ANALYSIS OF SEDIMENT LOADING RATES AND IMPACTS OF LAND-USE CHANGE ON THE D'OLIVE AND TIAWASEE CREEK WATERSHEDS, BALDWIN COUNTY, ALABAMA, 2007

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ANALYSIS OF SEDIMENT LOADING RATES AND IMPACTS OF LAND-USE CHANGE ON THE D'OLIVE AND TIAWASEE CREEK WATERSHEDS, BALDWIN COUNTY, ALABAMA, 2007

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By

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Tuscaloosa, Alabama
2007

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INTRODUCTION

Land-use change can have tremendous deleterious impacts on water quality and biological habitat of streams. This is particularly true in parts of Baldwin County where topographic relief and highly erodable soils are subjected to disturbances related to residential and commercial development. Previous investigations of sedimentation by the Geological Survey of Alabama (GSA) have shown dramatic increases in sediment loading and loss of biological habitat in streams downstream from areas affected by land-use change. These data are valuable in quantifying negative impacts so that limited regulatory and remedial resources may be employed 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 the eastern shore of Mobile Bay, activities associated with land-use change are particularly effective in eroding and transporting large volumes of sediment that eventually is deposited in Mobile Bay.

The purpose of this project is to assess the impacts of land-use change by determining sedimentation rates in streams that receive sediment from construction sites in the watershed. These data will be useful in the development of remediation plans to limit erosion and sediment transport into Lake Forest and Mobile Bay.

ACKNOWLEDGMENTS

Several individuals contributed to the completion of this project including Congressman Jo Bonner, Representative Randy Davis, Mayor Fred Small and Ms. Ashley Campbell (City of Daphne), Mr. Phillip Heinsley (Alabama Department of Conservation and Natural Resources), Mr. David Yeager (Mobile Bay National Estuary Program), Mr. John Peterson (Lake Forest Property Owners Association), and numerous others from the Daphne and Spanish Fort communities.

PROJECT AREA

The D'Olive and Tiawasee Creeks project area is in east-central Baldwin County, southwest Alabama (fig. 1). The project consists of 10 monitoring sites and a monitored area of 12.4 square miles (mi^2) (fig. 2).

Figure 1.--D’Olive and Tiawasee Creeks project area, Baldwin County, Alabama.

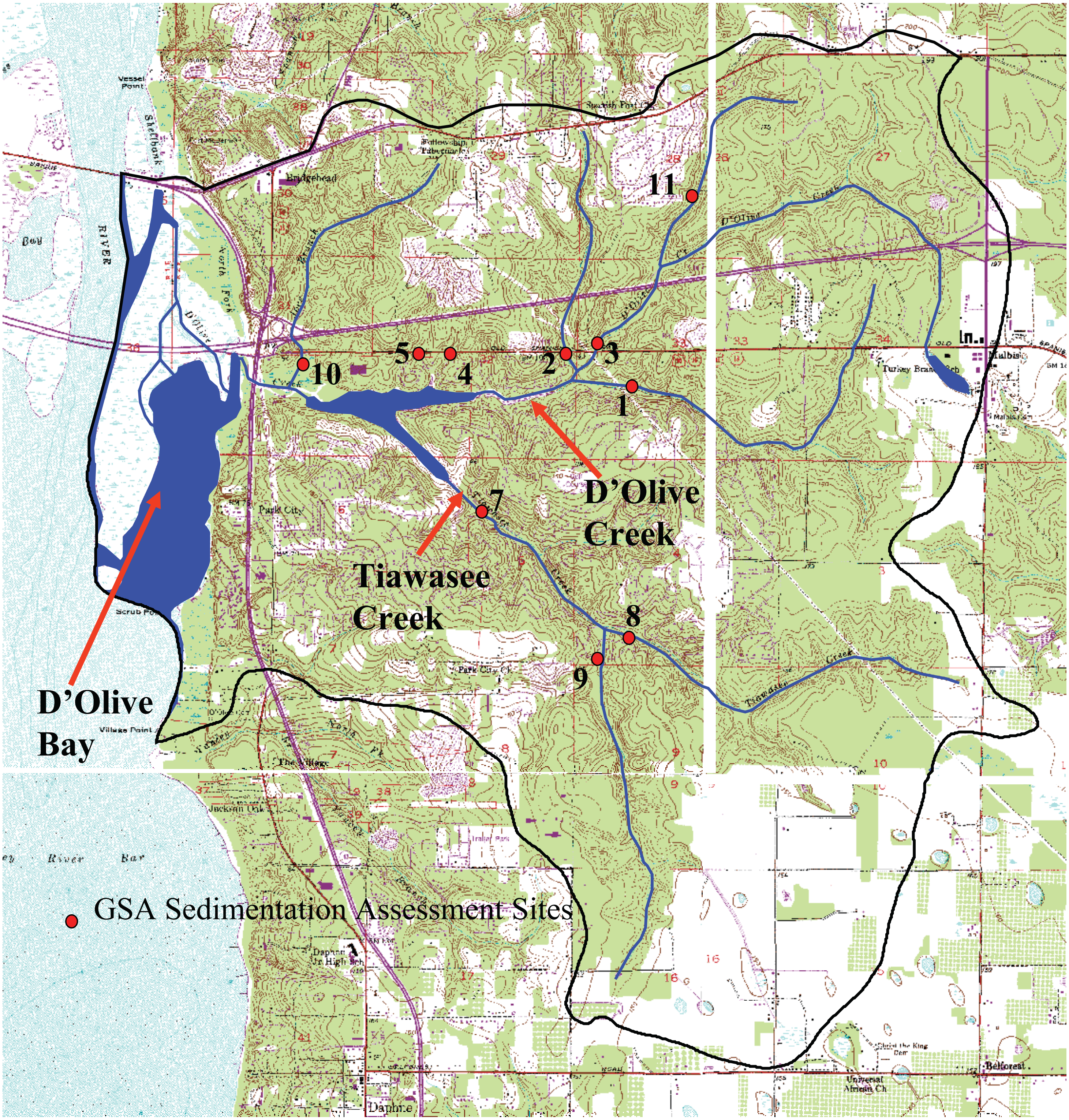


Figure 2.--Monitored sites in the D'Olive and Tiawasee Creeks project area.

