GEOLOGICAL SURVEY OF ALABAMA

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FACTORS POTENTIALLY AFFECTING THE PROPAGATION AND REINTRODUCTION OF FRESHWATER MUSSELS (BIVALVIA: UNIONIDAE) INTO THE BUTTAHATCHEE RIVER SYSTEM, ALABAMA AND MISSISSIPPI

Open File Report 0609

by

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Prepared in cooperation with the World Wildlife Fund
Agreement Number LX 30

Tuscaloosa, Alabama
2006

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INTRODUCTION

A valuable remnant mussel fauna remains in the Buttahatchee River. An important component of that fauna is the presence of federally listed species, especially the only known population of the critically imperiled *Epioblasma penita.* Continued threats to that fauna include gravel mining, agricultural and silvicultural practices, and other point and nonpoint pollution sources. An effort is underway to propagate mussels in captivity and return them to suitable historic locations within the Mobile River basin, including the Buttahatchee system. In 2005 the Geological Survey of Alabama (GSA) entered into a contract with the World Wildlife Fund to assess factors that may influence the successful reintroduction of mussels in the Buttahatchee River system. Many factors influence reintroductions of mussels, but some are of paramount importance. These factors include suitable habitat quality, including a stable substrate unburdened by chemicals toxic to freshwater mussels, and the presence of suitable fish species for the obligate parasitic larval stages of mussels. Information on the historic mussel fauna and reproductive needs of mussels in the Buttahatchee River system was compiled from literature and museum sources. A sample of shallow bed sediment was collected and its chemical constituents analyzed and compared with information for nearby streams with healthy mussel faunas. Measurements of sediment loading taken during this project were synthesized with those of a previous study of sediment loading to determine current loading rates and identify sources of sedimentation.

ACKNOWLEDGMENTS

Tom Mann of the Mississippi Museum of Natural Science provided information on distribution and conservation status of mussels and fishes in the Mississippi portion of the study area. Jim Williams and Sherry Bostick of the U.S. Geological Survey (USGS) Florida/Caribbean Science Center in Gainesville, Florida, provided information on historic records of mussels in the study area. Paul Johnson of the Alabama Aquatic Biodiversity Center provided comments on the mussel propagation section, and Teresa Newton of U.S. Geological Survey Upper Midwest Science Center in LaCrosse, Wisconsin, provided comments on the results of chemical analyses of sediment for potential toxins. World Wildlife Fund Southeast Rivers and Streams Program provided financial support for this report.

DISCUSSION

MUSSEL FAUNA

Mussels are an important food resource for many animals, such as wading birds, fishes, and mammals (including, historically, humans), and are used commercially in the cultured pearl industry. Because of their role as benthic filter-feeders, mussels are also valuable indicators of ecological health, and trends in mussel health and uptake of toxins may predict potential environmental problems (Naimo, 1995). As a group, mussels are widely considered to be among the most imperiled organisms in the world (Williams and others, 1993, Lydeard and Mayden, 1995; Neves and others, 1997; Lydeard and others, 2004; Strayer and others, 2004).

The Mobile River basin is the largest Gulf of Mexico river basin east of the Mississippi River and historically supported at least 72 species of freshwater mussels.

The Tombigbee River system, which is part of the Mobile River basin, supported over 50 species. The Mobile River basin's mussel fauna is also noteworthy for its high degree of endemism (Williams, 1982). Significant human-induced impacts to the basin over the past 100 years, including impoundment, eutrophication, sedimentation, pollution, and channel modifications, have caused a drastic decline in mussel diversity (Williams and others, 1992; Hartfield, 1994; McGregor and Haag, 2004). Currently, 17 species of freshwater mussels in the Mobile River basin are recognized as endangered or threatened by the U.S. Fish and Wildlife Service (USFWS), and 14 species in the genus *Pleurobema* endemic to the basin are considered extinct (Hartfield, 1994).

The Buttahatchee River is one of four major tributaries that flow into the Tombigbee River. Historically, the Buttahatchee River sustained a diverse mussel fauna, with an aggregate total of 43 species documented from literature and museum records (table 1). Yokley (1978) reported 40 species from the lower 70 miles of the river in Alabama and Mississippi, and Hartfield and Jones (1990) reported 30 species from the Mississippi section. McGregor and Haag (2004) reported 30 species from stations in Alabama and Mississippi (table 2, fig. 1).

There are records of nine federally listed mussel species from the Buttahatchee River system (table 1). Two of those species (*Quadrula stapes* and *Pleurobema taitianum*) were generally restricted to large river habitats in the Mobile basin, and records in the Buttahatchee were restricted to the lowermost reach. Those species have declined since the opening of the Tennessee/Tombigbee Waterway to the point that *Q. stapes* is now considered extinct and *P. taitianum* is only known from isolated populations in the lower Tombigbee and upper Alabama Rivers (Mirarchi, 2004).

Table 1.—Status and recovery potential for freshwater mussels in the Buttahatchee River system, Alabama and Mississippi

Species (federal status)[1]	State Conservation Status[2]		Buttahatchee River status	Broodstock sources	Recovery Locations
	Alabama	Mississippi			
Amblema plicata	P4	NA	Known recently from weathered shells at one station in lower river; possibly extirpated	NA	NA
Anodonta suborbiculata	P4	S3/S4	Known recently from a fresh dead shell in lower river; may be expanding range as streams are altered	NA	NA
Anodontoides radiatus	P2	S2	Recently found live in tributary Sipsey Creek; rare throughout its range but perhaps most abundant in upper Tombigbee system	Buttahatchee River, Coal Fire, Sipsey, and Lubbub Creeks	Buttahatchee River headwaters, tributaries
Arcidens confragosus	P3	S2	Known recently from a few shells in lower river	Gainesville Bendway of Tombigbee River, Mississippi	Lower Buttahatchee River
Elliptio arca	P1	S3	Recently found live or fresh dead at several lower main channel stations; along with Sipsey River, may be last stronghold in Mobile basin	Sipsey River, Yellow Creek	Coosa, Cahaba, lower Buttahatchee Rivers
Elliptio arctata	P1	S1/E	Recently found fresh dead at a lower main channel station; extremely rare in Buttahatchee and Sipsey Rivers in upper Tombigbee system	Sipsey River	Coosa, Cahaba, lower Buttahatchee Rivers
Elliptio crassidens	P5	NA	Recently found live at several lower main channel stations; common and widespread	NA	NA
Epioblasma penita (E)	P1	S1/E	Recently found live but rare at several lower main channel stations; only known extant population	Buttahatchee River	Cahaba, lower Buttahatchee Rivers
Fusconaia cerina	P5	NA	Recently found live and common in lower river; also common elsewhere in Mobile basin	NA	NA
Fusconaia ebena	P5	NA	Recently collected live but uncommon in lower river	NA	NA
Lampsilis ornata	P4	NA	Recently found live and common in lower river; common in Mobile basin; restricted to Buttahatchee and Sipsey Rivers in upper Tombigbee system	NA	NA
Lampsilis perovalis (T)	P2	S3/E	Not recently collected in Buttahatchee; otherwise widely distributed but rare in eastern tributaries of upper Tombigbee system	Sipsey River and Sipsey Fork	Buttahatchee, Cahaba, and North Rivers
Lampsilis straminea	P3	S3	Recently found live at numerous stations throughout the river and in tributaries; common and widespread in Mobile basin	NA	NA
Lampsilis teres	P5	NA	Recently found live at two stations in the main channel; common elsewhere	NA	NA
Lasmigona alabamensis	P3	NA	Recently found live at four lower main channel stations	NA	NA
Leptodea fragilis	P5	NA	Recently found live at several lower main channel stations; common elsewhere	NA	NA

Table 1.—Status and recovery potential for freshwater mussels in the Buttahatchee River system, Alabama and Mississippi--continued

