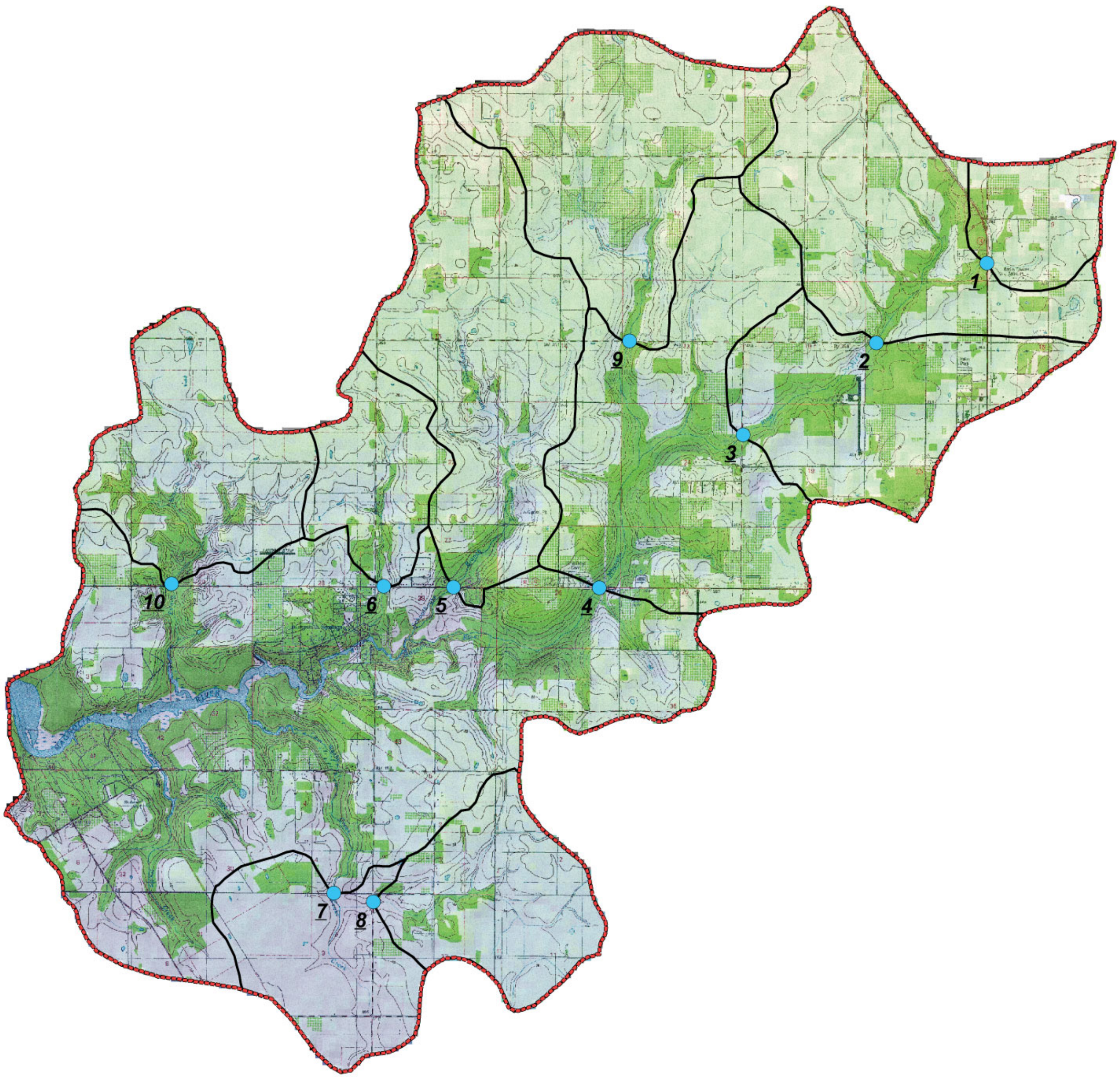
ANALYSIS OF SEDIMENT LOADING RATES FOR THE MAGNOLIA RIVER WATERSHED, BALDWIN COUNTY, ALABAMA 2009



Mobile Bay National Estuary Program

Geological Survey of Alabama Founded 1848

Town of Magnolia Springs

GEOLOGICAL SURVEY OF ALABAMA

Berry H. (Nick) Tew, Jr.
State Geologist

ANALYSIS OF SEDIMENT LOADING RATES FOR THE MAGNOLIA RIVER WATERSHED, BALDWIN COUNTY, ALABAMA 2009

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By

Marlon R. Cook,
Neil E. Moss, and
Dorina Murgulet

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Tuscaloosa, Alabama
2009

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INTRODUCTION

Baldwin County is characterized by highly variable surface-water and habitat quality related to diverse land use, topographic relief, and erodable soils. Previous investigations of sedimentation by the Geological Survey of Alabama (GSA) have shown links between patterns of land use and impacts on sediment loads and biological habitat in watersheds (Cook and others, 2002, Cook, 2005, Cook and Moss, 2007, Cook and others, 2008). Sedimentation data are valuable in quantifying impacts so that remedial plans can be developed and limited regulatory and remedial resources employed where needs are greatest. Due to the geologic and hydrologic character of much of Baldwin County, activities associated with land-use change are particularly effective in promoting erosion and transport of large volumes of sediment that are eventually deposited in Mobile Bay and the Gulf of Mexico. Parts of Baldwin County are among the fastest growing areas in Alabama where agricultural and forested land is being converted to residential and commercial developments. In contrast, many Baldwin County communities such as the town of Magnolia Springs, located along the Magnolia River, have made commitments to maintain and protect the water and habitat quality in the watershed.

The purpose of this project is to determine sediment loads for the Magnolia River watershed in southeastern Baldwin County so that sources of sediment can be identified and land treatment efforts can be focused on subwatersheds with excessive erosion and sediment transport.

ACKNOWLEDGMENTS

Contributors to the completion of this project include the Honorable Charles Houser, Mayor, Magnolia Springs, Mr. Brett Gaar, Town Councilman, Magnolia Springs, and Ms. Roberta Swann, Director, Mobile Bay National Estuary Program.

PROJECT AREA AND MONITORED STREAM SEGMENTS

The Magnolia River project area includes the town of Magnolia Springs and part of the city of Foley in southeastern Baldwin County, southwest Alabama (fig. 1). The project consists of 10 monitoring sites and a monitored area of 30.6 square miles (mi^2) (plate 1, table 1).

Site 1 is on Magnolia River at the State Highway 59 crossing. The watershed area upstream from the monitoring site contains the headwaters of the river (plate 1). The stream upstream from site 1 has a gradient of about 10 feet per mile (ft/mi).

Site 2 is on Magnolia River at the Baldwin County Highway 24 crossing downstream from site 1 (plate 1). The stream has a gradient of 11 ft/mi, upstream from the monitoring site.

Site 3 is on Magnolia River at the Baldwin County Highway 65 crossing (plate 1). The river has a gradient of 10 ft/mi, upstream from the monitoring site. However, the gradient between sites 2 and 3 is about 5 ft/mi.

