually transported to Mobile Bay was reduced from 33,770 cubic yards or 7 acre-feet per year to 1,915 cubic yards or about 0.4 acre-feet per year.

Table 2—Discharge, turbidity, total suspended solids, and suspended sediment loads, measured during pre- and post-restoration monitoring periods at Joes Branch monitored sites.

Monitored site	Average discharge	Average discharge duration	Average turbidity	Maximum turbidity	Average TSS	Maximum TSS	Estimated suspended sediment load		
	(cfs[1])	(minutes)	(NTU)	(NTU)	(mg/L)	(mg/L)	lbs/min	t/yr	t/mi^2/yr
JB1—Pre	4.8	115	166	369	719	5,850	5.7[4]		
JB1—Post	9.5	725	262	948	536	1,350	7.2	53.6[5]	
JB6—Pre	13.6	165[1]	4,292	6,280	93,276	341,000	1,840		
JB6—Post	6.4	n/a[2]	349	863	370	805	51[6]	34.7	
JB7—Pre	4.9	n/a[3]	797	3,640	4,061	20,000		18,236	82,890[7]
JB7—Post	2.4	n/a[3]	150	490	263	747		1,034	4,700

[1] Discharge at site JB6 was intermittent during the pre-restoration monitoring period
[2] Discharge at site JB6 was perennial during the post-restoration monitoring period
[3] Discharge at site JB7 was perennial during the pre- and post-restoration monitoring periods
[4] pounds per minute
[5] tons per year
[6] Sediment load estimated for discharge greater than base flow
[7] tons per square mile per year

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 11.—The step pool conveyance system after an intense storm event with discharge of about 43 cfs on July 11, 2013.

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. Traditionally, bed sediment has been difficult to quantify due to deficiencies in monitoring methodology or inaccuracies of estimating volumes of sediment being transported along the streambed. This is particularly true in streams that flow at high velocity or in streams with excessive sediment loads.

The Geological Survey of Alabama developed a portable bed sedimentation rate-monitoring device to accurately measure bed sediment in shallow streams with sand or gravel beds (Cook and Puckett, 1998). The device was utilized during this project to measure bed loads periodically over a range of discharge events to calculate daily and annual bed sedimentation rates at sites JB6 and JB7 during the pre-restoration monitoring period and at site JB7 during the post-sedimentation monitoring period. As mentioned previously, due to hard surfaces installed in the step pool conveyance system, all sediment measured at sites JB1 and JB6 during the post-restoration monitoring period was assumed to be suspended. Comparison of pre- and post-restoration bed sediment loads at site JB7 indicates a reduction of 72 percent during the post-restoration monitoring period, despite continued headward erosion near the downstream terminus of the restored wetland area (table 3).

Table 3—Measured discharge, stream flow velocity,
and estimated bed sediment loads for site JB7.

Monitored site	Average discharge (cfs)	Average stream-flow velocity (ft/s)	Estimated bed sediment loads (t/yr)	Estimated normalized annual bed sediment loads ($t/mi^2/yr$)
JB7—Pre	4.9	1.1	3,948	17,946
JB7—Post	2.4	1.3	1,113	5,059

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 project watershed, upstream from site JB7 (drainage area 0.22 mi^2), is 14 t/yr (table 4). Due to the intermittent character of flow at sites JB1 and JB6 during the pre-restoration monitoring period, total sediment loads are reported in pounds of sediment transported per minute of stream discharge. Continuous discharge data were available during the post-restoration monitoring period that facilitated estimation of sediment loads in t/yr and $t/ mi^2/yr$ (table 4).

The total annual sediment load estimated at site JB1 during the pre-restoration monitoring period was 5.7 lbs/min as compared with the post-restoration period load of

Table 4.—Estimated total sediment loads for Joes Branch sites.

Monitored site	Estimated geologic erosion rate (total sediment load) (t/yr)	Estimated total sediment load		Estimated normalized total annual sediment load ($t/mi^2/yr$)
		lbs/min	t/yr	
JB1—Pre	0.6	5.7		n/a
JB1—Post		7.2	53.6	596
JB6—Pre	7.7	2,252		n/a
JB6—Post		51	34.7	289
JB7—Pre	14		22,148	100,836
JB7—Post			2,147	9,759

7.2 lbs/min and 53.6 t/yr. Total loads at site JB6 were 2,252 lbs/min during the pre-restoration monitoring period compared to 51 lbs/min and 34.7 t/yr during the post-restoration period. This represents a 98 percent reduction in sediment transport at site JB6. The total load at site JB7 was 22,184 t/yr (100,836 t/mi^2/yr) during the pre-restoration monitoring period and 2,147 t/yr (9,759 t/mi^2/yr) during the post-restoration monitoring period. This represents a 90 percent reduction in total sediment load transported at site JB7 (table 4).