Species (federal status)[1]	State Conservation Status[2]		Buttahatchee River status	Broodstock sources	Recovery Locations
	Alabama	Mississippi			
Margaritifera marrianae	P1	NA	Known from a few shells collected near Hamilton in 1909; generally found only in a restricted area of Conecuh River system and Limestone Creek in lower Alabama River system	Cedar Creek of Conecuh River system	Near Hamilton
Medionidus acutissimus (T)	P2	S1/E	Recently found live at several lower main channel stations and the tributary Sipsey Creek; this and Sipsey Fork and Sipsey River are its strongholds	Sipsey Fork; Sipsey River	Coosa; Cahaba, Buttahatchee Rivers; Lubbub, Trussells and Town Creeks
Medionidus parvulus (E)	X	NA	Not recently collected in Buttahatchee; known from a few shells collected 50 years ago	Upper Coosa system	Lower Buttahatchee
Megalonaias nervosa	P5	NA	Recently found live at a single lower main channel station; common throughout its range	NA	NA
Obliquaria reflexa	P5	NA	Recently found live at several lower main channel stations; common throughout its range	NA	NA
Obovaria jacksoniana	P3	S2	Recently found live at a single lower main channel station; fairly common only in Sipsey River	NA	NA
Obovaria unicolor	P2	S3	Recently found live at two stations in the main channel; Sipsey River is stronghold in diminishing range	Sipsey River, Lubbub Creek	Buttahatchee, Cahaba and Noxubee Rivers; Trussells Creek
Plectomerus dombeyanus	P5	NA	Known from a few shells in lower river collected about 1990	NA	NA
Pleurobema decisum (E)	P2	S1/S2/E	Recently found live at several lower main channel stations; historically known upstream to Hamilton; Buttahatchee and Sipsey Rivers are its strongholds	Sipsey River, Lubbub Creek	Lower Buttahatchee River
Pleurobema perovatum (E)	P1	S1/E	Recently found live at several lower main channel stations; Buttahatchee and Sipsey Rivers are its strongholds	Sipsey River	Coosa, Cahaba, Buttahatchee Rivers, Trussells Creek
Pleurobema taitianum (E)	P1	SH/E	Not recently found in Buttahatchee River; isolated populations known only from lower Tombigbee and upper Alabama Rivers	Upper Alabama and lower Tombigbee Rivers	Buttahatchee, Cahaba, Coosa, Sipsey and upper Tombigbee Rivers
Potamilus inflatus (T)	P4	S3	Known from a few shells in lower river collected about 50 years ago	NA	NA
Potamilus purpuratus	P5	NA	Known from a few shells collected in the lower river 15 years ago	NA	NA
Pyganodon grandis	P5	NA	Recently found live at one lower main channel station; common throughout its range	NA	NA
Quadrula apiculata	P5	NA	Recently found live at one main channel station; common throughout its range	NA	NA
Quadrula asperata	P5	NA	Recently found live at several lower main channel stations; common throughout its range	NA	NA
Quadrula metanevra	P3	SH	Known from a single shell collected in lower river 25 years ago	NA	NA

Table 1.—Status and recovery potential for freshwater mussels in the Buttahatchee River system, Alabama and Mississippi--continued

Species (federal status)[1]	State Conservation Status[2]		Buttahatchee River status	Broodstock sources	Recovery Locations
	Alabama	Mississippi			
Quadrula rumphiana	P4	S2	Recently found live at several lower main channel stations; common throughout its range	NA	NA
Quadrula stapes (E)	Extinct	SH/E	Not recently collected in Buttahatchee River; likely extinct	NA	NA
Strophitus subvexus	P3	S2	Recently collected live in lower and middle reaches of Buttahatchee River; widespread but rare in eastern tributaries of upper Tombigbee	NA	NA
Toxalasma sp.	NA	NA	Known from a few shells collected in lower river about 50 years ago	NA	NA
Tritogonia verrucosa	P4	NA	Recently collected live in lower and middle reaches of Buttahatchee River; widespread in eastern tributaries of upper Tombigbee	NA	NA
Truncilla donaciformis	P3	NA	Recently found live at several lower main channel stations, though rare; widespread	NA	NA
Uniomerus declivis	P4	S2	Recently found live in tributary Beaver Creek	NA	NA
Utterbackia imbecillis	P5	NA	Known from a few shells collected in lower river 25 years ago	NA	NA
Villosa lienosa	P5	NA	Recently collected live throughout the Buttahatchee system; common and widespread	NA	NA
Villosa vibex	P5	NA	Recently collected live at several headwater and tributary stations; fairly common and widespread	NA	NA

[1] E=endangered; T=threatened.

[2] Alabama priority conservation ranks follow Mirarchi and others (2004): P1=Highest Conservation Concern, P2=High Conservation Concern, P3=Moderate Conservation Concern, P4=Low Conservation Concern, P5=Lowest Conservation Concern, X=Extirpated; Mississippi priority conservation ranks determined from Mississippi Museum of Natural Science Natural Heritage website: S1=Critically Imperiled, S2=Imperiled, S3=Rare or Uncommon, S4=Widespread and Abundant but with Cause for Concern, SH=Historical but with No Recent Records. Endangered status in Mississippi from Mississippi Museum of Natural Science (2001).

Table 2.—Mussel sampling station locations in the Buttahatchee River system, Alabama and Mississippi, 1993-2001 (from McGregor and Haag, 2004)

Station number[1]	Location		County[2]	Date
113	Buttahatchee River at MS Highway 373	N 33ºE 39' 54" W 88ºE 27' 23"	Monroe, MS	June 23, 1999
114	Buttahatchee River 1.1 miles upstream of railroad bridge	N 33ºE 40' 40" W 88ºE 24' 1"	Monroe, MS	Sept. 20, 1999
115	Buttahatchee River 3.0 miles downstream of Lawrence Bridge	N 33ºE 41' 42" W 88ºE 22' 47"	Monroe, MS	Sept. 29, 1999
116	Buttahatchee River at Bartahatchee Road (Cockerham Bridge)	N 33ºE 47' 45" W 88ºE 18' 88"	Monroe, MS	June 23, 1999
117	Buttahatchee River 1.3 miles upstream of Bartahatchee Road	N 33ºE 48' 3" W 88ºE 18' 43"	Monroe, MS	Sept. 20, 1999
118	Sipsey Creek near Splunge on Sipsey Fork Road	N 33ºE 57' 00" W 88ºE 15' 19"	Monroe, MS	July 23, 1999
119	Sipsey Creek at unpaved county road, 1 mi. W of AL Highway 19	N 34ºE 03' 45" W 88ºE 08' 45"	Marion, AL	May 4, 1999
120	Hurricane Creek at County Highway 94 near Bexar	N 34ºE 10' 59" W 88ºE 08' 22"	Marion, AL	May 4, 1999
121	Buttahatchee River at U.S. Highway 278 near Greenwood Springs	N 33ºE 53' 00" W 88ºE 17' 23"	Monroe, MS	July 23, 1999
122	Buttahatchee River at AL Highway 17	N 33ºE 06' 20" W 87ºE 59' 28"	Lamar, AL	July 22, 1999
123	Beaver Creek at County Highway 77 at Crews, N U.S. Highway 278	N 33ºE 55' 10" W 88ºE 04' 42"	Lamar, AL	Dec. 2, 1999
124	Beaver Creek at County Highway 49 at Beaverton, N U.S. Highway 278	N 33ºE 15' 11" W 88ºE 01' 24"	Lamar, AL	Dec. 2, 1999
125	Beaver Creek at U.S. Highway 43/78, N Guin	N 33ºE 59' 51" W 87ºE 55' 42"	Marion, AL	Dec. 3, 1999
126	Buttahatchee River upstream of County Highway 16	N 34ºE 01' 09" W 88ºE 03' 11"	Lamar, AL	July 23, 1999
127	Buttahatchee River at U.S. Highway 43 near Hamilton	N 34ºE 06' 20" W 87ºE 59' 28"	Marion, AL	July 23, 1999
128	Buttahatchee River at AL Highway 253 near Pearce=s Mill	N 34ºE 07' 57" W 87ºE 49' 06"	Marion, AL	July 30, 1999
129	West Branch Buttahatchee River at AL Highway 129 and U.S. Highway 278	N 34ºE 07' 44" W 87ºE 44' 18"	Marion, AL	July 30, 1999
130	Buttahatchee River at AL Highway 129 near U.S. Highway 278	N 34ºE 06' 42" W 87ºE 43' 51"	Marion, AL	July 30, 1999