Site 4 is on Magnolia River at the U.S. Highway 98 crossing (plate 1). The river upstream from the monitoring site is 6.0 miles long and has a gradient of 10 ft/mi.

Site 5 is on Schoolhouse Branch at the U.S. Highway 98 crossing about 3,000 ft upstream from Magnolia River (plate 1). Schoolhouse Branch flows southwestward and drains the northern part of the project area upstream from the monitoring site. The stream has a gradient of 17 ft/mi.

Site 6 is on an unnamed tributary about 0.5 stream mile from its confluence with Magnolia River at the U.S. Highway 98 crossing (plate 1). Upstream from the monitored site, the stream has a gradient of 30 ft/mi.

Site 7 is on Weeks Creek at the Bay Road crossing, 2.4 stream miles from the confluence with Magnolia River (plate 1). The stream has extensive beaver activity and is impounded immediately downstream from the monitored site. The stream gradient upstream from the monitored site is about 7 ft/mi.

Site 8 is on Weeks Creek at the Baldwin County highway 49 crossing about 0.3 stream mile upstream from its confluence with an unnamed tributary (plate 1). The stream upstream from the monitored site has a gradient of 15 ft/mi.

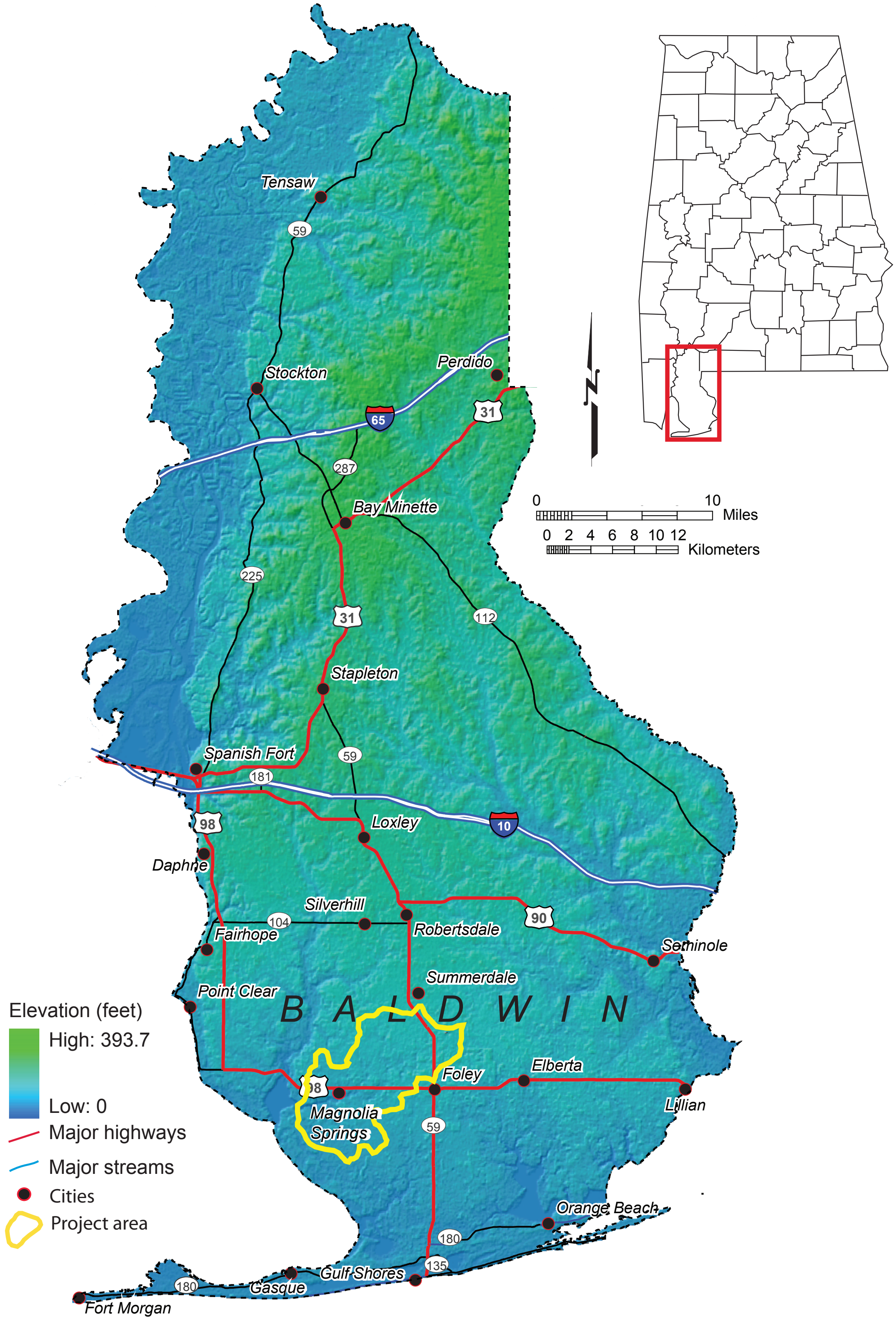


Figure 1.--Magnolia River project area, Baldwin County, Alabama.

Site 9 is on an unnamed tributary at the Baldwin County Highway 24 crossing about 1.1 stream miles from its confluence with Magnolia River (plate 1). The stream has extensive beaver activity and is impounded at several points along its path.

Site 10 is on Eslava Branch at the U.S. Highway 98 crossing, 1.1 stream miles from the confluence with Magnolia River (plate 1). The stream gradient upstream from the monitored site is about 19 ft/mi.

Table 1—Monitoring sites and watershed areas in the Magnolia River watershed.

Stream monitoring site	Site no.	Watershed area (mi^2)	Upstream gradient (ft/mi)
Magnolia River at Alabama Hwy. 59	1	1.1	10
Magnolia River at Baldwin County Hwy. 24	2	4.8	11
Magnolia River at Baldwin County Hwy. 65	3	7.7	5
Magnolia River at U.S. Hwy. 98	4	16.2	10
Schoolhouse Branch at U.S. Hwy 98	5	4.2	17
Unnamed tributary to Magnolia River at U.S. Hwy. 98	6	1.4	30
Weeks Creek at Baldwin County Bay Road	7	4.1	7
Weeks Creek at Baldwin County Hwy 49	8	2.1	15
Unnamed tributary to Magnolia River at Baldwin County Hwy. 24	9	3.7	N/A[1]
Eslava Branch at U.S. Hwy. 98	10	2.6	19

[1]No gradient could be determined due to beaver-constructed impoundments.

LAND USE

The 2001 USGS Land Use/Land Cover data (Homer and others, 2004) were used in delineating land use/land cover classes for the Magnolia River watershed (plate 2). This dataset was compiled from Landsat Thematic Mapper Plus (ETM+) satellite imagery (circa 2001) and it was supplemented by various ancillary data such as the National Land Cover Database 2001 for mapping zone 46, produced by the Multi-Resolution Land Characteristics Consortium. Land use and vegetative cover in the Magnolia River watershed is characterized by uplands dominated by agriculture, commercial and residential development along roadways and floodplains with wetland and forest vegetation (plate 2).