Comparisons of sediment loads from other watersheds are helpful in determining the severity of erosion problems in a watershed of interest. Estimates of total sediment loads from Dog River site 2 (Spencer Branch), Magnolia River site 4 (Magnolia River at U.S. Highway 98), D'Olive Creek site 3 (D'Olive Creek at U.S. Highway 90), and Tiawasee Creek site 7 (Tiawasee Creek upstream from Lake Forest), in Baldwin County, are compared to Joes Branch site JB7 loads in figure 12 (Cook and Moss, 2008, 2012; Cook and others, 2009). Figure 13 shows a comparison of normalized total sediment loads with the same watersheds. Figure 14 compares the total sediment load at

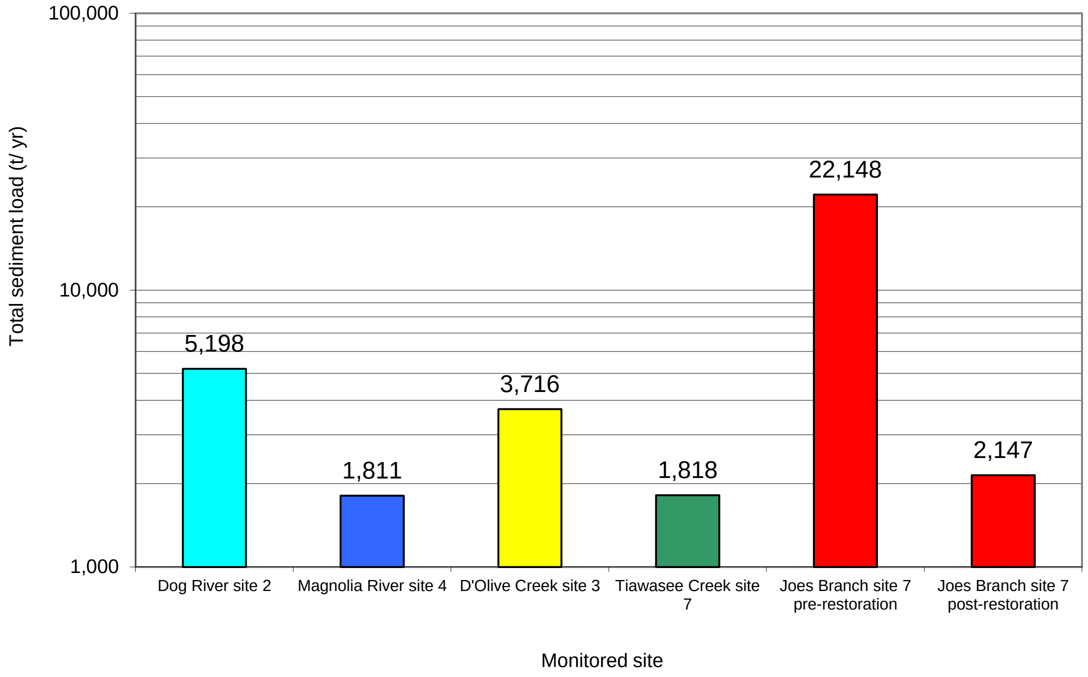

Figure 12.—Comparisons of estimated total sediment loads from selected Baldwin County streams.

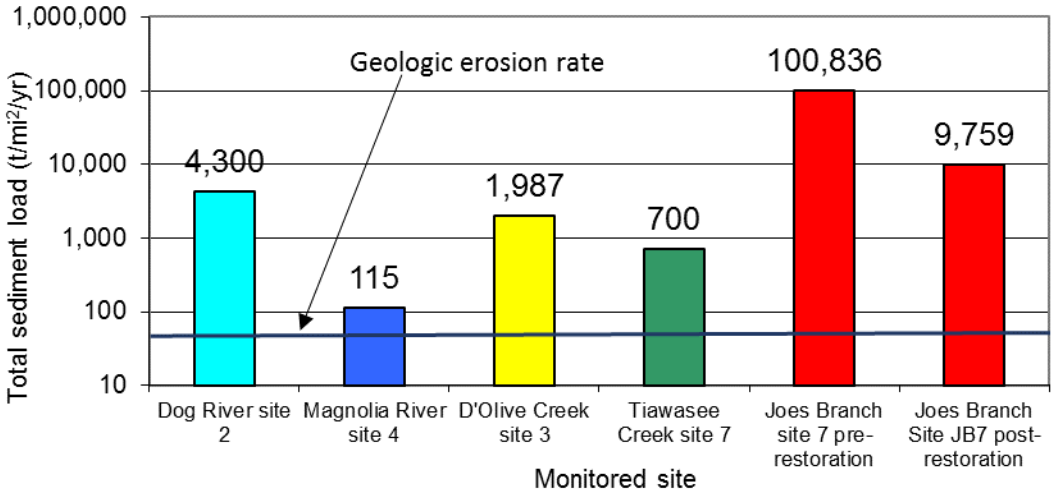

Figure 13.—Comparisons of estimated normalized total sediment loads from selected Baldwin County streams.