PROJECT MONITORING SITE CHARACTERISTICS

Site 1 is on an unnamed tributary to D'Olive Creek on the south side of U. S. Highway 90. The stream drains 1.6 mi^2 of the eastern part of the project area upstream from the monitoring site (fig. 2).

Site 2 is on an unnamed tributary to D'Olive Creek near the confluence (fig. 2). The stream flows southward with headwaters north of U. S. Highway 31 in Spanish Fort. It enters D'Olive Creek immediately south from U. S. Highway 90 and drains 0.8 mi^2. The stream has a gradient of 90 feet per mile, upstream from the monitoring site.

Site 3 is on D'Olive Creek at the U. S. Highway 90 crossing (fig. 2). D'Olive Creek upstream from the monitoring site drains 1.9 mi^2 of the northeastern part of the project area with headwaters near U. S. Highway 31 and Alabama Highway 181 near Malbis. D'Olive Creek has a gradient of 60 feet per mile, upstream from the monitoring site

Sites 4 and 5 are on unnamed streams that drain southward into Lake Forest (fig. 2). The streams drain 0.14 and 0.08 mi^2 upstream from the monitoring sites, respectively.

Site 6 was combined with site 1. Therefore, no data were collected for site 6.

Site 7 is on Tiawasee Creek about 500 feet upstream from Lake Forest (fig. 2). Tiawasee Creek flows northwestward and drains about 5.0 mi^2 of the southern part of the project area upstream from the monitoring site. Tiawasee Creek has a gradient of 40 feet per mile.

Sites 8 and 9 are on unnamed tributaries to Tiawasee Creek that drain 2.3 and 1.8 mi^2, respectively (fig. 2). The gradient upstream from site 9 is 50 feet per mile.

Site 10 is on Joe's Branch immediately upstream from the confluence with D'Olive Creek near D'Olive Bay (fig. 2). Joe's Branch flows southward from Spanish Fort north of Interstate 10 and drains about 0.9 mi^2. Prior to construction in the watershed, Joe's Branch had a gradient of about 110 feet per mile.

Site 11 is on an unnamed tributary near the confluence with D'Olive Creek (fig. 2). The stream flows southwestward from U. S. Highway 31 near Spanish Fort and drains about 0.6 mi^2.

STREAM FLOW CONDITIONS

Sediment transport conditions in the D'Olive Creek area are segregated by particular stream segments based on instream conditions that are influenced by the topography and soils of the watershed, construction activities, and associated erosion prevention and runoff detention efforts. Precipitation, stream gradient, geology, and land use are all important factors that influence sediment transport characteristics of streams. Average observed stream flow conditions are shown in table 1.

Estimates of sediment loads are based on measured sediment and stream discharge. Therefore, a stream flow dataset composed of values that vary from base flow to flood is desirable. However, monitored stream flow events during the project period were affected by drought conditions that limited the frequency and magnitude of high flow at all sites. In most cases, high flow events were estimated using regression analyses. Monitoring will continue during late 2007 through mid 2008. Estimates of high flow will be verified during subsequent monitoring.

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 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 sediment.

Changes in land use are the primary causes of excessive erosion and sedimentation in the D'Olive Creek watershed. Highly erodable soils formed from undifferentiated Miocene sediments combined with relatively high topographic relief related to the formation of Mobile Bay result in excessive sediment transport. 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. The movement of this material is accelerated by periodic large precipitation events that cause increased stream flow and stream flow velocity.

Table 1. Stream flow characteristics for monitored sites in the D'Olive and Tiawasee Creek watersheds.

Monitored site	Average discharge (cfs[1])	Maximum discharge (cfs)	Minimum discharge (cfs)	Average flow velocity (ft/s[2])	Maximum flow velocity (ft/s)	Minimum flow velocity (ft/s)
1	2.1	3.1	1.5	0.65	0.90	0.52
2	0.7	1.7	0.2	0.50	0.77	0.30
3	3.7	9.6	1.3	0.74	0.99	0.61
4	0.2	0.4	0.1	0.32	0.48	0.12
5	0.2	0.9	0.1	0.34	0.58	0.19
7	24.9	131.0	3.8	0.63	1.70	0.43
8	10.2	29.3	1.1	0.58	1.10	0.16
9	10.2	32.9	1.2	0.71	1.10	0.40
10	2.3	7.9	0.3	0.65	1.10	0.34
11	2.1	0.9	0.2	0.57	0.89	0.20

[1]cfs- cubic feet per second
[2]ft/s- feet per second

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 (fig. 3). Turbidity and stream discharge for Joe's Branch (site 10) is shown in figure 4. Turbidity values for all monitoring sites are shown in table 2.

Annual suspended sediment loads were estimated 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 (Cohn and others, 1992). The regression with centering program requires TSS concentrations and average daily stream discharge to estimate annual loads. Although average daily discharge for project streams was not available from direct measurement, it was estimated by establishing a ratio between periodic measured discharge in project streams and discharge values for the same times obtained from the USGS discharge station located on the Fish River near Silver Hill, Alabama (USGS site 02378500). Total suspended solids concentrations and estimated suspended sediment loads for each monitored site are shown in table 2 and figure 5. Data were insufficient to estimate suspended sediment loads for sites 1 and 11.

Sites 7, 10, and 3 had the largest loads with 135, 129, and 120 tons per year (t/yr), respectively. Normalizing suspended loads to unit watershed area permits comparison of monitored watersheds. Figure 6 shows normalized suspended sediment loads and indicates that sites 5, 4, and 8 had the largest loads with 1,013, 216, and 211 tons per mi^2 per year ($t/mi^2/yr$), respectively.

Figure 3.--Turbid discharge during storm event at Tiawasee Creek tributary, site 8.