[1] Station numbers correspond to those reported in McGregor and Haag (2004).
[2] AL= Alabama; MS= Mississippi

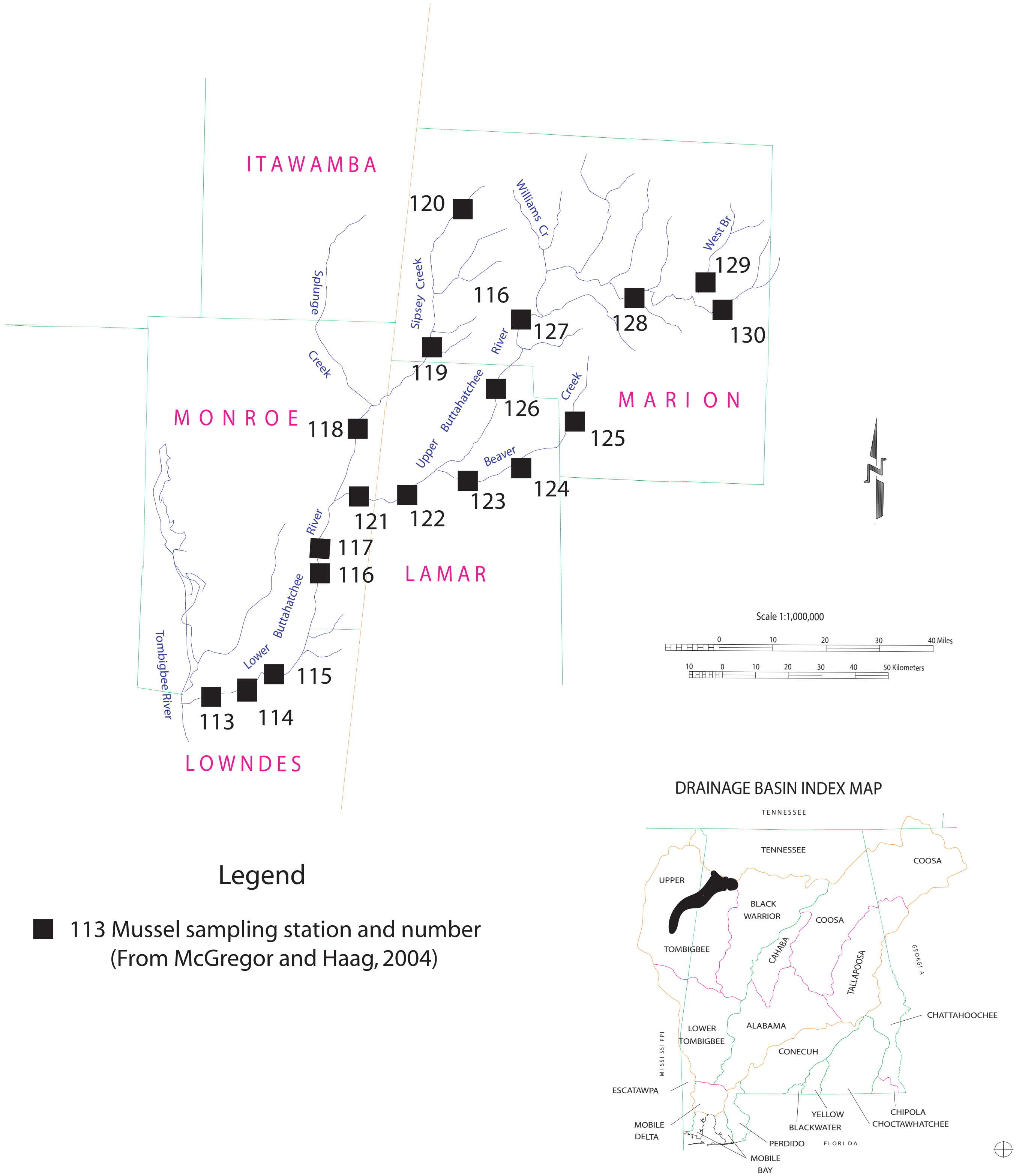


Figure 1. Mussel sampling stations in the Buttahatchee River system, Alabama, 1993-2001.

Epioblasma penita was once widespread in the Mobile basin but is now restricted to the lower Buttahatchee River in Mississippi (USFWS, 1989; McGregor and Haag, 2004). *Hamiota perovalis* was not reported from the Buttahatchee River in recent surveys, though it is still widespread in the western Mobile basin (McGregor and Haag, 2004). The reason for its absence in the Buttahatchee system is unclear, but may be related to suspended sediment. *Hamiota perovalis* employs a complex method of reproduction including a visual cue for potential host fishes, and if those hosts fail to see the lure containing the glochidia (larvae), reproductive success will be limited and the population may decline through attrition. *Medionidus acutissimus* has been found recently at several lower main channel stations and the tributary Sipsey Creek in Mississippi. *Medionidus parvulus* is known in the Buttahatchee River system from three specimens collected in 1956 in the lower reach in Mississippi. It was once widespread in the Mobile basin but it is now restricted to the upper Coosa River system in Georgia (Mirarchi, 2004). *Pleurobema decisum* has recently been collected in the lower reach of Buttahatchee River and was once known as far upstream as Hamilton. *Pleurobema perovatum* has also been collected recently in the lower river, as well as the tributary Sipsey Creek, and historically was known as far upstream as Hamilton (Jim Williams, USGS, pers. comm., 2005). *Potamilus inflatus* is known from a few shells collected in the lower reach of river in Mississippi in the mid 1950s.

A list of mussel species found in the Buttahatchee River system from 1993-2001 (McGregor and Haag, 2004), and some that have been reported in the literature for the system but not recently collected there, is found in table 1. Additional information in that table includes the current status of each species, including formal protection at the federal and state levels, and the levels of conservation concern afforded to each species by each state, if available. Also included are the most likely sources of broodstock for potential propagation and reintroduction efforts based on current distribution and abundance information, and possible recovery locations. Some broodstock sources are within the Buttahatchee system due to the presence or abundance of those species within the system versus other systems, while some sources of broodstock are in other streams within their historic ranges. Criteria for ranking the conservation status of each species are similar between the states and are based on historical distribution and abundance accounts, observed or perceived downward population trends, imminent threats, and combinations of these and other factors. All mussel species in Alabama have been given a conservation priority status ranging from Highest Conservation Concern (P1) to Lowest Conservation Concern (P5). Species with documented conservation concern in Mississippi were given a similar designation (S1=Critically Imperiled, S2=Imperiled, etc.). The species in the top two tiers in both states, P1 and P2 in Alabama and S1 and S2 in Mississippi, were selected as species most in need of recovery in the Buttahatchee River system. Since conservation priority status has recently been designated by authorities in each state based on recognized needs, no further level of priority was given for recovery potential of any species.