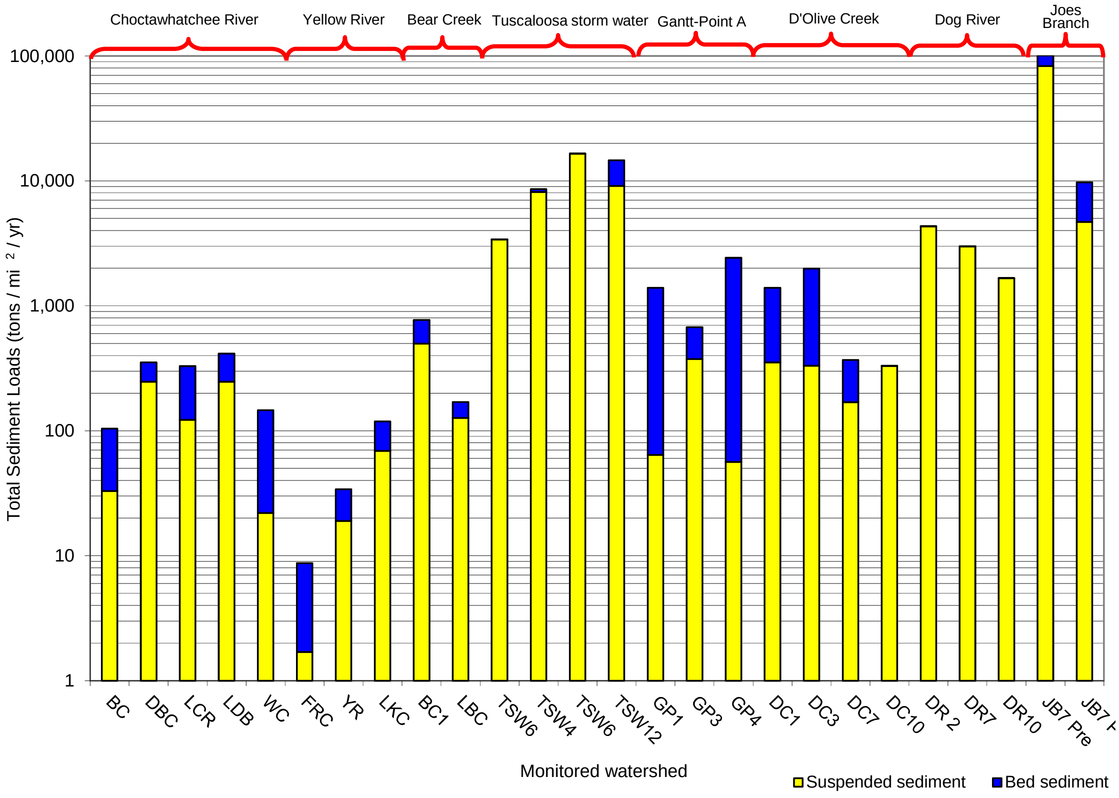

Figure 14.—Comparisons of estimated normalized total sediment loads from selected streams throughout Alabama and Joes Branch site JB7.

Joes Branch site JB7 with loads from other selected streams throughout Alabama. Figure 14 shows that the smallest sediment loads are in the Yellow River watershed (primarily forested). Streams in the Choctawhatchee River watershed in southeast Alabama and the Bear Creek watershed in northwest Alabama have moderate sediment loads (primarily from row crop agriculture and timber harvesting). Tributaries to the Gantt and Point A reservoirs in south-central Alabama have large sediment loads, primarily from eroding unpaved roads, and D'Olive Creek sediment is primarily from urban and developing urban areas of the watershed. Figure 14 also shows that sites with the largest sediment loads are from storm-water runoff in the more mature urban watersheds in the city of Tuscaloosa and Dog River in the city of Mobile. The sediment load estimated for Joes Branch site JB7 during the pre-restoration monitoring period was the largest of about 55 streams assessed by GSA. The post-restoration load, although greatly reduced from the pre-restoration load continues to be relatively large, due to continued erosion of the stream channel immediately downstream from the restored wetland area.

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 eutrophic levels. Toxins also can be produced during blooms of particular algal species. Nutrient-impaired water can dramatically increase treatment costs required to meet drinking water standards. Nutrients discussed in this report are nitrate (NO_3-N) and phosphorus (P-total).

NITRATE

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

The upstream-downstream monitoring strategy described previously was employed to measure nitrate in water samples collected at sites JB1 and JB6. The critical nitrate concentration in surface water for excessive algae growth is 0.5 mg/L (Maidment, 1993). During the pre-restoration monitoring period, the 0.5 mg/L nitrate criterion was exceeded in 11 percent of samples at site JB1 (upstream) and in 60 percent of samples collected at site JB6 (downstream) (fig. 15). This indicated a significant increase of nitrate between sites JB1 and JB6, which may result from runoff entering the drainage channel between the sites or addition of nitrate from shallow groundwater discharging from the headcutting erosional feature. During the post-restoration monitoring period, the 0.5 mg/L nitrate criterion was not exceeded at site JB1 (upstream) but was exceeded in 40 percent of samples collected at site JB6 (downstream) (fig. 16). Nitrate in a baseflow (groundwater) sample collected on August 15, 2013, at site JB6 was undetectable. Therefore, the source of nitrogen between sites JB1 and JB6 is most likely runoff entering the step pool conveyance system downstream from site JB1.