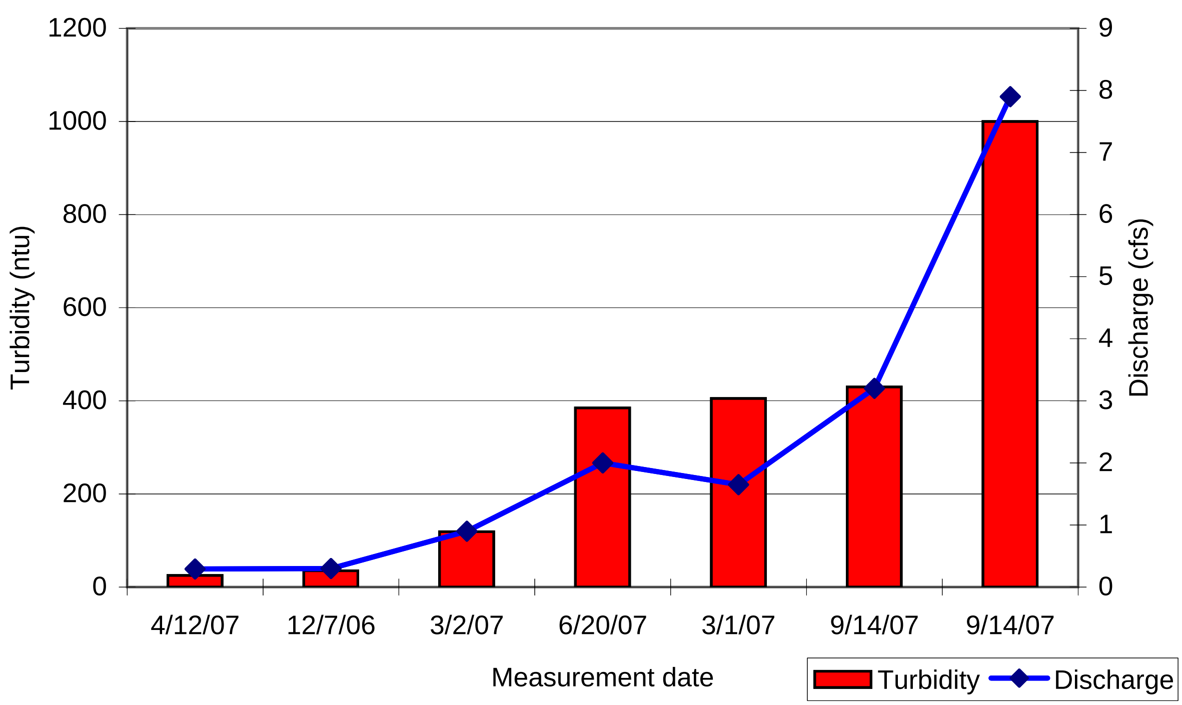


Figure 4.--Measured turbidity and discharge at Joe's Branch, site 10.

Table 2—Total suspended solids and suspended sediment loads measured in project streams.

Monitored site	Average Turbidity (NTU)	Maximum turbidity (NTU)	Average TSS (mg/L)	Maximum TSS (mg/L)	Estimated suspended sediment load (tons/yr)	Estimated normalized suspended sediment load ($t/mi^2/yr$)
1[1]	3	6				
2	37	206	26	74	4.6	6
3	25	173	42	145	120	64
4	160	>1,000	64	269	30	216
5	74	403	89	410	81	1,013
7	83	281	68	242	135	27
8	201	490	66	187	71	31
9	90	192	32	90	35	20
10	343	>1,000	122	350	129	142
11[1]	144	465				

[1]Data were insufficient to estimate sediment loadings at sites 1 and 11

BED SEDIMENT

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

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

Figure 5.--Annual estimated suspended sediment loads for selected streams in the D'Olive and Tiawasee Creek watersheds.