The reproductive strategies of many mussel species are poorly known. In order to reproduce, mussels must have a suitable fish host, and little or no information is available regarding host fishes for numerous mussel species. The currently understood reproductive needs and recovery options for species selected for recovery in the Buttahatchee River are summarized in table 3. This information was found on the website

Table 3.—Reproductive needs and recovery options for species of recovery potential in the Buttahatchee River system, Alabama and Mississippi (website, Mollusc Division of the Museum of Biological Diversity, The Ohio State University)

Species	Known fish hosts	Host present in Buttahatchee system	Biology	Recovery options
Anodontoides radiatus	Generalist?	Unknown	Females gravid September to December	Translocation of adults Release of infected host fishes Release of cultured juveniles Release of infected fishes into culture cages
Elliptio arca	*Ammocrypta meridiana*	Yes	Females gravid June and July	Translocation of adults Release of infected host fishes Release of cultured juveniles Release of infected fishes into culture cages
	Etheostoma artesia	Yes		
	Percina nigrofasciata	Yes		
Elliptio arctata	Unknown	Unknown	Females gravid probably June and July like congeners	Release of infected host fishes when determined Release of cultured juveniles Release of infected fishes into culture cages
Epioblasma penita	Unknown, probably darters as its congeners	Unknown	Females gravid spring	Translocation of adults Release of infected host fishes Release of cultured juveniles Release of infected fishes into culture cages
Hamiota perovalis	*Micropterus coosae*	No	Females gravid February to May	Translocation of adults Release of infected host fishes Release of cultured juveniles Release of infected fishes into culture cages
	Micropterus punctulatus	Yes		
	Micropterus salmoides	Yes		
Margaritifera marrianae	Unknown	Unknown	Females gravid in December	Release of infected host fishes Release of cultured juveniles Release of infected fishes into culture cages
Medionidus acutissimus	*Ammocrypta beani*	Yes	Females gravid February to May	Release of infected host fishes Release of cultured juveniles Release of infected fishes into culture cages
	Ammocrypta meridiana	Yes		
	Etheostoma artesia	Yes		
	Etheostoma nigrum	Yes		
	Etheostoma rupestre	Yes		
	Etheostoma stigmaeum	Yes		
	Etheostoma swaini	Yes		
	Percina nigrofasciata	Yes		
	Percina vigil	Yes		

Table 3.—Reproductive needs and recovery options for species of recovery potential in the Buttahatchee River system, Alabama and Mississippi—continued

Species	Known fish hosts	Host present in Buttahatchee system	Biology	Recovery options
Obovaria jacksoniana	Unknown, probably darters as are its congeners	Unknown	Probably similar to congeners	Release of infected host fishes Release of cultured juveniles Release of infected fishes into culture cages
Obovaria unicolor	*Ammocrypta beani*	Yes	Females gravid April to June	Release of infected host fishes Release of cultured juveniles Release of infected fishes into culture cages
	Ammocrypta meridiana	Yes		
	Etheostoma artesia	Yes		
	Etheostoma nigrum	Yes		
	Etheostoma swaini	Yes		
	Percina nigrofasciata	Yes		
	Percina sciera	Yes		
Pleurobema decisum	*Cyprinella venusta*	Yes	Females gravid June and July	Translocation of adults Release of infected host fishes Release of cultured juveniles Release of infected fishes into culture cages
	Luxilus chrysocephalus	Yes		
Pleurobema perovatum	*Cyprinella callistia* *Cyprinella venusta*	Yes	Females gravid May to July	Release of infected host fishes Release of cultured juveniles Release of infected fishes into culture cages
Pleurobema taitianum	Probably similar to congeners	Yes	Unknown	Release of infected host fishes Release of cultured juveniles Release of infected fishes into culture cages

of the Mollusc Division of the Museum of Biological Diversity (The Ohio State University, 2005). Some species are considered host generalists, that is, a wide range of fish species may be suitable as hosts; however, some mussel species are considered host specialists, indicating a limited range of species are available as suitable hosts. Availability of suitable hosts for species of recovery potential in the Buttahatchee River was determined from historical distribution information found in Mettee and others (1996), Ross (2001), and Boschung and Mayden (2004).

SEDIMENT TOXICITY

Freshwater mussels are benthic filter-feeding organisms, and as such are exposed to metals and other pollutants that are dissolved in water, associated with suspended sediments, or deposited in bottom sediments (Naimo, 1995). Because mussels are relatively long-lived, generally sedentary in nature, easily collected, large enough to provide sufficient tissue mass for analysis, tolerant of a wide assortment of pollutants, and known to bioconcentrate or bioaccumulate contaminants, their value as indicator organisms for evaluation of long-term ecosystem function and health is paramount. While relatively little is known about the lethal limits of various pollutants to freshwater mussels, ongoing research documents the different tolerances of various species and life history stages of mussels. The toxic effects of pollutants on mussels have been examined in some acute toxicity tests, but the sublethal effects of long-term exposure to low environmental concentrations are poorly understood (see Naimo, 1995 for review of effects of heavy metals). Also, it is widely understood that, despite improvements in modern effluent treatment facilities, freshwater mollusks are still affected by such contaminants as ammonia, chlorine, elevated temperature, organic waste, suspended solids, and nutrients.

The accumulation of contaminants in mussel tissue depends on the presence of the chemical in a form that is available for uptake into its tissue (Spacie and Hamelink, 1985). This “bioavailability” is determined by numerous environmental or chemical factors. These factors include: which chemical species is present and in what concentration; solubility of the compound in water compared to its tendency to adsorb onto organic matter; hardness of water; presence of competing compounds; sediment or water pH; level of sediment oxygenation; concentration of organic or inorganic carbon; total suspended solids concentration of the water; and water temperature. Bioavailability is also dependent on biological factors, such as age or body size, gender, reproductive status, and species. Adsorption may occur by direct exposure to the water column and movement across cell membranes (bioconcentration), from particulate matter filtered from the water and digested, or from sediment interstitial water (Elder and Collins, 1991; Spacie and Hamelink, 1985). Various studies have shown that the major route of uptake of organic contaminants for freshwater and marine bivalves is from water, where chemicals desorb off of sediment or suspended particles into the water column or interstitial water and are taken up by mollusks (Boryslawskyj and others, 1987; Kauss and Hamdy, 1985, 1991; Livingstone and Pipe, 1992). Adults, which are predominantly filter feeders that collect plankton and organic particles from the water column, may be more affected by exposure to pollutants in overlying water while juveniles take up contaminants from sediments or sediment interstitial water (Yeager and others, 1994). The most contaminated sediments in many temperate lakes and rivers are often in the top

30 cm (Rada and others, 1989, 1990). Adult freshwater mussels tend to burrow to from 1-25 cm into the substrate, while juvenile mussels typically burrow less than 8 cm (Pennak, 1978; McMahon, 1991; Neves and Widlak, 1987).

A review of all available literature on this subject is not practical here, but some discussion is warranted. Acute toxicity studies, with death as an endpoint and lasting from a few days to several weeks, determine concentrations of pollutants that kill 50% of test organisms (LC50). Chronic toxicity tests evaluate sublethal effects of exposure to contaminants for weeks or months and measure such parameters as excretion rate, energy stores, growth, and a variety of other biological activities. Tests have been performed on different species at various life history stages and with different rates of exposure (both time and concentration) and with different combinations of contaminants and ambient physical and chemical conditions. Generally, the metals most toxic freshwater mussels include cadmium, chromium, copper, mercury, nickel, and zinc (Keller and Zam, 1991; Naimo, 1995), with mercury, copper, and cadmium the most toxic (Khangarot and Ray, 1987). It should be noted that freshwater mussels become stressed at metal concentrations much lower than those reported in acute toxicity tests, and that most tests are conducted under laboratory conditions and might not reflect conditions in nature (Naimo, 1995). Exposures to metals and other contaminants may not be immediately lethal, but over time may interrupt metabolic activities, enzyme function, respiration, and other important biological activities, leading to death. Organic contents of the sediment and water column are also very important in the ability of mussels to uptake toxins. Graney and others (1984) observed that Asian clams (*Corbicula fluminea*) decreased the uptake of cadmium as the organic content of test substrates increased, and that clams in tanks with no substrate or with sand only had much higher tissue burdens than those in tanks with organic or clay-enriched substrates. They also found that clams accumulated more cadmium at 21EC than at 9EC and at pH 7.8 than at pH 5.0. Jacobson and others (1997) reported that juvenile mussels are at greater risk to contamination than adults due to their shallow residency in benthic sediments, where toxicants such as metals may be sequestered at high levels.