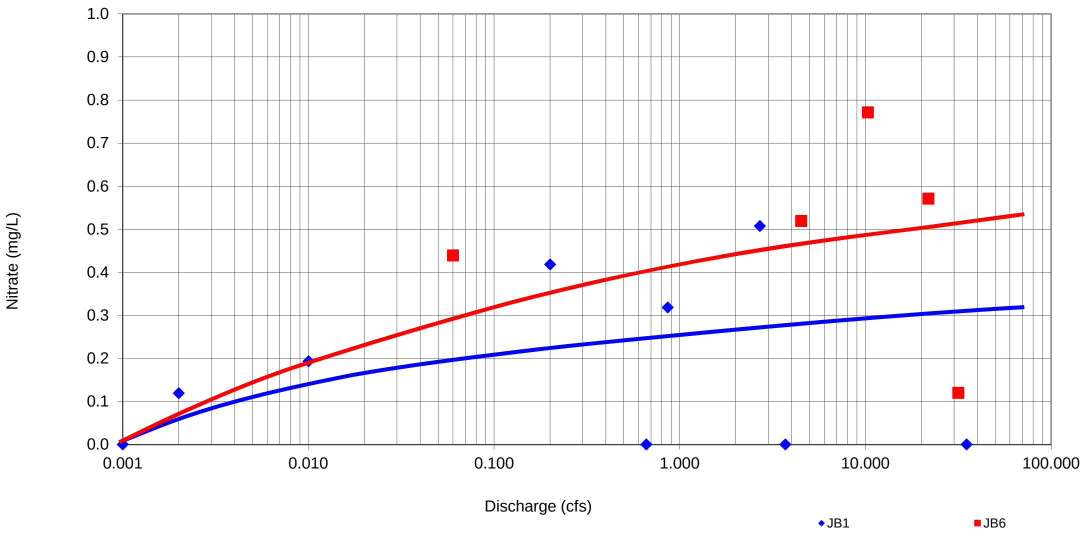

Figure 15.—Nitrate concentrations and stream discharge during the pre-restoration monitoring period at sites JB1 and JB6.

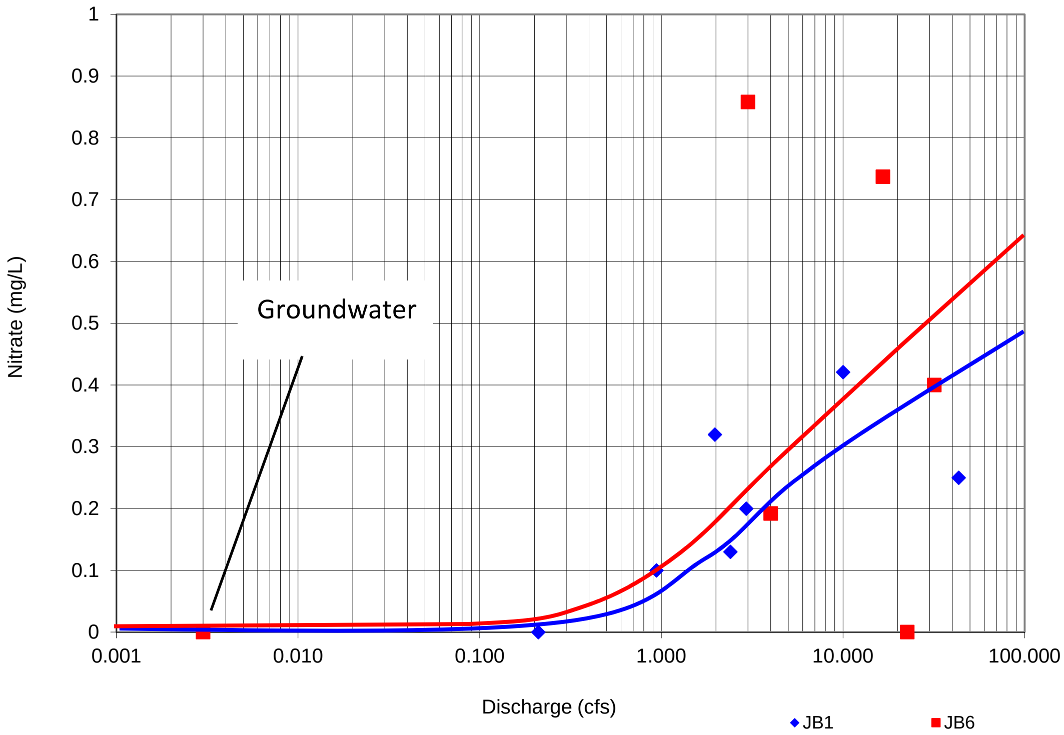

Figure 16.—Nitrate concentrations and stream discharge during the post-restoration monitoring period at sites JB1 and JB6.

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, phosphorus should not exceed 0.05 mg/L in any stream or 0.025 mg/L within a lake or reservoir in order to prevent the development of biological nuisances (Maidment, 1993). In many streams phosphorus is the primary nutrient that influences excessive biological activity. These streams are termed “phosphorus limited.”

During the pre-restoration monitoring period, the 0.05 mg/L total phosphorus criterion was exceeded for total phosphorus in 67 percent of samples at site JB1 (upstream) and in 100 percent of samples collected at site JB6 (downstream) (fig. 17). The total phosphorus criterion was exceeded in 70 percent of samples at site JB1 and in 60 percent of samples collected at site JB6 during the post-restoration monitoring period (fig. 18). The criterion was exceeded for orthophosphate during the pre-restoration monitoring period in 33 percent of samples collected at site JB1, but no samples exceeded 0.05 mg/L at site JB6. During the post-restoration monitoring period, the criterion was exceeded for orthophosphate during the pre-restoration monitoring period in 20 percent of samples collected at site JB1, but no samples exceeded 0.05 mg/L at site JB6. The general downstream increase of total phosphorus and decrease of orthophosphate observed at site JB6 indicates that inorganic orthophosphate is being adsorbed onto sediment particles eroded and transported by storm events.