The primary land use in the northern and southwestern parts of the watershed is row crop (mostly soybeans) and turf farming (plate 2). Land use in the eastern part of the unnamed tributary watershed upstream from site 9 is dominated by a major turf farming operation, as is most of the watershed upstream from site 7 (fig. 2).

Commercial development in the Magnolia River watershed is confined to the cities of Foley (in the headwaters on the eastern margin of the watershed) and Magnolia Springs (in the western part of the watershed near the downstream margin of the project area) and minimal development along major roadways. Residential development is characterized by widely spaced single-family homes and small subdivisions. The city of Foley airport is near the Magnolia River immediately downstream from site 2 (plate 1).

The floodplains of Magnolia River and major tributaries are composed of natural forest and wetland vegetation (plate 2, fig. 3). Extensive beaver activity in much of the floodplain has led to numerous impoundments with aquatic habitat that supports communities of fish, reptiles, mammals, and birds (figs. 3, 4).

STREAM FLOW CONDITIONS

Sediment transport conditions in the Magnolia River area are segregated by particular stream segments based on instream conditions influenced by topography and soils, impoundments (human and beaver constructed), construction and excavation, and existing erosion prevention and runoff detention efforts. Natural conditions including

Figure 2.—Weeks Creek monitoring site 7, turf (upper left) and soybean farming (upper right). Note exposed soil where turf was recently harvested.

Figure 3.—Monitoring site 9 impoundment caused by a beaver dam (water discharging over dam in upper right).

Figure 4.—Floodplain vegetation and stream flow restriction (upper photograph Weeks Creek, site 8, lower photograph Magnolia River, site 4).

precipitation, stream gradient, geology, and vegetative cover are also important factors that impact sediment transport characteristics of streams.

Estimates of sediment loads are based on regressions determined from measured sediment and stream discharge. Therefore, a stream flow dataset composed of values that vary from base flow to flood is desirable (table 2). However, monitored stream flow events during the project period at sites 1, 5, 6, 7, 8, and 9 were affected by beaver activity that periodically restricted flow or prevented direct measurement (figs. 3, 4).

Table 2. Measured stream flow characteristics for monitored sites in the Magnolia River watershed.

Site no.	Average discharge (cfs[1])	Maximum discharge (cfs[2])	Minimum discharge (cfs)	Average flow velocity (ft/s[3])	Maximum flow velocity (ft/s)	Minimum flow velocity (ft/s)
1	(4)	(4)	(4)	(5)	(5)	(5)
2	8.7	359	3.8	0.6	0.8	0.3
3	17.7	731	7.4	0.8	0.9	0.7
4	33.4	1,380	14.0	0.9	1.2	0.6
5	1.1	47	0.5	(5)	(5)	(5)
6	0.2	16	0.1	(5)	(5)	(5)
7	8.4	357	3.5	(5)	7.0	0.3
8	4.3	334	1.8	(5)	1.9	0.02
9	(4)	(4)	(4)	(5)	(5)	(5)
10	5.3	221	2.2	0.65	1.10	0.34

[1]cfs- cubic feet per second
[2]high flow estimated by regression analysis and unit area calculations
[3]ft/s- feet per second
[4]discharge estimated due to beaver impoundment
[5]velocity not available

Therefore, a number of discharge events were determined using unit area discharge estimation in which measured discharge is used to establish a unit area discharge that can be used in watersheds with similar geology, soils, hydrology, and land use where direct discharge measurement is not possible (table 2). Also, in most cases, due to limited high flow events, high flows were estimated using regression analyses and unit area calculations (table 2).

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 primarily 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 MONITORED STREAMS

The transport rate 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.

Land surface disturbance and removal of vegetation are the primary causes of excessive erosion and sedimentation in the Magnolia River watershed. In several monitored subwatersheds, highly erodable soils formed from Citronelle Formation sediments combined with relatively steep topographic relief result in excessive sediment transport (table 1). Excessive sedimentation causes changes in base level elevation of streams in the watershed and triggers downstream movement of the material as streams attempt to regain base level equilibrium. The movement of this material is accelerated by periodic large precipitation events that cause increased stream flow and stream flow velocity.

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 considered 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. Turbidity values for all monitoring sites are shown in table 3.

Table 3—Measured total suspended solids (TSS) and estimated suspended sediment loads for monitored streams.

Site no.	Average turbidity (NTU)	Maximum turbidity (NTU)	Average TSS (mg/L)	Maximum TSS (mg/L)	Estimated suspended sediment load (t/yr)	Estimated normalized suspended sediment load ($t/mi^2/yr$)	Estimated suspended sediment load 10 yr. avg. (t/yr)
1	30	112	24	60	48	44	34
2	37	175	61	125	351	73	255
3	18	64	26	88	448	58	231
4	44	229	49	140	1,811	112	758
5	35	35	20	85	2	0.4	0.7
6	28	28	14	50	0.2	0.04	0.2
7	92	346	93	180	623	168	590
8	115	415	31	116	121	33	116
9	102	250	86	350	595	161	572
10	19	64	23	50	101	27	98

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 annual average daily discharge for all project streams was not available from direct measurement, it was estimated by establishing a unit area discharge or a ratio between periodic measured discharge in project streams and discharge values for the same times obtained from the USGS stream flow monitoring station (USGS, 2008-2009) located on Magnolia River at Alabama Highway 98 (USGS stream monitoring site 2378300). Estimated suspended sediment loads for each monitored site are shown in table 3 and figure 5. Sites 4, 7, and 9 had the largest loads with 1,811, 623, and 595 tons per year (t/yr), respectively. Normalizing suspended loads with respect to unit watershed area permits comparison of monitored watersheds. Figure 6 shows normalized suspended sediment loads with sites 7, 9, and 4 having the largest loads with 168, 161, and 112 tons per mi^2 per year ($t/mi^2/yr$), respectively. Suspended sediment loads were also estimated using average annual discharge for the period 1999-2009, which led to loads that were 35 percent lower than those estimated during the project period in 2008 and 2009 (table 3).

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.

Figure 5.--Estimated annual suspended sediment loads for monitored sites in the Magnolia River watershed.