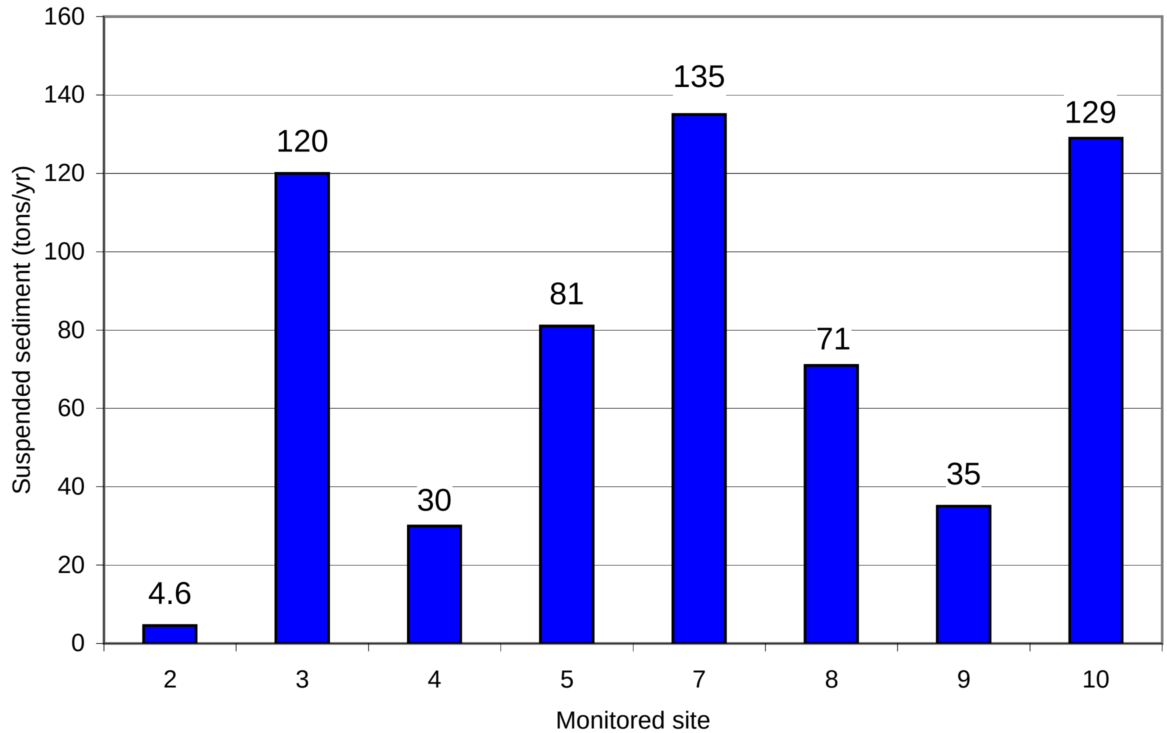
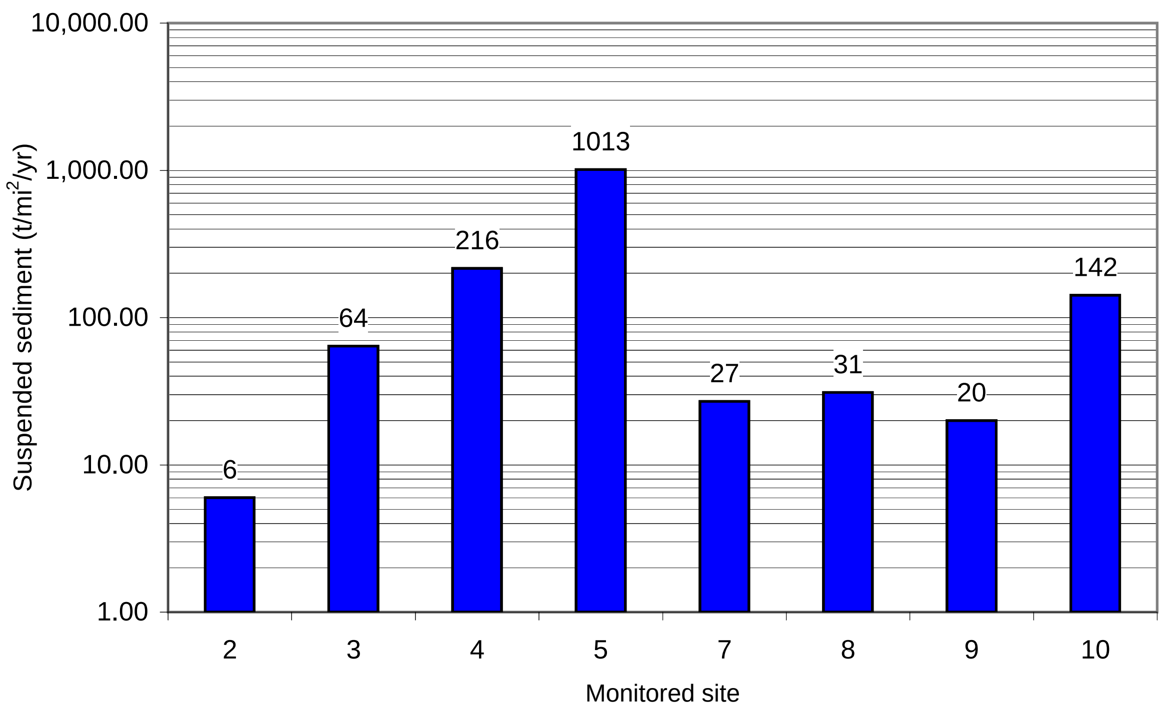


Figure 6.--Annual estimated normalized suspended sediment loads for selected streams in the D'Olive and Tiawasee Creek watersheds.



The Geological Survey of Alabama developed a portable bed load 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 bed load sedimentation rates. Figures 7 and 8 show measured stream discharge and bed sediment at sites 3 and 7. Note the excellent correlation between measured discharge and corresponding bed sediment transport rates. As with suspended sediment, it is possible to use discharge/sediment relationships to develop regression models to determine mean daily bed load volumes and annual bed sediment loads. Figure 9 shows estimated annual bed sediment loads for monitoring sites in selected streams in the project area. Figure 10 shows estimated annual bed sediment loads normalized with respect to watershed drainage area. Table 3 gives stream discharge, stream-flow velocity, daily and annual bed sediment loads, and normalized annual bed sediment loads for monitoring sites in selected streams in the project area. Sites 7 and 3 had the largest loads with 796 and 531 tons per year, respectively. After normalization of bed sediment loads, sites 4, 3, and 7 had the largest loads with 1,150, 284, and 159 tons/mi ^{2}/yr, respectively.

Insufficient data for bed sediment load estimation were available for sites 1 and 11. Sediment loads for sites 9 and 10 are primarily composed of suspended material. Therefore, no bed loads were estimated for these sites.

Table 3—Measured discharge, stream-flow velocity, and estimated bed sediment loads for monitoring sites on selected streams in the project area.

Monitored site	Average discharge (cfs)	Average stream-flow velocity (f/s)	Estimated annual bed sediment loads (tons/yr)	Estimated normalized annual bed sediment loads (tons/mi ^{2}/yr)
2	0.7	0.50	110	147
3	3.7	0.74	531	284
4	0.2	0.32	161	1,150
5	0.2	0.34	8.3	104
7	24.9	0.63	796	159
8	10.2	0.58	89	39

*No bed sediment loads were estimated for sites 1, 9,10, and 11 due to insufficient data

Figure 7.--Measured discharge and bed sediment loads at site 3 in D'Olive Creek.