METALLIC CONSTITUENTS

The USEPA compiled national recommended water quality criteria for the protection of aquatic life and human health in surface water for approximately 150 pollutants. These criteria are published pursuant to Section 304(a) of the Clean Water Act (CWA) and provide guidance for states and tribes to use in adopting water quality standards (USEPA, 2009). The criteria were developed for acute (short-term exposure) and chronic (long-term exposure) concentrations. Table 5 shows metals and their measured and recommended acute and chronic maximum concentrations.

Numerous metals are naturally present in streams in small concentrations. However, toxic metals in streams are usually a result of man’s activities. Water samples collected from sites JB1 and JB6 were analyzed for selected metallic constituents. Table 5 shows maximum concentrations and percentage of samples collected that exceed the recommended criteria for protection of aquatic life. Metals detected in water samples can occur naturally as a result of the erosion of fine grained sediments. This is probably true of aluminum and iron maximum concentrations measured during the pre-restoration

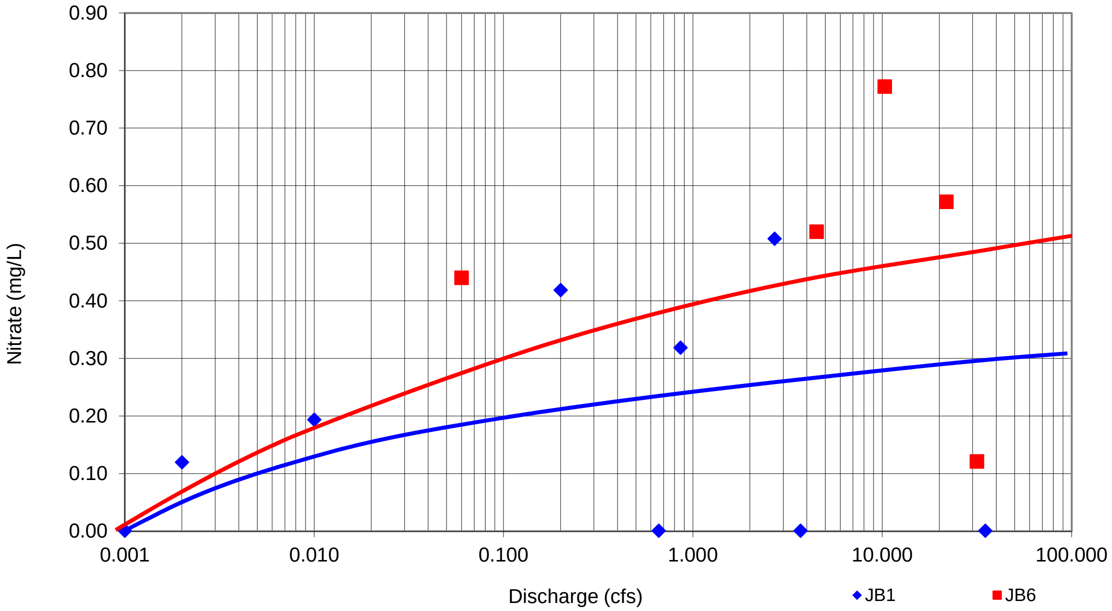

Figure 17.—Total phosphorus concentrations and stream discharge during the pre-restoration monitoring period at sites JB1 and JB6.

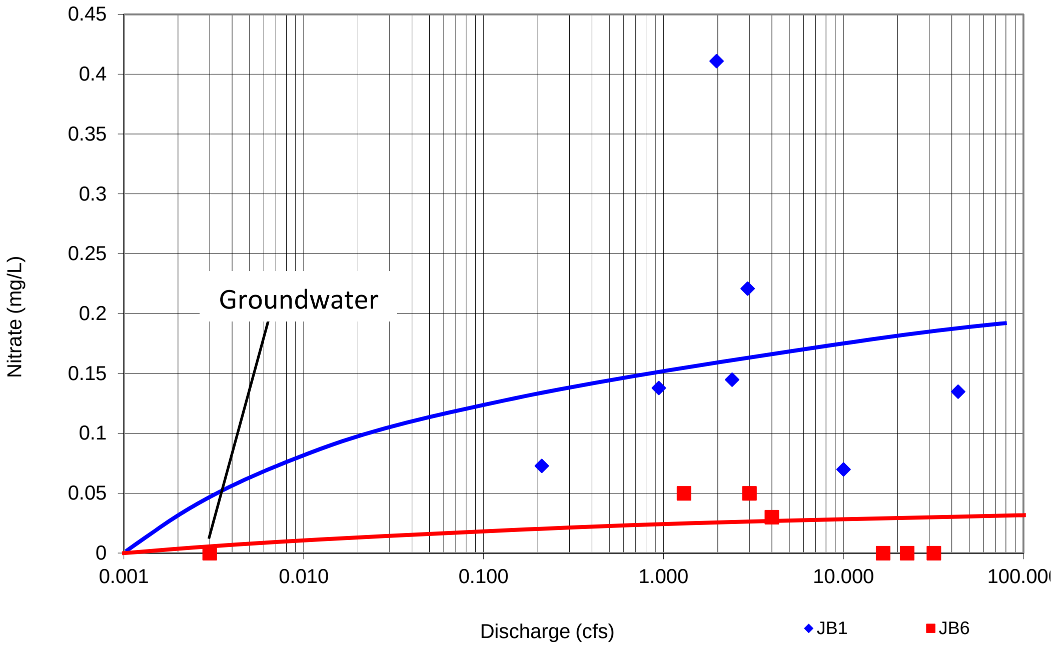

Figure 18.—Total phosphorus concentrations and stream discharge during the post-restoration monitoring period at sites JB1 and JB6.