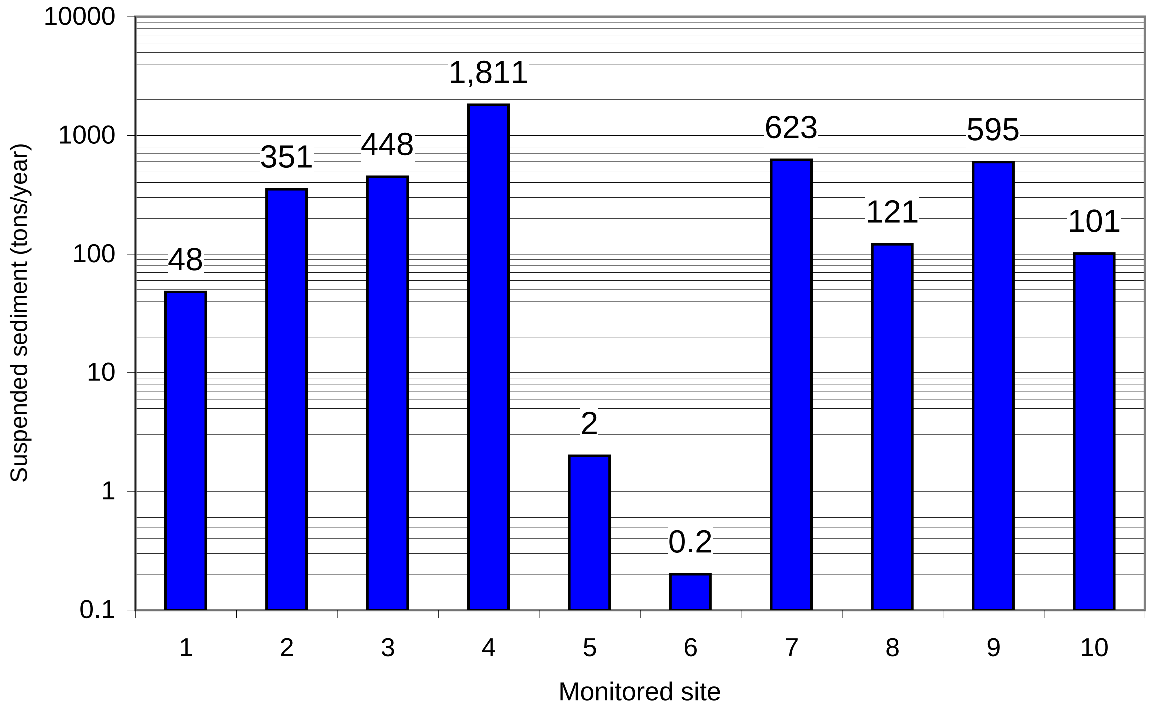
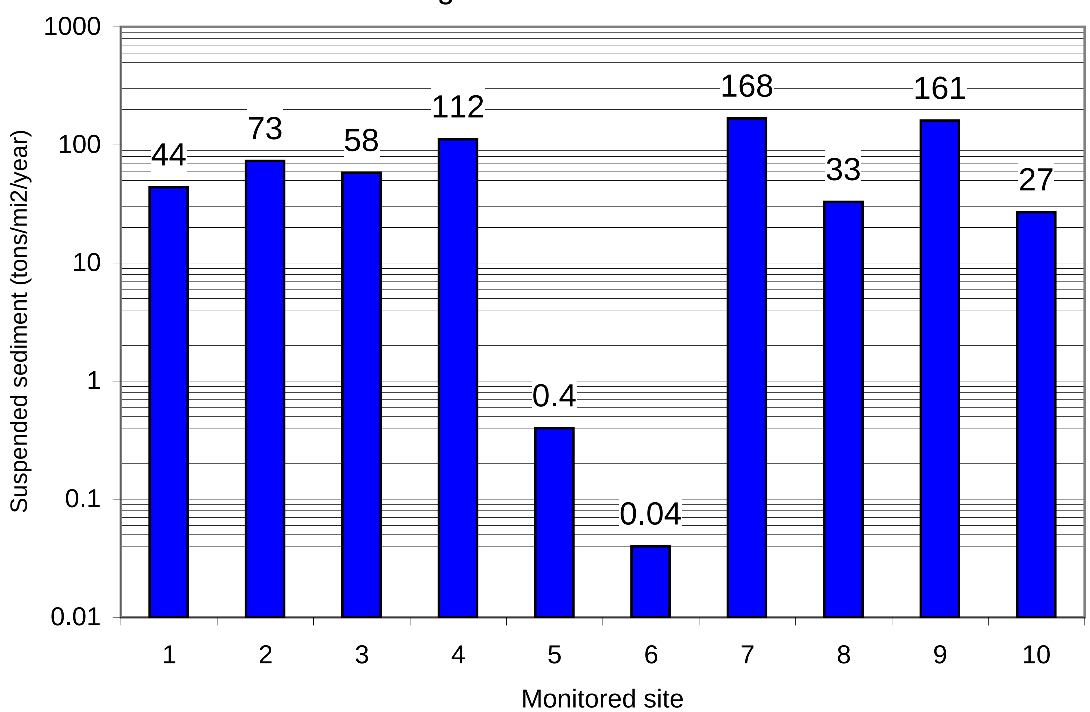


Figure 6.--Estimated normalized annual suspended sediment loads for monitored sites in the Magnolia River watershed.



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 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.

The Geological Survey of Alabama developed a portable bed load sedimentation rate-monitoring device to accurately measure bed sediment in shallow sand or gravel bed streams (fig. 7) (Cook and Puckett, 1998). The device was utilized during this project to measure bed load periodically over a range of discharge events to calculate daily bed load sedimentation rates. Figures 8 and 9 show measured stream discharge and bed sediment at sites 2 and 3 on Magnolia River. Note the excellent correlation between measured discharge and corresponding bed sediment transport rates. All other sites monitored in the

Figure 7.—Bed sediment measured in Magnolia River at site 3.

Figure 8.--Measured discharge and bed sediment for Magnolia River site 2.