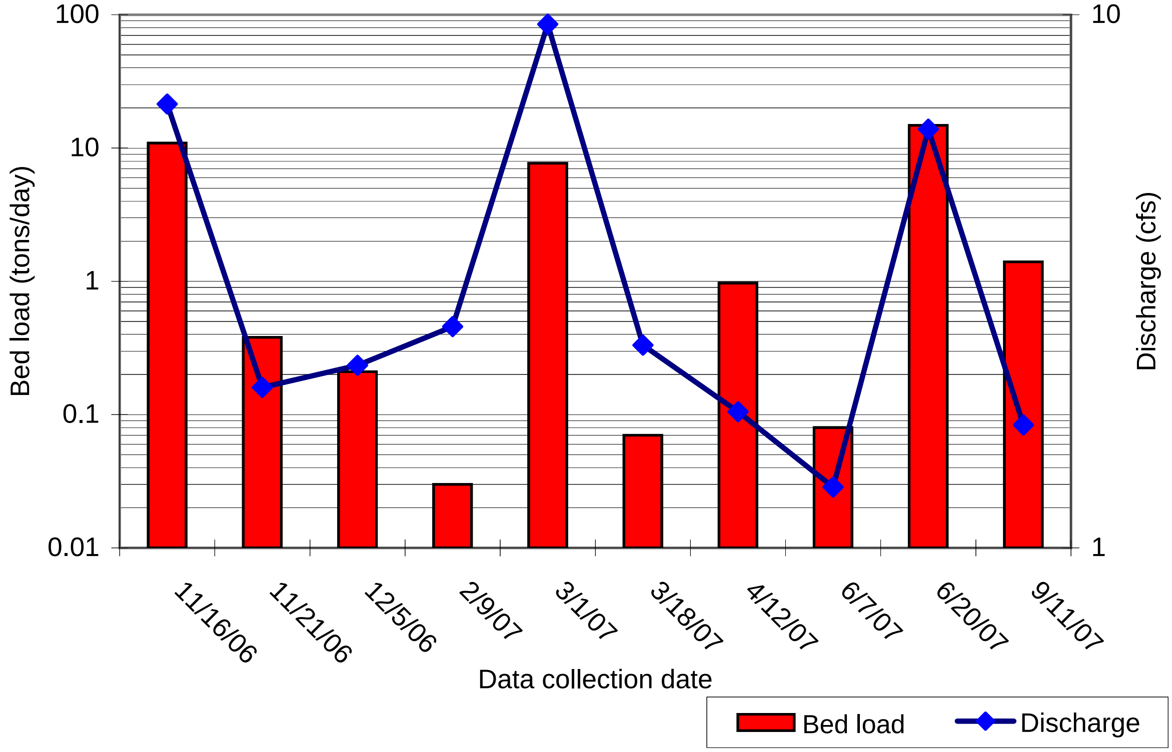


Figure 8.--Measured discharge and bed sediment loads at site 7 in Tiawasee Creek.

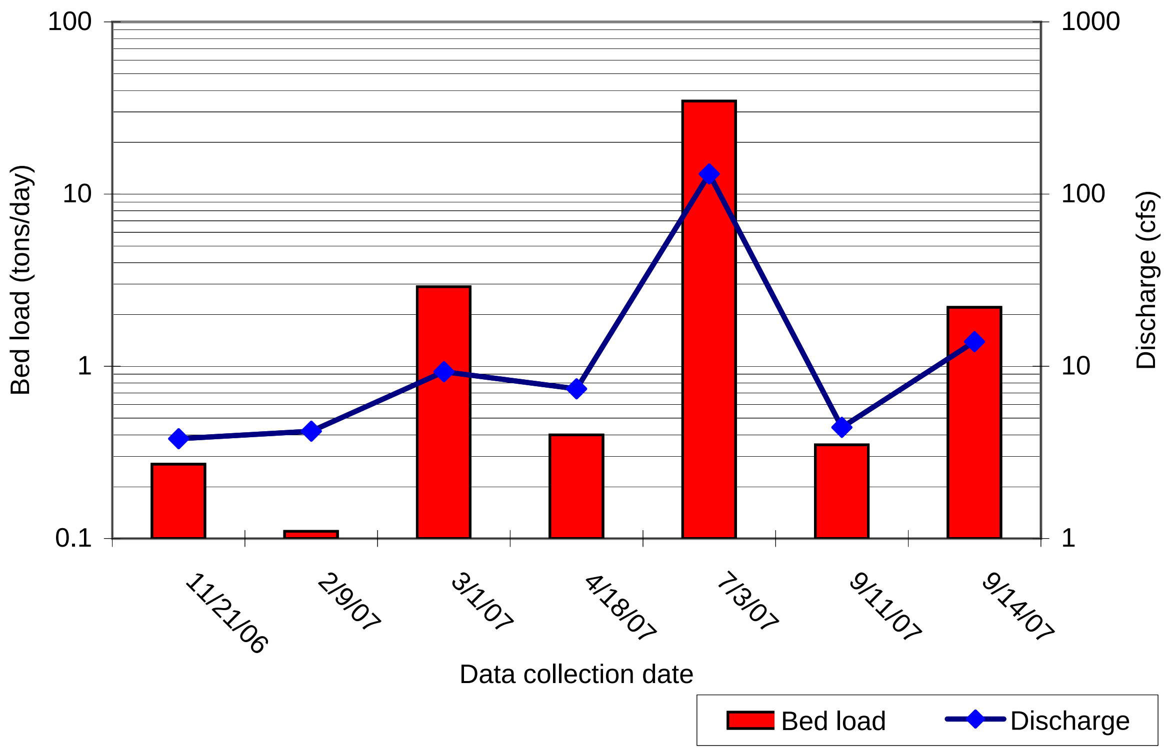


Figure 9.--Estimated annual bed loads for selected streams in the D'Olive and Tiawasee Creek watersheds.