Table 5.—Average concentrations of metallic constituents detected in water samples at selected monitoring sites in the Joes Branch project area.

Metallic constituent	USEPA standards for protection of aquatic life (µg/L[a])		Maximum concentrations (µg/L)				Percentage of samples exceeding the acute/chronic recommended criteria			
	Acute	Chronic	JB1—Pre	JB1—Post	JB6—Pre	JB6—Post	JB1—Pre	JB1—Post	JB6—Pre	JB6—Post
Aluminum	750.0	87.0	107.00	1,280.00	2,600.00	2,590.00	0/11	13/50	100/100	30/40
Arsenic	340.0	150.0	0.43	1.76	0.57	2.07	0/0	0/0	0/0	0/0
Cadmium	2.0	0.3	0.25	BDL	0.21	0.11	0/0	0/0	0/0	0/0
Chromium (Cr_3)	570.0	74.0	1.54[c]	4.80	27.10	2.69	0/0	0/0	0/0	0/0
Copper	4.7	n/a	BDL[b]	BDL	BDL	BDL	0	0	0	0
Cyanide	22.0	5.2	0.06	BDL	0.01	0.01	0/0	0/0	0/0	0/0
Iron	n/a	1,000.0	46.90	655.00	1,030.00	1,420	0	0	20	10
Lead	65.0	2.5	1.25	11.90	2.10	20.70	0/0	0/38	0/0	0/60
Mercury	1.4	0.8	0.01	0.02	0.01	0.03	0/0	0/0	0/0	0/0
Nickel	470.0	52.0	BDL	BDL	BDL	BDL	0/0	0/0	0/0	0/0
Selenium	n/a	5.0	0.95	1.0	0.84	BDL	0	0	0	0
Silver	3.2	n/a	BDL	BDL	BDL	BDL	0	0	0	0
Zinc	120.0	120.0	95.10	245.00	115.00	61.10	0/0	0/0	0/0	0/0
	pH range		pH range							
pH	n/a	6.5-9.0	[d]5.6-6.4	5.4-7.9	4.9-6.6	6.1-7.5	[d]100	77	80	13

[a] µg/L = micrograms per liter.

[b] BDL = below detection limit.

[c] Chromium reported as total chromium and is assumed to be primarily Cr_3.

[d] pH range. Percentage indicates pH values outside of the recommended range.

monitoring period at site JB6, which were 24 and 22 times higher, respectively, than concentrations measured during the same period at the upstream site JB1 (table 5). Aluminum and iron concentrations did not change significantly during the post-restoration monitoring period at site JB6. Also, aluminum and iron concentrations at site JB1 were 12 and 14 times higher during the post-restoration monitoring period than during the pre-restoration period. This is probably a result of utilities excavation mentioned earlier, which contributed large volumes of sediment into the project drainage area upstream from site JB1 during the post-restoration monitoring period. In addition to aluminum and iron, other detected metals at both site JB1 and JB6 included arsenic, cadmium, chromium, cyanide, lead, mercury, selenium, and zinc (table 5). Maximum concentrations for all metals in table 5 were higher at site JB1 during the post-restoration monitoring period than during the pre-restoration period. Again, this is most likely related to utilities excavation that occurred upstream from site JB1 during the post-restoration monitoring period and disturbance of sediments during construction of the step pool conveyance system (figs. 19, 20). However, aluminum, iron, and lead were the only metals that exceeded the USEPA criteria (table 5).

Although not included in USEPA criteria, barium, manganese, and magnesium were also detected in water samples collected at sites JB1 and JB6 during pre- and post-restoration monitoring periods. These constituents are common in Alabama streams and are a result of dissolution or erosion of rocks and sediment.

Although not a metallic constituent, pH is included in table 5 due to its importance in the occurrence and solubility of metals. pH was consistently low during the pre-restoration monitoring period, with 100 percent of values at site JB1 and 80 percent of values at site JB6 below the USEPA criteria. However, during the post-restoration monitoring period, 77 percent of values at site JB1 were below the criteria, but only 13 percent of values at site JB6 were below the criteria. This improvement in pH is probably a result of runoff pH buffering attained in the step pool conveyance system.