On December 2, 2005 a single composite sample of bed sediment was collected from the Buttahatchee River at station BR1, the lowermost sampling station in the Alabama portion of the watershed (fig. 2). The sample was prepared for chemical analysis according to procedures described in Fishman and Friedman (1989) and USEPA (1999b) according to the methods for parameters to be determined. Subsequently, chemical analyses of the sediment sample was conducted in accordance with U.S. Environmental Protection Agency (McLean (1982), Crock and others (1987), USEPA 1983, 1993, 1994, 1999a, 1999b), and Fishman and Friedman (1989). The sediment sample was collected in accordance with the Quality Assurance-Quality Control Plan for GSA (O'Neil and Meintzer, 1995).

While many parameters were analyzed in sediment during this study (table 4), this discussion will be limited to selected trace metals with the most potential to impact existing and future mussel faunas based on the literature. The values reported here were determined from a one-time grab sample randomly collected from the stream bed and should not be relied upon as an absolute indicator of a persistent or widespread presence of any toxin in the system and provide no information on sources of possible contamination.

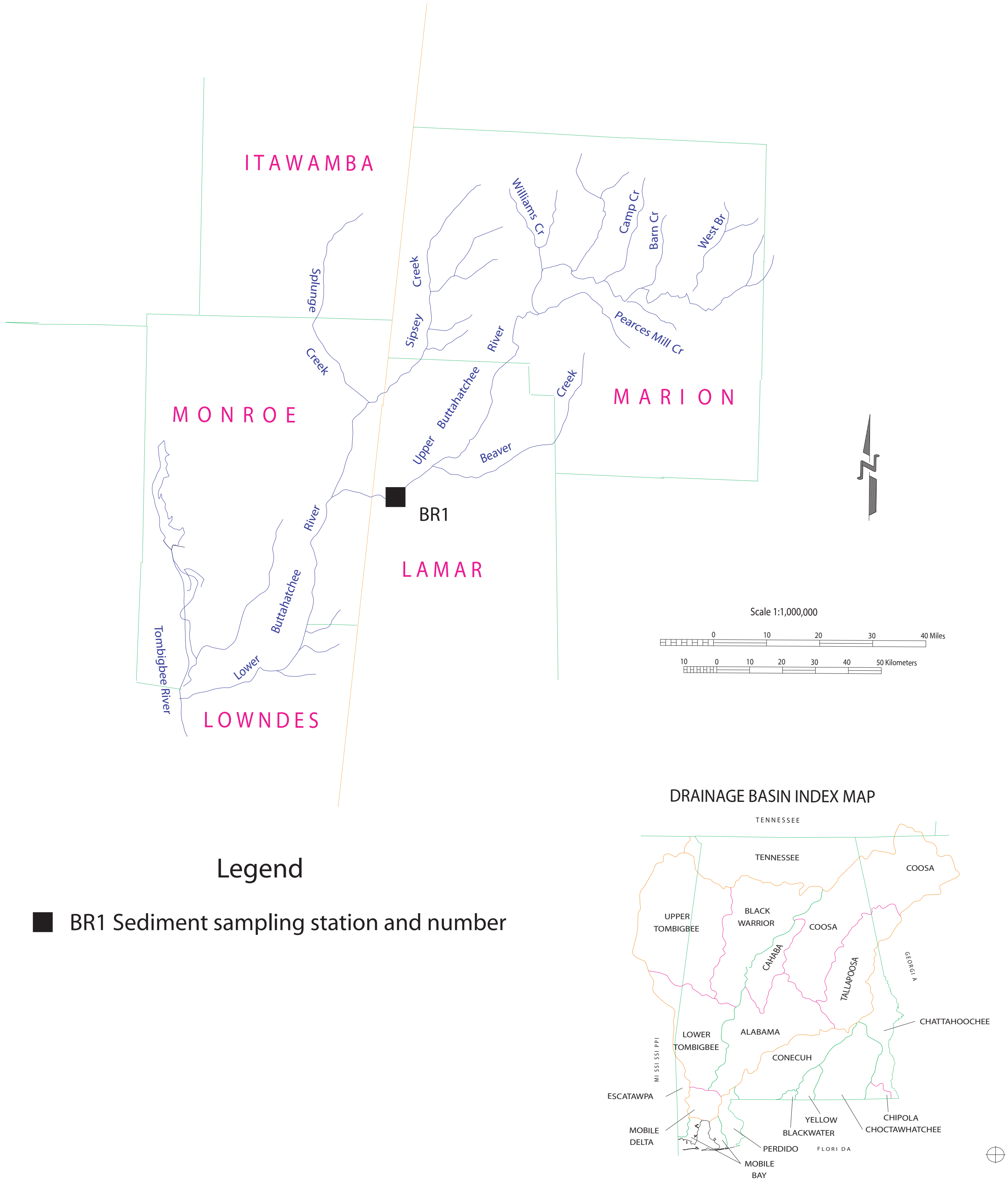


Figure 2. Sampling station for sediment toxicity in the Buttahatchee River system, Alabama, 2005.

Table 4.—Comparison of sediment toxicity values from the Buttahatchee River with those of other streams

	Buttahatchee	Bear Cr.[1]		Black Warrior R.[2]		Cahaba R.[3]	
	BR1	min	max	min	max	min	max
Major Elements (mg/kg):							
Bromide	<.6	<.7	<.7	<.5	<.5	--	--
Calcium	156	66.7	81,000	110	2,110	465	42,600
Chloride	<.4	0.882	10.5	10.7	38.5	<.4	<.4
Cyanide	0.09	<.06	<.06	<.1	0.55	--	--
Fluoride	<.06	<.25	0.514	<.2	8.75	<.2	34.4
Magnesium	92	26.3	2370	106	1970	231	12,600
Ammonia (as N)	22.7	<.4	7.43	0.98	27.8	1	48.6
Total Kjeldahl Nitrogen	695	34.6	804	112	4,300	337	7,300
Total Nitrate-Nitrite (as N)	0.45	<.06	17.5	0.65	11.2	0.8	3.5
Total Phosphorus (as P)	70	27	156	41.7	641	118	477
Orthophosphate	<1	<.4	2.24	<.5	1.61	<.5	11
Potassium	75	<40	276	<60	1,200	119	1,260
Sodium	6	<6	48	<6	182	<6	107
Sulfate	4.99	4.11	49.5	7.08	356	<.4	28.6
Trace Elements (mg/kg):							
Aluminum	1,290	538	6,390	597	16,600	1,680	9,340
Antimony	<.2	<.2	<.2	<.2	0.965	--	--
Arsenic	1.57	0.54	4.9	0.318	22.7	2.58	12.3
Barium	19.8	6.32	52.6	7.64	156	21.7	119
Beryllium	0.21	<.1	0.57	<.05	1.1	0.16	2.55
Cadmium	<.3	<.4	<.4	<.4	2.11	<.4	2.07
Chromium	1.5	2.2	19.2	<2	25	5	49.1
Cobalt	2.5	<.7	8.1	1.34	30.3	1.9	17.7
Copper	1.3	<.8	5.2	0.975	26.4	2.28	9.29
Iron	4,410	1,700	12,800	473	29,900	6,620	27,800
Lead	1.88	<.1	15	0.347	21	<.1	4.06
Lithium	<.8	<.5	2.37	<1	23.9	<1	8.6
Manganese	156	35.3	615	61.8	2130	240	2,580
Mercury	<.006	<.006	0.131	0.0066	0.195	0.0103	0.0619
Molybdenum	<2	<2	<2	<7	11.5	<7	14.4
Nickel	3.1	<1	6.1	<1	39.5	5	68.7
Selenium	<.3	<.3	<.3	<.3	0.922	<.3	0.49
Silver	<1	<1	<1	<2	<2	<2	<2
Strontium	1.74	0.38	127	1.02	17.3	1.85	21.6
Thallium	<.2	<.2	<.2	<.3	0.44	--	--
Vanadium	4.15	1.76	20.2	<.6	32.9	5.27	31.6
Zinc	25.7	5.12	43.4	8.19	155	14.9	192