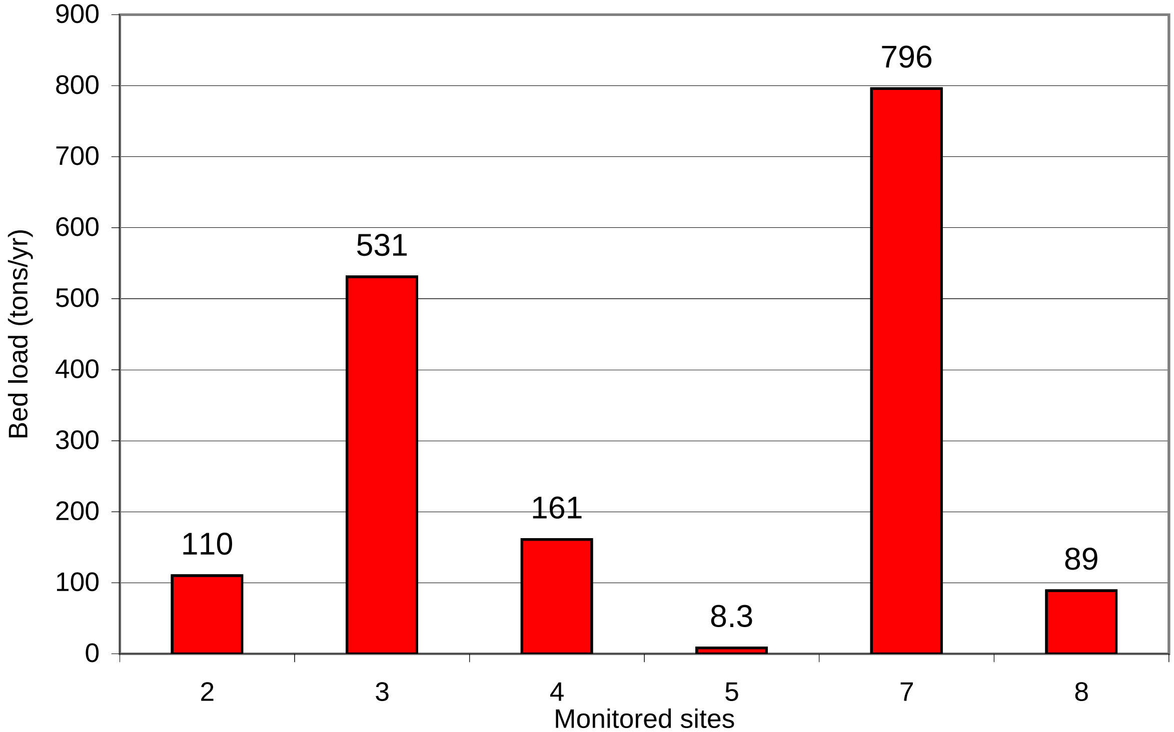
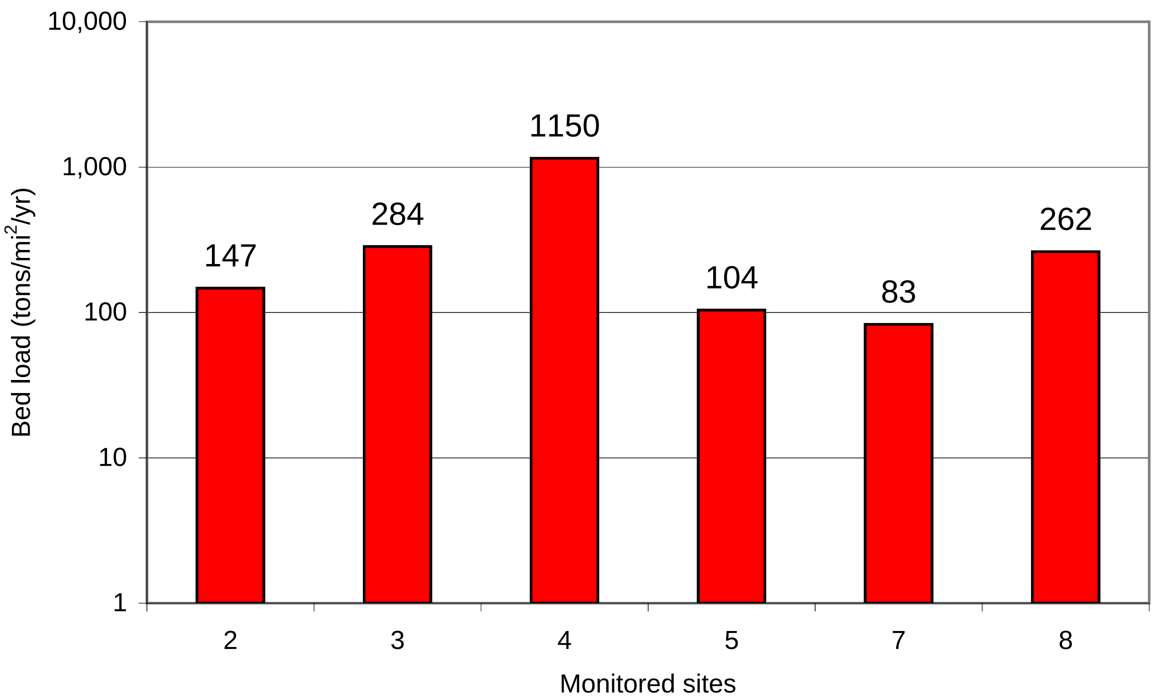


Figure 10.--Estimated annual normalized bed loads for selected streams in the D'Olive and Tiawasee Creek watersheds.



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. Numerous commercial and residential construction projects were ongoing in the project area during the monitoring period. Without human impact, erosion rates in the watershed, called the geologic erosion rate would be 64 tons per square mile per year (Maidment, 1993). The estimated geologic erosion rates for the project watersheds are shown in table 4.

The largest total annual sediment load (931 tons/year) was estimated for site 7 in Tiawasee Creek (table 4, fig. 11). This is not surprising since site 7 has the largest drainage area. When the data are normalized, allowing comparison of sediment loads with respect to unit drainage areas, site 4 had the largest load (1,366 tons/mi^2/year) (table 4, fig. 12). Sediment loads were estimated for 5 of the 8 streams that drain into Lake Forest. The total annual sediment load for these streams was 1,977 tons.

Comparisons of sediment loads from other watersheds are helpful in determining the severity of erosion problems in a watershed of interest. Estimates of sediment loads from 25 streams throughout Alabama indicate that sediment loads estimated for selected sites in the D’Olive Creek watershed are comparable to watersheds with other types of anthropogenic erosional impacts. Figure 13 shows similar sediment loads in streams in the Choctawhatchee River watershed in southeast Alabama and the Bear Creek watershed in northwest Alabama (erosion primarily from row crop agriculture and timber harvesting), and tributaries to the Gantt and Point A reservoirs in south-central Alabama (erosion primarily from unpaved roads). Figure 13 also shows that the only sites with consistently higher sediment loads were from storm-water runoff in the more mature urban watersheds in the city of Tuscaloosa. If land use in the D’Olive Creek watershed continues to change from rural to urban without treatments for increased storm-water runoff, sediment loads will increase due to increased stream discharge and flow velocity that cause erosion and stream channel degradation.