Another nonmetallic constituent detected in water samples collected at sites JB1 and JB6 is boron. Although no water quality criteria for boron has been established, concentrations as small as 1 mg/L may be toxic to plant life (Hem, 1985). Boron is naturally associated with igneous rocks and is present in active volcanic areas. In areas without a natural source, it may originate from cleaning wastes and may be present in sewage and industrial wastes (Hem, 1985). Boron was detected in 3 of 9 samples collected at site JB1 (maximum concentration of 50 µg/L) and 5 of 5 samples collected at site JB6 (maximum concentration of 220 µg/L) during the pre-restoration monitoring period and in 4 of 5 samples collected at site JB1 (maximum concentration of 40 µg/L) and 6 of 6 samples collected at site JB6 (maximum concentration of 99 µg/L).

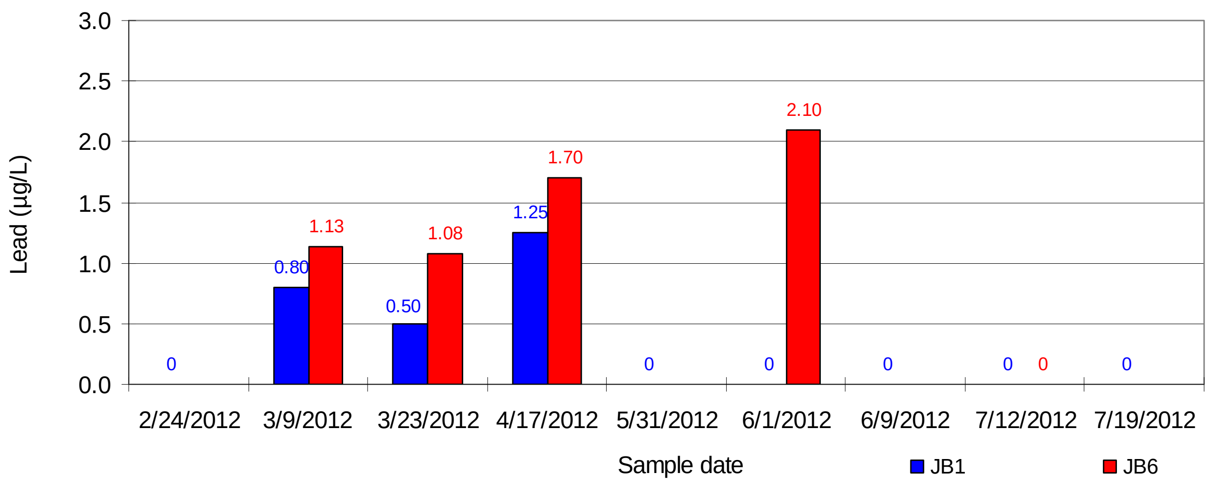

Figure 19.—Measured lead concentrations from water samples collected at Joes Branch sites JB1 and JB6 during the pre-restoration monitoring period.

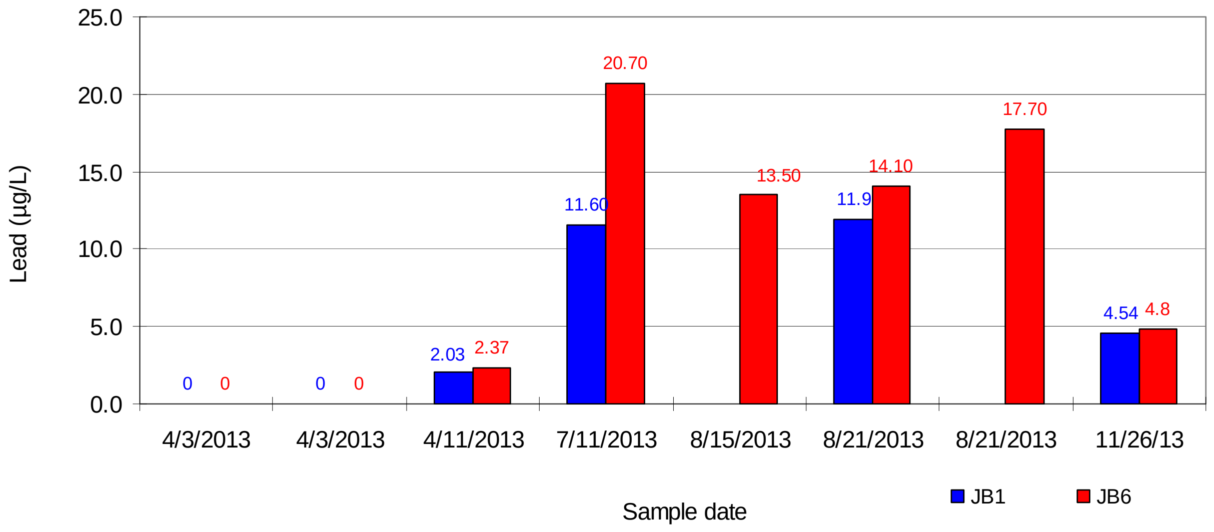

Figure 20.—Measured lead concentrations from water samples collected at Joes Branch sites JB1 and JB6 during the post-restoration monitoring period.

ORGANIC CONSTITUENTS

Organic compounds are commonly used in our society today. Frequently, these compounds appear in streams and groundwater aquifers. Many of these compounds are harmful to human health and to the health of the aquatic environment. Selected organic constituents including total organic carbon and phenols were analyzed from samples collected at sites JB1 and JB6 in order to make a general determination of the presence of organic anthropogenic contaminants in the watershed.