1. Bear Creek - 10 samples collected from 10 stations in the Bear Creek system (McGregor, 2003).
2. Black Warrior River - 23 samples collected from 8 stations in the Oliver Pool section (unpublished GSA data, 1992-93).
3. Cahaba River - 18 samples collected from 6 stations in upper Cahaba River system (Shepard and others, 1994).

Values of major elements and trace elements for the sample collected for this study are presented in table 4, along with values determined from sediment samples collected for unrelated projects in three other stream systems with recognized valuable mussel faunas. The other systems include the Bear Creek system of the Tennessee Valley (one sample collected at each of 10 stations) (McGregor, 2003), the Black Warrior River (23 samples from eight stations in the Oliver Pool near Tuscaloosa) (unpublished data, GSA), and the upper Cahaba River system (18 samples from six stations) (Shepard and others, 1994).

Chromium was detected in at least some samples from every stream system sampled, with the value from the Buttahatchee sample near the lower end of the range, at 1.5 mg/kg. The high value among these four systems was 49.1 mg/kg in the Cahaba River, with highs of 25 and 19.2 in the Black Warrior River and Bear Creek studies, respectively. Keller and Zam (1991) reported the 48h (hour) LC50 (lethal concentration to 50 percent of test organisms) of chromium, nickel, and mercury exposures to juvenile *Anodonta imbecillis* in soft water (40-48 mg/L $CaCO_3$) ranged from 216 to 295 Φg/L, and that LC50s increased 8 to 200% with exposure to moderately hard water (80 to 100 mg/L $CaCO_3$). Keller (1993) reported that LC50s of *Anodonta imbecillis* in an effluent containing 6.4 mg/L chromium decreased between 48h and 96h tests.

Copper was also detected in each system, and again, the Buttahatchee River value was near the lower end recorded. Highest values were reported from the Black Warrior River (26.4 mg/kg). Keller and Zam (1991) reported the 48h LC50 of copper to juvenile *Anodonta imbecillis* to be 171 Φg/L and the 96h LC50 to be reduced to 86 Φg/L. Foster and Bates (1978) reported *Quadrula quadrula* mussels in the Muskingum River, Michigan, that were exposed to copper-containing industrial outfall accumulated a lethal level of 20.64 Φg copper per gram wet weight, or 10 times the background level, after only 14 days, with 100% mortality. Imlay (1971) similarly reported copper at a concentration of 25 Φ/L was lethal to mussels (species not given).

Mercury was below detection limit in the Buttahatchee River sample but was detected in all other systems, with the highest values found in Black Warrior and Bear Creek sediments. Keller and Zam (1991) reported the 48h and 96h LC50s of chromium, nickel, and mercury exposures to juvenile *Anodonta imbecillis* in moderately hard water (80 to 100 mg/L $CaCO_3$) increased over exposures in soft water (40 to 48 mg/L $CaCO_3$) by 8 to 200%. Reservoir construction is often cited as a cause of elevated mercury concentrations in fish, as naturally occurring mercury in flooded soils is released by bacterial methylation (Bodaly and others, 1984).

Nickel was reported from all streams sampled, ranging from undetectable levels to a high of 68.7 mg/kg in the Cahaba River. The value from the Buttahatchee River sediment was again the lowest maximum value recorded (3.1 mg/kg). Keller and Zam (1991) reported the 48h LC50 of nickel to juvenile *Anodonta imbecillis* at a water hardness of 39 mg/L $CaCO_3$ to be 240 Φ/L and in moderately hard water (60 to 120 mg/L $CaCO_3$) to be 471 Φ/L.

Zinc was reported from all streams sampled as well, with a value of 192 mg/kg in the Cahaba River the highest value. The value from the Buttahatchee was the lowest maximum value recorded. Zinc was found to be the least toxic metal tested on *Anodonta imbecillis* juveniles by Keller and Zam (1991). Their results indicated water hardness of

39 mg/L $CaCO_3$ yielded a 48h LC50 of 355 Φ/L, and a 48h LC50 of 588 Φ/L in moderately hard water (60 to 120 mg/L $CaCO_3$).

SEDIMENTATION MONITORING

Impaired water quality from point- and nonpoint-source pollution can negatively impact mussel populations and has been documented as a causal factor in the decline of freshwater mussel populations not only in the Mobile basin but in many parts of their ranges (Bogan, 1993; Lydeard and Mayden, 1995; Lydeard and others, 1999; Neves and others, 1997; Williams and others, 1993). Hartfield and Jones (1990) reported that extensive turbidity after rains is a water-quality problem in the Buttahatchee system and attributed that turbidity to runoff from abandoned kaolin strip mines in Camp Creek, a headwater tributary. They reported about 27,000 tons of sediment per year enter Camp Creek from the abandoned kaolin mines. More recently, data were collected from nine stations on the Buttahatchee River and selected tributaries in the Alabama portion of the watershed in a preliminary assessment of sediment loading rates (McGregor and Cook, 2005). Results of that preliminary study indicated that loading rates in the watershed were elevated and that much of the sediment originated in the upstream portion of the watershed.

During 2005-06, monitoring in the Buttahatchee River watershed was expanded to 11 sites, four on the Buttahatchee River and one each on seven tributaries (fig. 3). The sites were chosen to evaluate critical portions of selected watersheds. The monitored areas of the selected watersheds varied from 12 to 469 square miles (mi^2) (table 5).

Parameters measured on site included water temperature, pH, specific conductance, dissolved oxygen (DO), turbidity, stream water level, discharge, total