Figure 11.--Estimated annual total sediment loads for selected streams in the D'Olive and Tiawasee Creek watersheds.

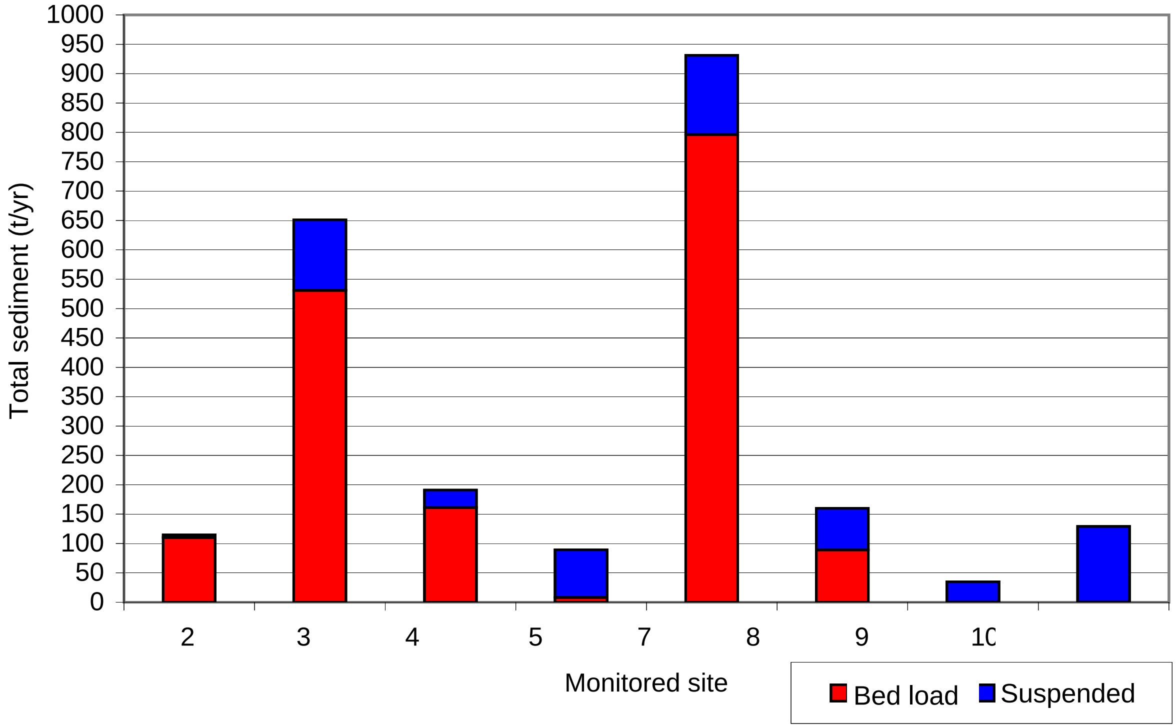


Figure 12.--Estimated normalized annual total sediment loads for selected streams in the D'Olive and Tiawasee Creek watersheds.

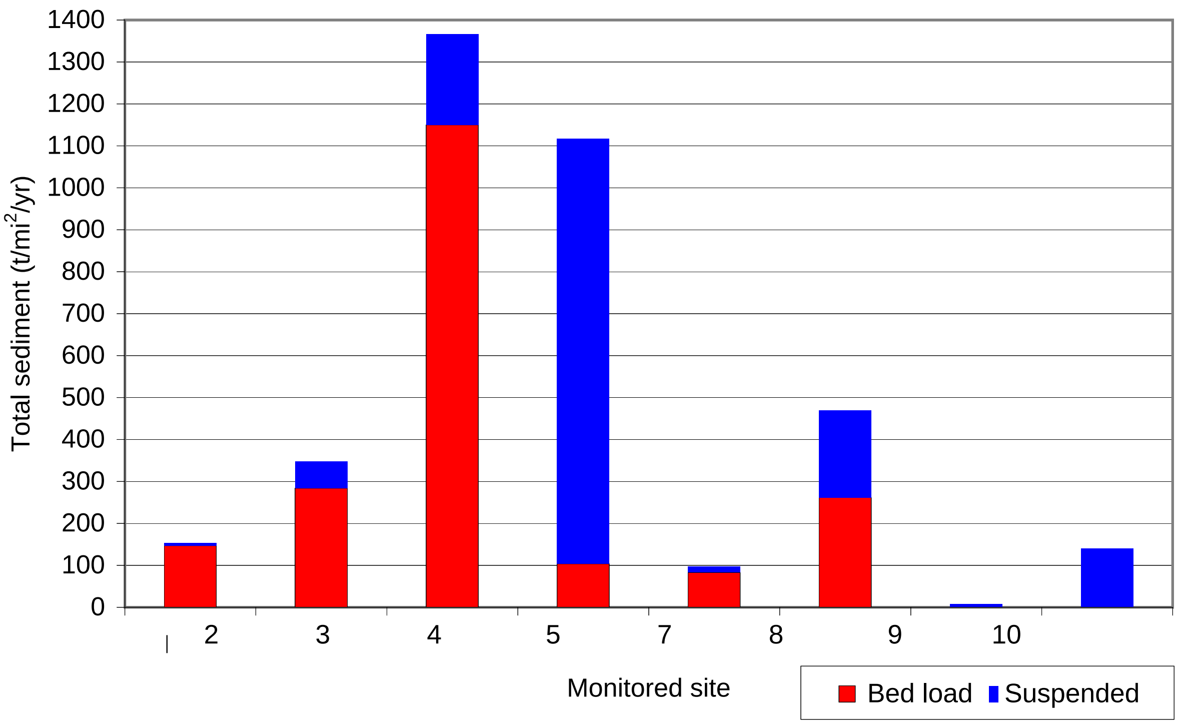


Figure 13.--Estimated annual total sediment loads for selected watersheds in Alabama.