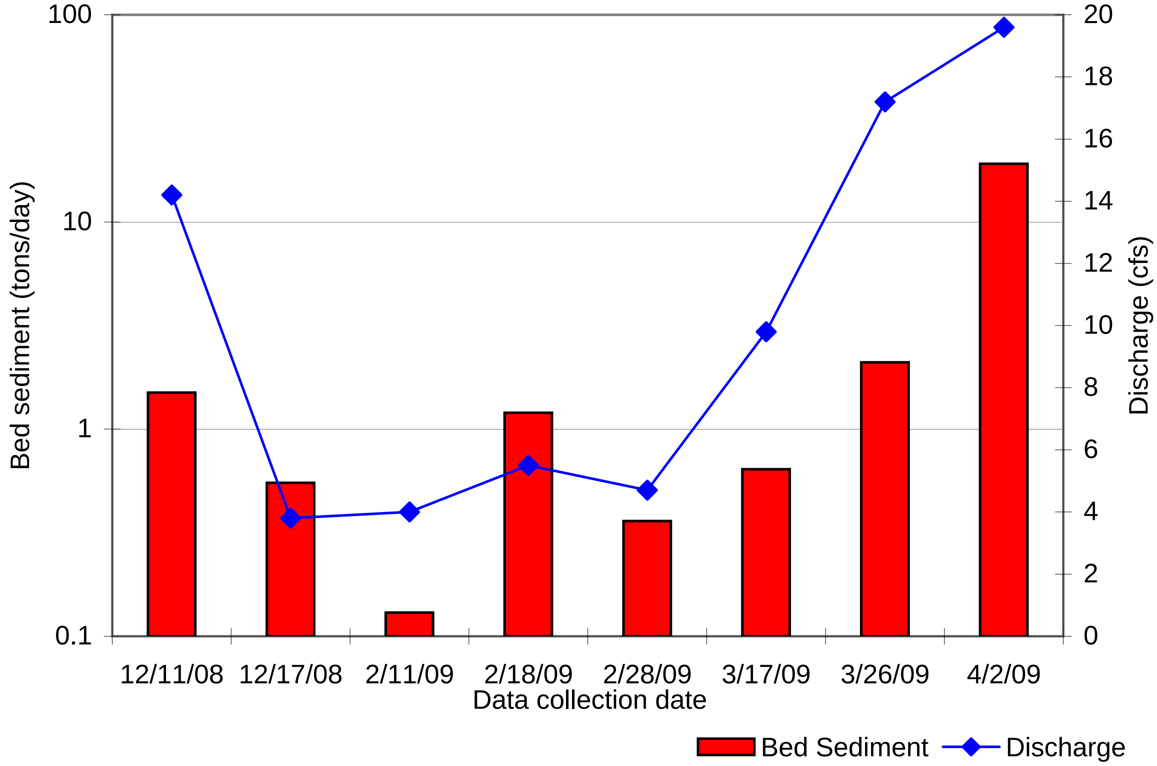
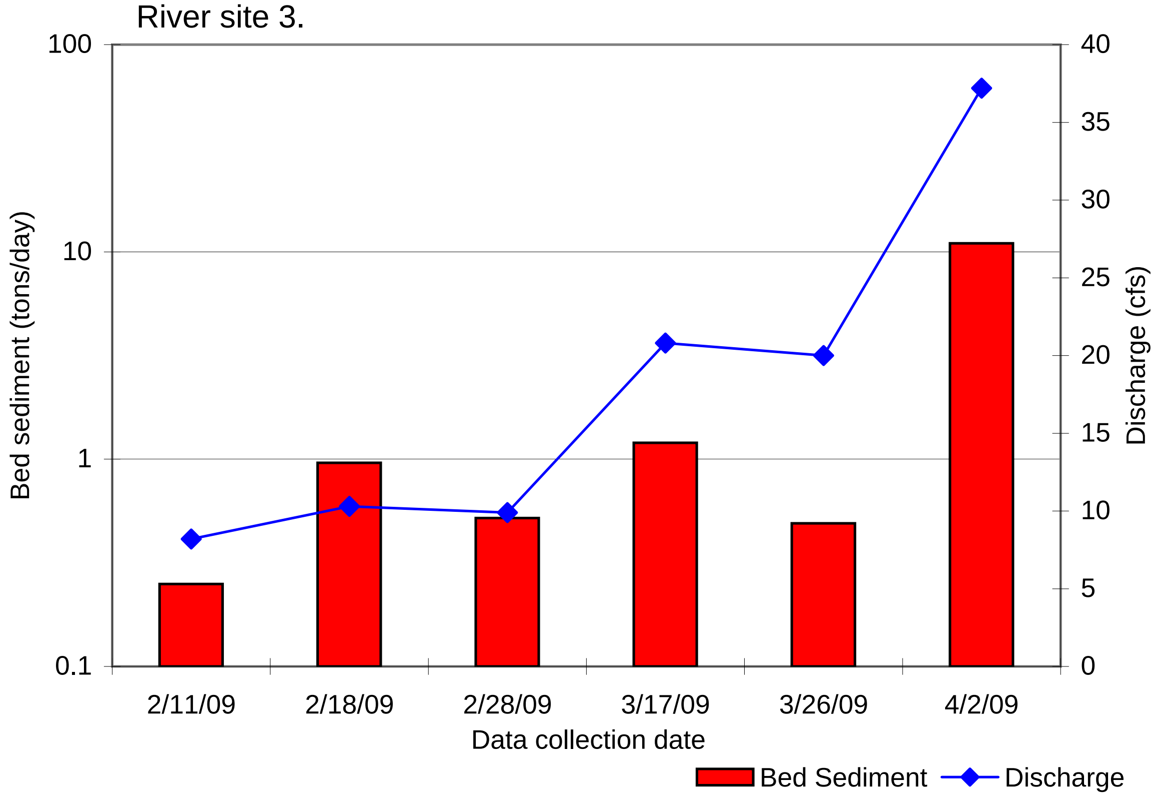


Figure 9.--Measured discharge and bed sediment for Magnolia River site 3.



project area are characterized by stream channel and discharge conditions that disrupted bed sediment movement and prevented estimation of bed sediment loads. 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. Table 4 gives stream discharge, stream-flow velocity, annual bed sediment loads, and normalized annual bed sediment loads for monitoring sites in selected streams in the project area. Figure 10 shows estimated annual bed sediment loads for monitoring sites 2 and 3 in the project area. Figure 11 shows estimated annual bed sediment loads normalized with respect to watershed drainage area. Sites 2 and 3 had the loads with 777 and 861 t/year, respectively. After normalization of bed sediment loads, sites 2 and 3 had loads with 162 and 112 t/mi ^{2}/yr, respectively. The largest load was at the more upstream

Table 4—Measured discharge, stream-flow velocity, and estimated bed sediment loads for monitoring sites on selected streams in the project area.

Site no.	Average discharge (cfs)	Average stream-flow velocity (ft/s)	Estimated annual bed sediment loads (t/yr)	Estimated Normalized annual bed sediment loads (t/mi ^{2}/yr)
2	9.9	0.61	777	162
3	25.0	0.81	861	112

site 2, indicating that more bed sediment originates from sources in the watershed upstream from site 2 than from the watershed area between sites 2 and 3.

TOTAL SEDIMENT LOADS

Total sediment loads are composed of suspended and bed sediment. As discussed 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 watersheds, called the geologic erosion rate, would be 64 t/mi ^{2}/yr (Maidment, 1993). The geologic erosion rates for the project watersheds are shown in table 5.

The largest total annual sediment load (1,811 t/yr) was estimated for site 4 in Magnolia River (table 5, fig. 12). This is not surprising since site 4 (main stem Magnolia River) has the largest drainage area. However, no bed sediment load was

Figure 10.--Estimated annual bed sediment loads for selected streams in the Magnolia River watershed.