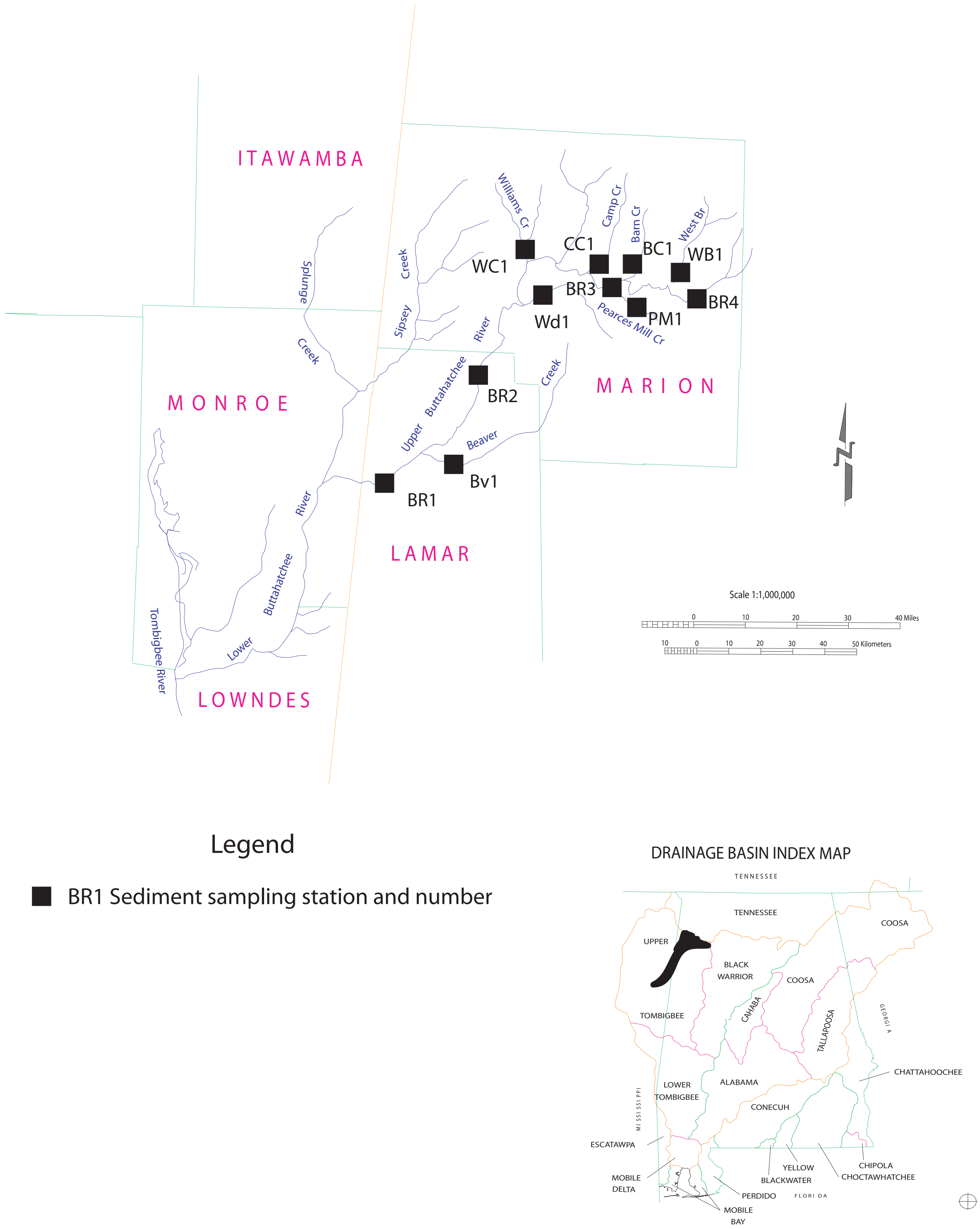


Figure 3. Sediment sampling stations in the Buttahatchee River system, Alabama, 2005-2006.

Table 5.—Monitored areas of project watersheds

Station number	Stream	Watershed area (mi^2)
BR1	Buttahatchee River at Alabama Hwy. 17	469
BR2	Buttahatchee River and county road 16	330
BR3	Buttahatchee River at Alabama Hwy. 253	106
BR4	Buttahatchee River at Alabama Hwy. 129	31
BC1	Barn Creek at U.S. Hwy. 278	20
CC1	Camp Creek at Alabama Hwy. 253	12
PM1	Pearces Mill Creek at Alabama Hwy. 253	13
WB1	West Branch Buttahatchee River at Alabama Highway 129	38
WC1	Williams Creek at Old Highway 43	30
Bv1	Beaver Creek at County Road 77	86
Wd1	Woods Creek at County Road 98	26

residual chlorine, and mean stream flow velocity. Grab samples of water from each station were analyzed in the laboratory to determine total suspended solids (TSS). TSS is the concentration of suspended solids in the stream at the time of sampling and is used in calculations of suspended sediment loads. Bedload sediment was determined in situ using an instantaneous measurement method developed by the GSA.

STREAM DISCHARGE

Discharge is a primary physical parameter that influences and/or controls surface-water quality. Ionic concentrations, specific conductance, DO, biochemical oxygen demand, suspended and bedload sediment transport, and bacterial concentrations are all influenced by the volume and velocity of stream discharge (Cook and Puckett, 1998). Streamflow measurements were selected to establish a well distributed data set from low to high flow. Discharge values were obtained by direct measurement and by estimation using USGS mean daily discharge values for Buttahatchee River at U.S. Highway 43 at Hamilton and water level data obtained by measurement from bridge deck reference points at monitored sites. Direct measurements were made using a Price AA flow meter mounted on a standard wading rod or bridge board. Discharge values gathered during this project were synthesized with discharge values reported previously, and some sediment values from the previous investigation were adjusted to reflect these changes (McGregor and Cook, 2005).

The largest discharge (6,873 cubic feet per second (cfs)) was measured at site BR1 on January 14, 2005. The smallest discharge was measured at site BC1 on April 19, 2006 (3 cfs). Maximum and minimum measured discharge values for each site are given in table 6.

Table 6.—Measured or estimated discharge values for monitoring sites

Station number	Monitoring Site	Maximum discharge (cfs)	Minimum discharge (cfs)
BR1	Buttahatchee River	6,873	487
BR2	Buttahatchee River	3,800	100
BR3	Buttahatchee River	2,059	40
BR4	Buttahatchee River	597	8
BC1	Barn Creek	265	3
Bv1	Beaver Creek	262	39
CC1	Camp Creek	464	13
PM1	Pearces Mill Creek	64	18
WB1	West Branch Buttahatchee River	310	10
WC1	Williams Creek	926	39
Wd1	Woods Creek	310	9

SEDIMENTATION

Sedimentation is a process by which eroded particles of rock are transported by moving water from areas of relatively high elevation to areas of relatively low elevation, where the particles are deposited. Upland sediment transport is accomplished by overland flow and rill and gully development. Lowland or floodplain transport occurs in varying order streams, where upland sediment joins sediment eroded from floodplains, 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 habitat, reduces storage volume of water impoundments, impedes the usability of aquatic recreational areas, and causes damage to structures. Sediment loads are composed of relatively small particles suspended in the water column (suspended solids) and larger particles that move on or periodically near the stream bed (bedload).

Total suspended solids 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 constituents 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.

The GSA uses two methods to estimate suspended sediment loads. If adequate discharge and suspended solids data are available, the computer model Regr_Cntr.xls (Regression with Centering) is used to calculate suspended sediment loads from the analytical and stream discharge data. The program is an Excel adaptation of the USGS seven-parameter regression model for load estimation (Cohn and others, 1992). The Regr_Cntr.xls program was adapted by R. Peter Richards at the Water Quality Laboratory at Heidelberg College (Richards, 1999). The program establishes a regression model using a calibration set of data composed of concentrations of the constituent of interest and discharge values measured at the time of sampling. Daily loads are calculated using mean daily discharge and summed to achieve annual loading. The resulting load estimates are given in annual metric tons and are converted to mass and volume per unit time.

If adequate discharge and analytical data are unavailable to use the regression with centering model, suspended loads may only be estimated for individual instantaneous values over a relatively short time interval (mass per day). This was the sole method used for sediment assessment for the previous, preliminary investigation (McGregor and Cook, 2005). Concentrations of suspended sediment in mg/L were determined by laboratory analysis of water grab samples collected periodically at variable stream discharge rates. The analytical results were used to determine suspended sediment loads for each sampled discharge event (instantaneous load). Instantaneous suspended sediment loads can be calculated by the formula:

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

where

Q_s is the sediment discharge, in tons per day (tons/day)

Q_w is stream discharge, in cubic feet per second (cfs)

C_s is the concentration of suspended sediment in 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).

Both methods described above were employed to assess suspended sediment loads for the current project.

Transport of stream bed material is controlled by a number of factors related to stream discharge and flow velocity, erosion and sediment supply, stream base level, and physical properties of the stream bed material. Most stream beds are in a state of flux in order to maintain a stable base level elevation. As such, the energy of flowing water in a stream is constantly changing in response to external forces to supply the required power for erosion or deposition of bedload 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.