Total organic carbon (TOC) analysis is a well-defined and commonly used methodology that measures the carbon content of dissolved and particulate organic matter present in water. Many water utilities monitor TOC to determine raw water quality or to evaluate the effectiveness of processes designed to remove organic carbon.
Some wastewater utilities also employ TOC analysis to monitor the efficiency of the treatment process. In addition to these uses for TOC monitoring, measuring changes in TOC concentrations can be an effective surrogate for detecting contamination from organic compounds (e.g., petrochemicals, solvents, pesticides). Thus, while TOC analysis does not give specific information about the nature of the threat, identifying changes in TOC can be a good indicator of potential threats to a hydrologic system (USEPA, 2005). Typical TOC values for natural waters vary from 1 to 10 mg/L (Mays, 1996). TOC concentrations from water samples collected during the pre-restoration monitoring period for sites JB1 and JB6 indicate elevated concentrations of TOC, probably originating from contaminated urban runoff in the headwaters upstream from site JB6 (fig. 21). Figure 22 shows TOC concentrations for water samples collected during the post-restoration monitoring period. Average TOC concentrations at site JB1, for the post-restoration monitoring period were about 45 percent lower than for the pre-restoration period, which indicates a reduction in the number or magnitude of TOC sources in the headwaters area or changes in runoff that reduced the volume of TOC mobilized in the watershed. No significant downstream reductions in TOC were observed at site JB6 during the post-restoration monitoring period (fig. 22).

Phenols are used in the production of phenolic resins, germicides, herbicides, fungicides, pharmaceuticals, dyes, plastics, and explosives (USGS, 1992). They may occur in domestic and industrial wastewaters, natural waters, and potable water supplies. The USEPA has set its water quality criteria, which states that phenols should be limited to 10,400 µg/L (micrograms per liter) (10.4 mg/L) in lakes and streams to protect humans from the possible harmful effects of exposure (USEPA, 2009). Phenols cause acute and chronic toxicity to freshwater aquatic life. Figure 23 shows that phenol concentrations in 2 of 9 samples collected at Joes Branch sites JB1 exceeded the recommended criteria dı e

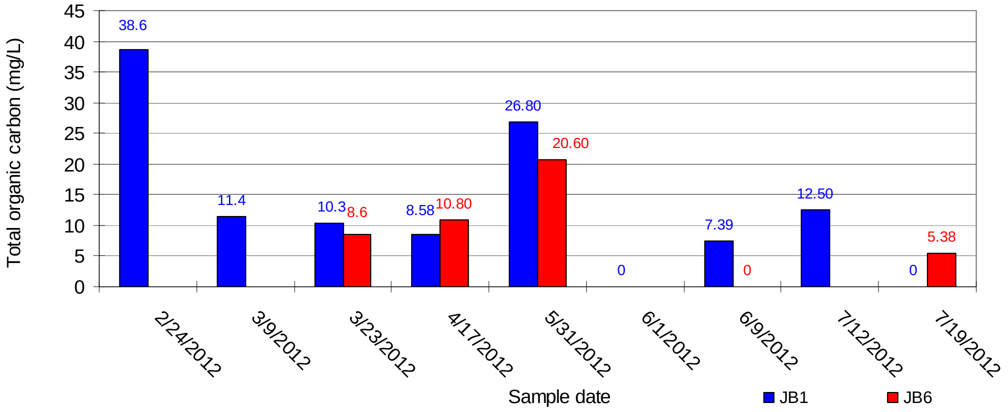

Figure 21.—Measured TOC concentrations from water samples collected at Joes Branch sites JB1 and JB6 during the pre-restoration monitoring period.

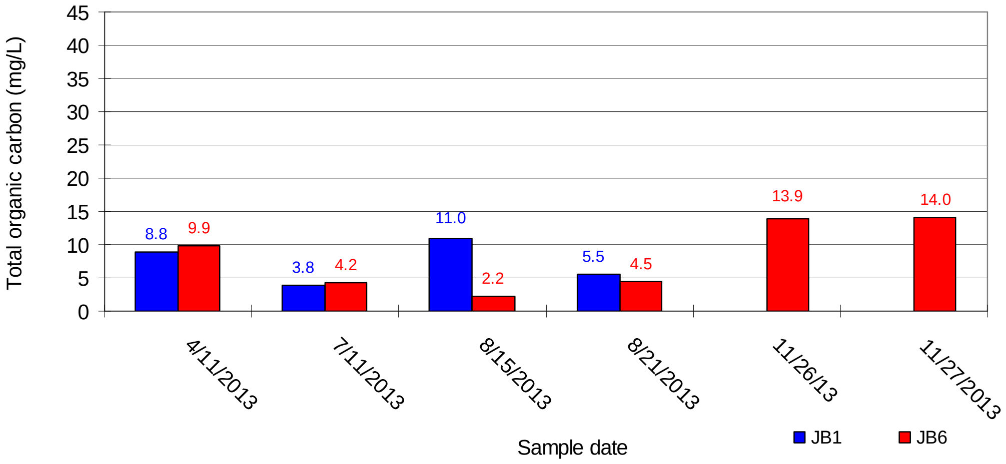

Figure 22.—Measured TOC concentrations from water samples collected at Joes Branch sites JB1 and JB6 during the post-restoration monitoring period.