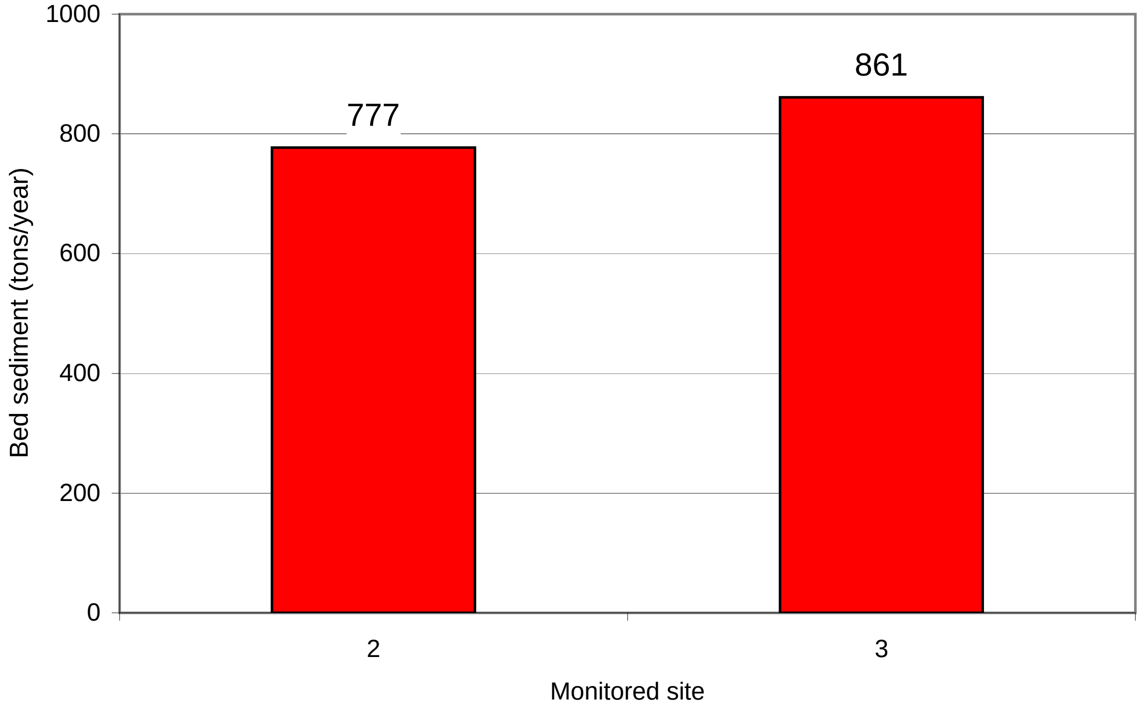


Figure 11.--Estimated normalized annual bed sediment loads for selected streams in the Magnolia River watershed.

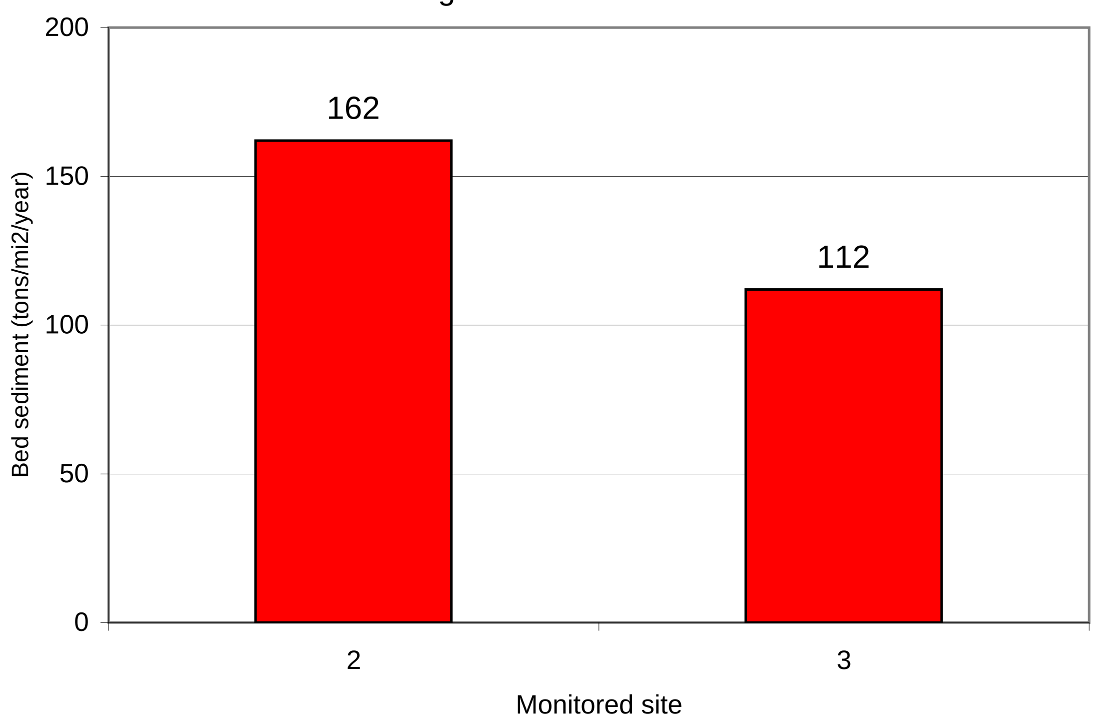


Table 5—Total estimated sediment loads for monitored streams.

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)	Estimated normalized total annual sediment load (cubic feet/yr)
1	70.4	48[1]	44[1]	89[1]
2	307	1,128	235	2,089
3	493	1,309	170	2,424
4	1,037	1,811[1]	112[1]	3,354[1]
5	269	2[1]	0.4[1]	4[1]
6	90	0.2[1]	0.04[1]	0.4[1]
7	262	623[1]	168[1]	1,154[1]
8	134	121[1]	33[1]	224[1]
9	237	595[1]	161[1]	1,102[1]
10	166	101[1]	27[1]	187[1]

[1]Sediment load composed of suspended sediment only

estimated due to obstructions in the stream channel that prevented accurate measurement and load estimation. The largest total sediment load for a tributary was site 7 (Weeks Creek) with 623 t/yr. When the data are normalized, allowing comparison of sediment loads with respect to unit drainage areas, site 2 (main stem Magnolia River) had the largest load (235 t/mi^2/yr) (table 5, fig. 13). Table 5 and figure 14 shows total sediment loads for each of the monitored stream segments in cubic feet per year.

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 26 streams throughout Alabama shown in figure 15 indicate that streams with the largest sediment loads estimated in the Magnolia River watershed are higher than watersheds that are primarily forested such as Yellow River in south-central Alabama (Cook and others, 2002) and Terrapin Creek in the northeast part of the state (Cook, 2005). However, they are much lower than watersheds with significant anthropogenic erosional impacts such as D’Olive Creek in Baldwin County (Cook and others, 2008) where the estimated normalized total sediment load was 1,987 t/mi^2/yr, urban streams in the city of Tuscaloosa (Cook and others, 2005), or erosion of unpaved roads in the

Figure 12.--Estimated annual total sediment loads for monitored sites in the Magnolia River watershed.