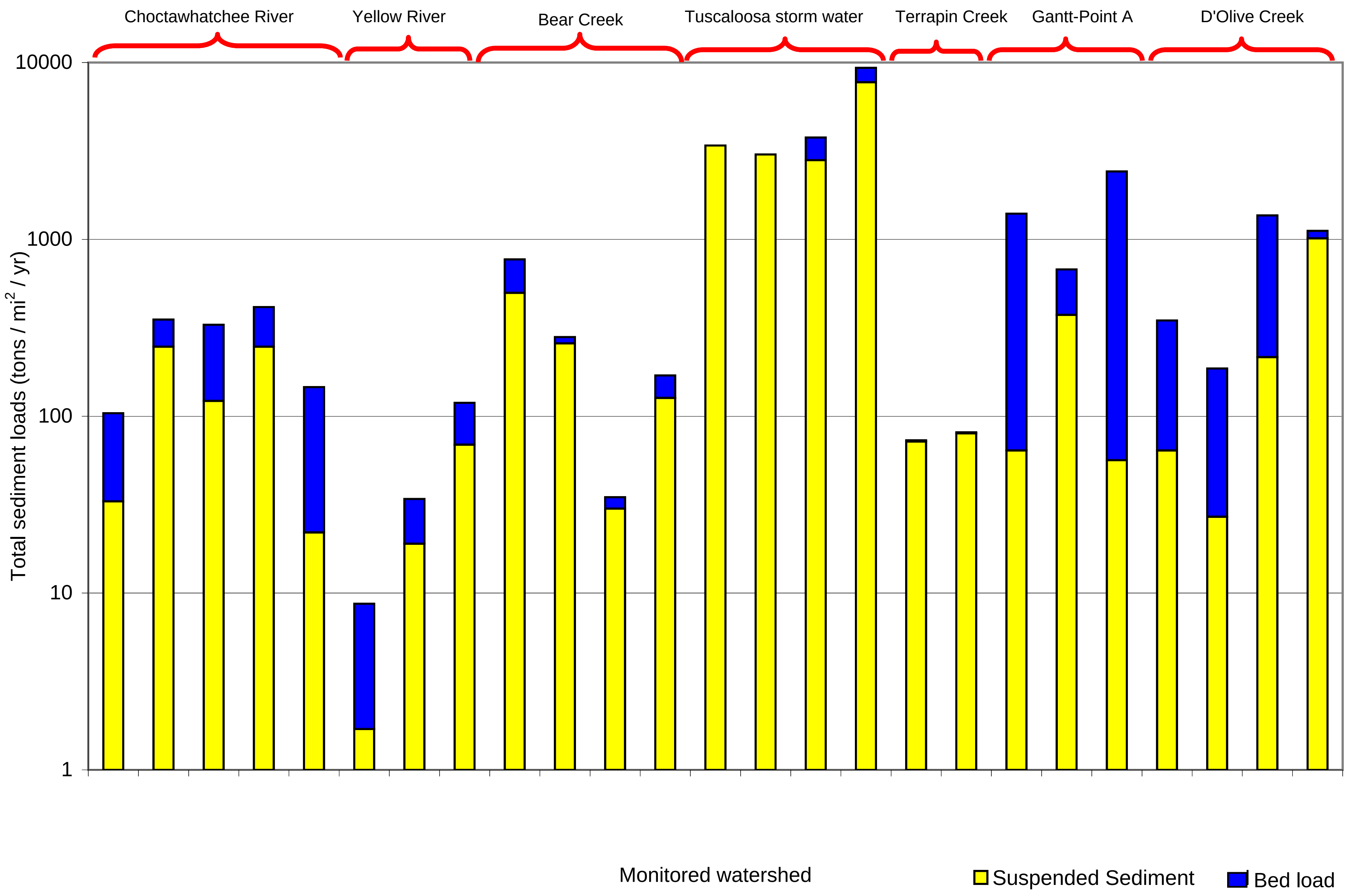


Table 4—Estimated total sediment loads for selected project streams.

Monitored site	Estimated geologic erosion rate total sediment load (tons/yr)	Estimated total annual sediment load (tons/yr)	Estimated normalized total annual sediment load (tons/mi ^{2}/yr)
2	51	115	153
3	122	651	348
4	9	191	1,366
5	5	89	1,117
7	614	931	186
8	19	160	70
9	275	35	20
10	58	129	140

SUMMARY

The purpose of this project is to assess the impacts of land-use change by determining sedimentation rates in streams that receive sediment from construction sites in the watershed. These data will be useful in the development of remediation plans to limit erosion and sediment transport into Lake Forest and Mobile Bay.

Sediment loads were determined by direct measurement of suspended and bed sediment for a range of discharge events. These data were evaluated by regression models to determine annual sediment loads.

Sites 7 (Tiawasee Creek immediately upstream from Lake Forest), 10 (Joe's Branch near the mouth of D'Olive Creek), and 3 (D'Olive Creek at U.S. Highway 90) had the largest suspended sediment loads with 135, 129, and 120 tons per year, respectively. When the data were normalized with respect to unit watershed area, sites 5 (tributary to Lake Forest at U.S. Highway 90), 4 (tributary to Lake Forest at U.S. Highway 90), and 10 (tributary to Tiawasee Creek) had the largest loads with 1,013, 216, and 142 tons per mi^2 per year, respectively. Sites 7 and 3 had the largest bed sediment loads with 796 and 531 tons per year, respectively. After normalization of bed sediment loads, sites 4, 3, and 7 had the largest loads with 1,150, 284, and 159 tons/mi ^{2}/yr, respectively.

Sediment loads were estimated for 5 of the 8 streams that drain into Lake Forest. The largest total annual sediment load (931 tons/year) was estimated for site 7. Normalization of total sediment loads indicates that site 4 had the largest load (1,366 tons/mi^2/year). The total annual sediment load transported by these streams was 1,977 tons.

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