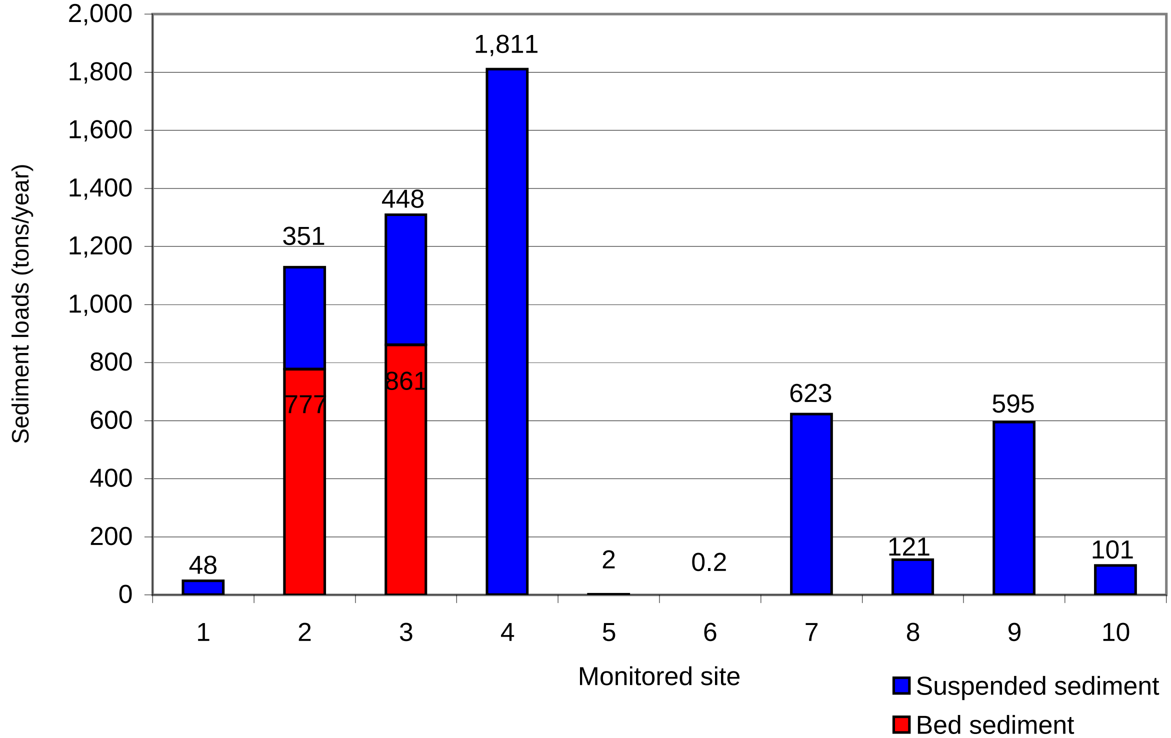


Figure 13.--Estimated normalized total annual sediment loads for monitored sites in the Magnolia River watershed.

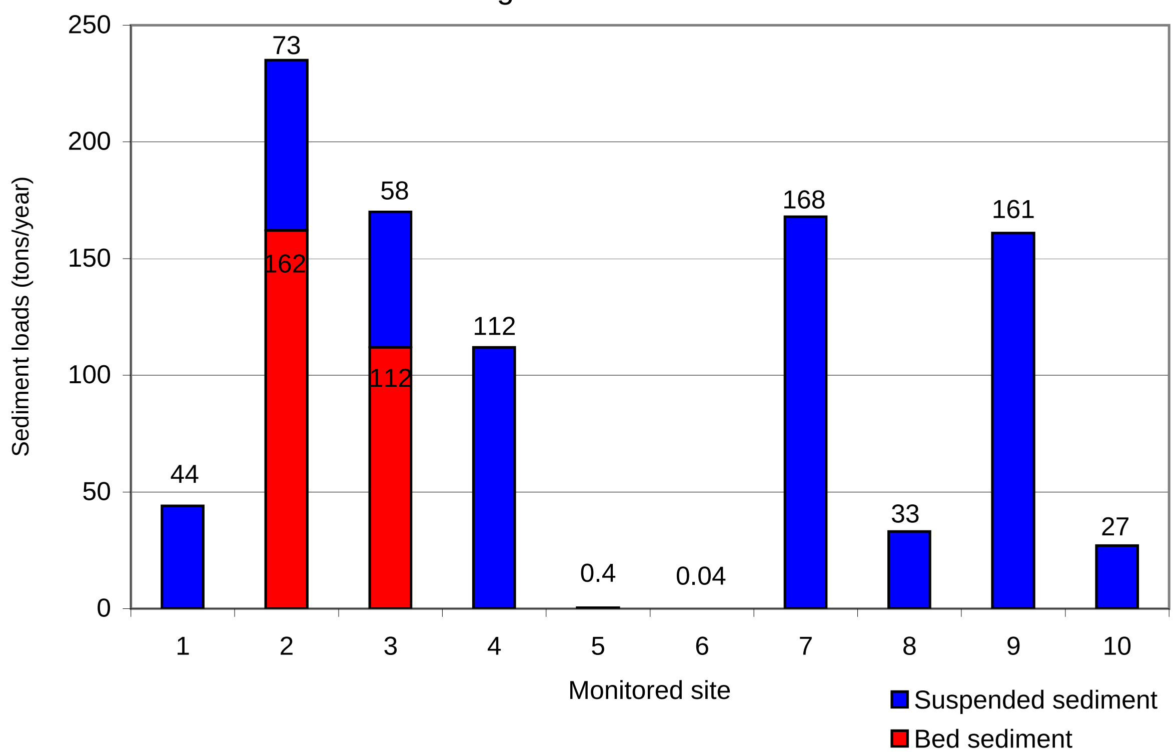


Figure 14.--Estimated annual total sediment loads for monitored sites in the Magnolia River watershed in cubic yards.

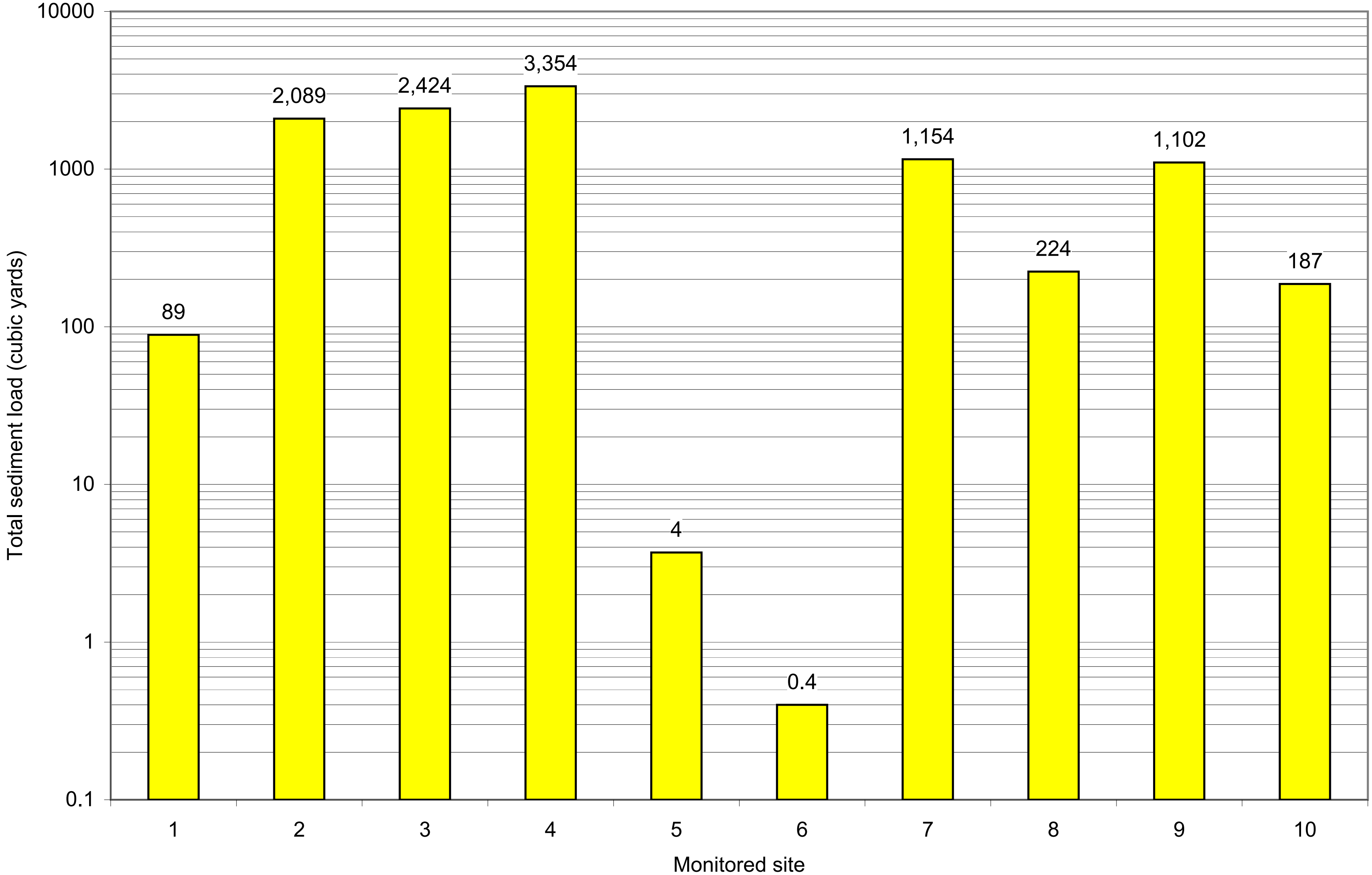
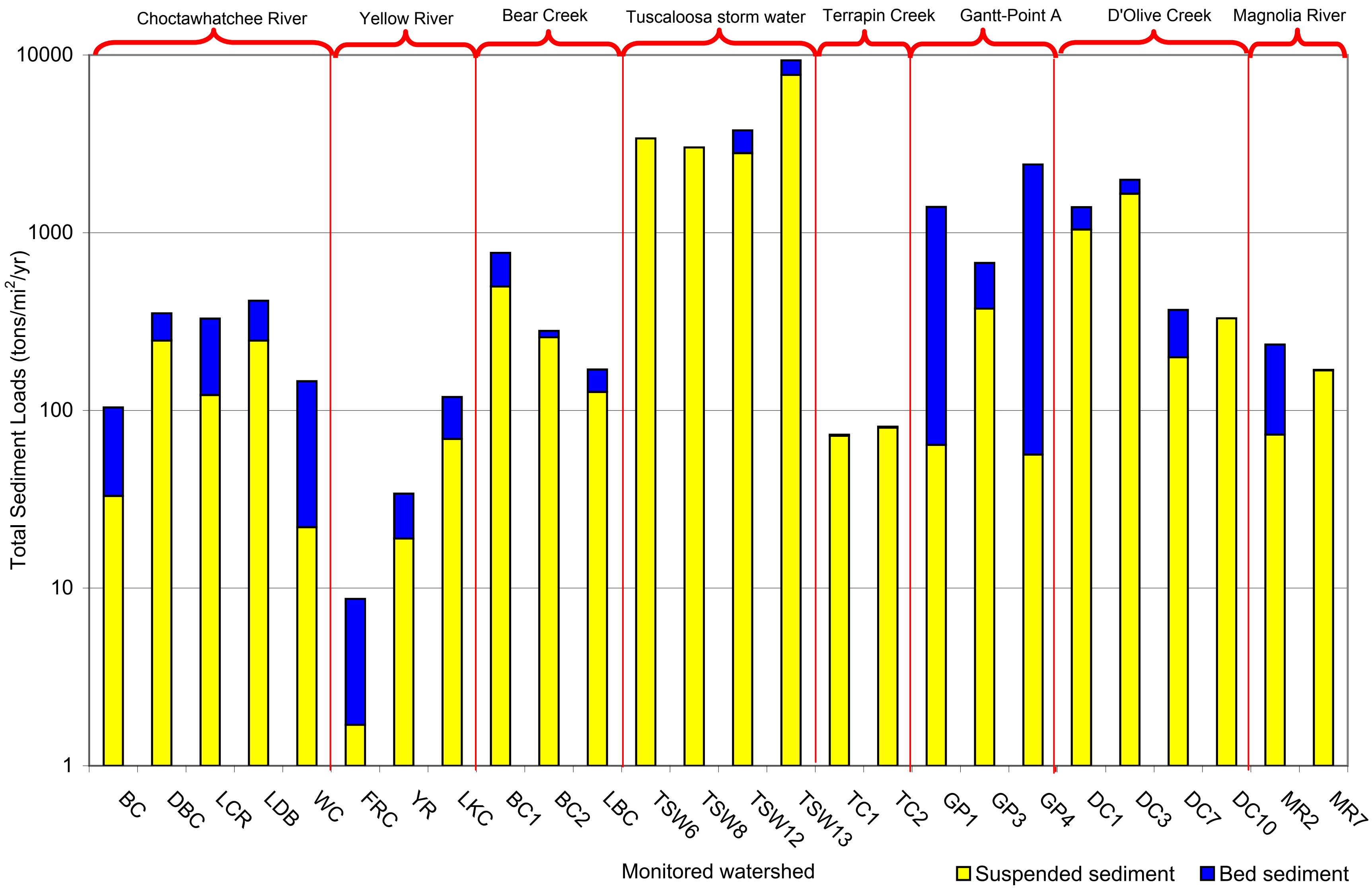


Figure 15.--Estimated normalized total annual sediment loads for selected watersheds in Alabama.



Gantt/Point A watershed (Cook and Moss, 2007). If land use in the Magnolia River watershed changes significantly 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.

SUMMARY

The purpose of the Magnolia River sedimentation assessment project was to assess the impacts of current land use in the watershed by determining rates of sediment transport in Magnolia River and major tributaries and to provide data to assist in the development of future plans to limit erosion and sediment transport and to protect water quality and habitat in the watershed.

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. Ten sites were monitored and had sediment rates estimated. Sites 1 through 4 were on the main channel and sites 5 through 10 were on tributaries to Magnolia River. Sites 4, 3, and 2 (main channel of Magnolia River) had the largest total sediment loads (bed and suspended sediment) with 1,811, 1,309, and 1,128 t/yr, respectively. This is not surprising since loads at main channel sites indicate cumulative sediment for the entire watershed upstream from each site. The largest total sediment loads estimated for tributaries includes sites 7 (Weeks Creek), and 9 (unnamed tributary) with 623 and 595 t/yr, respectively. When the data were normalized with respect to unit watershed area, sites 2, 3, 7, and 9 had the largest loads with 235, 170, 168, and 161 t/mi^2/yr, respectively. In contrast, the normalized total sediment load estimated for the main channel of D'Olive Creek at U.S. Highway 90 in Daphne during the 2008 GSA assessment was 1,987 t/mi^2/yr.

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GEOLOGICAL SURVEY OF ALABAMA
P.O. Box 869999
420 Hackberry Lane
Tuscaloosa, Alabama 35486-6999
205/349-2852

Berry H. (Nick) Tew, Jr., State Geologist

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