Bedload 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. Bedload sediment is difficult to quantify due to deficiencies in monitoring methodology or inaccuracies of estimating volumes of sediment being transported along the stream bed. This is particularly true with streams that flow at high velocity or in streams with substantial sediment loads.

The GSA has developed a portable sedimentation rate monitoring device designed to accurately measure bedload sediment values in shallow sand or gravel bed streams. The volume of bedload sediment at each station was measured directly in the stream channel of each sand or sand and gravel bed stream along with stream discharge and velocity. Due to funding limitations and time constraints, only a limited number of bedload measurements were made.

The total sediment load transported by a stream is composed of the suspended and bed loads. For streams with sand or gravel beds, the suspended and bed loads were measured separately and combined. For streams with beds composed of rock or in urban settings, stream beds may be composed of concrete or limestone rip-rap, and sediment loads are mostly suspended. In these cases, water samples collected near the stream bed will contain representative volumes of the total sediment load.

Stream beds at three of nine project sites (BC1, BR3, and BR4) (fig. 3) were composed of Pottsville Sandstone. The suspended sediment loads for these sites are assumed to be representative of the total sediment loads. Due to the limited bedload data, total annual sediment loads could not be determined during the current project.

Suspended sediment loads calculated from instantaneous measurements for the monitored sites were highly variable. The variability of suspended loads for individual samples collected at a particular site is primarily the result of discharge at the time of sample collection and if the sample was collected during rising or falling water levels. Figures 4 through 14 portray individual instantaneous suspended sediment loads determined at each monitored site from January 2005 to May 2006.

Variability of loads between sites is attributed to differences of watershed areas, stream flow conditions at the time of sampling, and erosion conditions and volume of sediment contributed to the stream in each watershed. Relative watershed size and discharge may be accounted for by normalizing sedimentation data to watershed area. The largest instantaneous suspended sediment loads (2,449, 2924, and 2,568 tons/day (t/d), respectively) were measured at main stem Buttahatchee River sites BR1, BR2, and BR3, indicating the cumulative impact of volumes of sediment contributed upstream

Figure 4.--Instantaneous suspended sediment loads and measured discharge for site BR1, Buttahatchee River at Alabama Highway 17, Lamar County, Alabama.

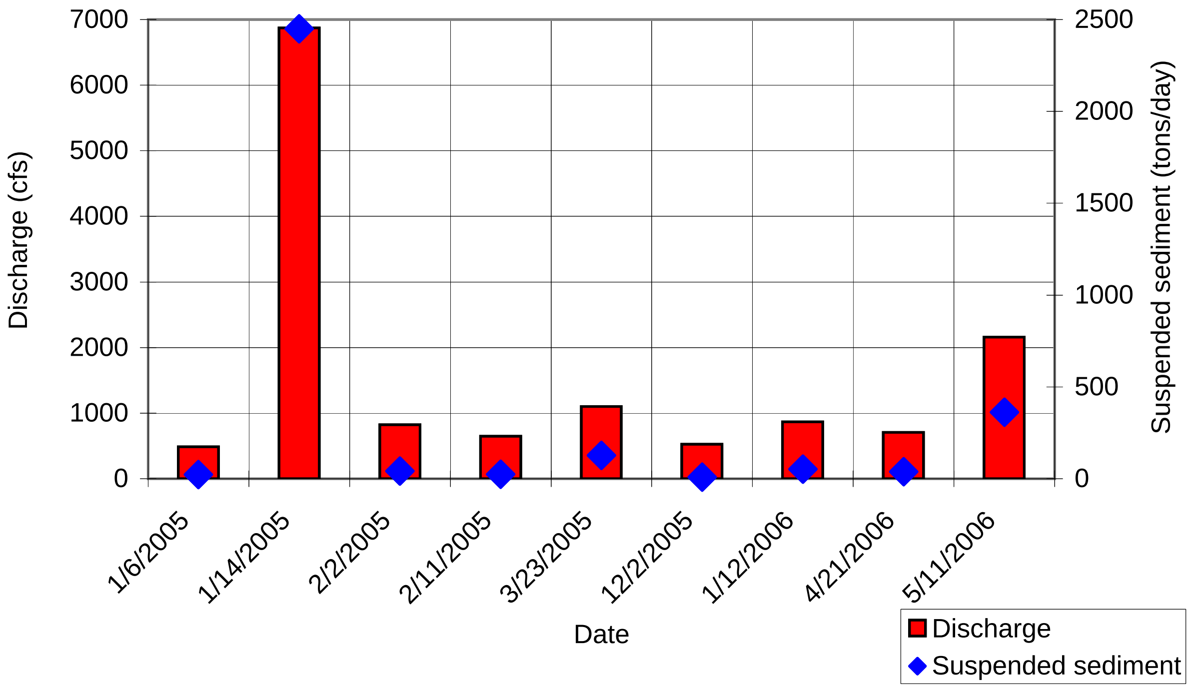


Figure 5.--Instantaneous suspended sediment loads and measured discharge for site BR2, Buttahatchee River at County Road 16, Lamar County, Alabama.

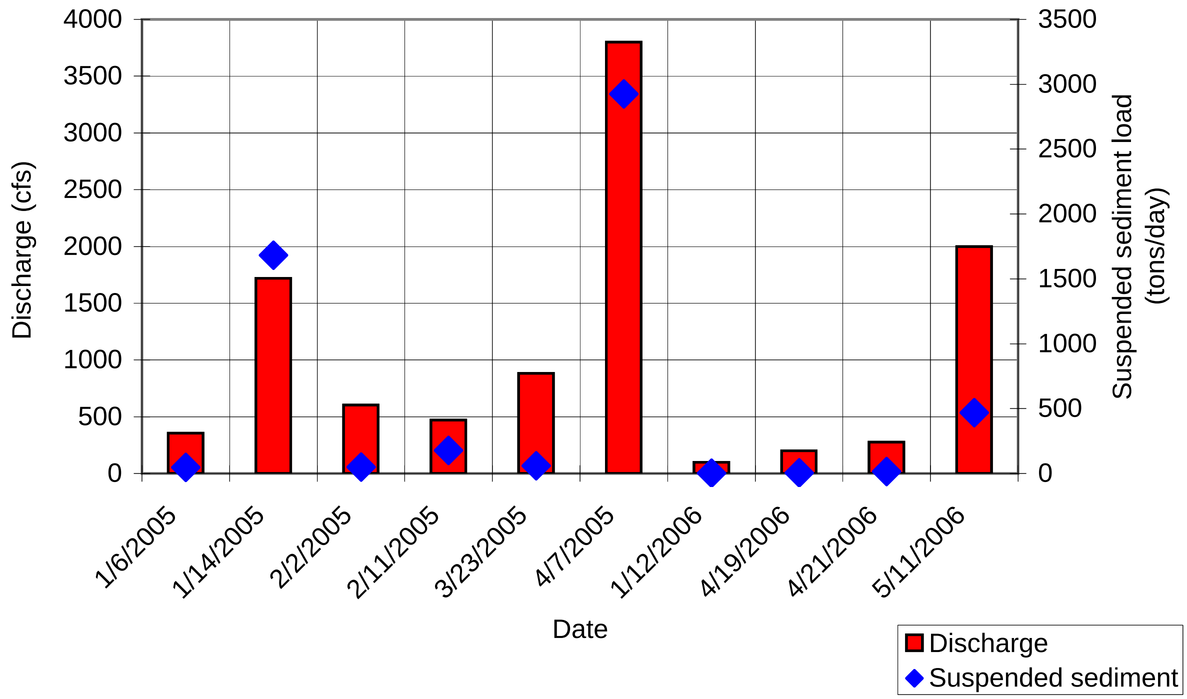


Figure 6.--Instantaneous suspended sediment loads and measured discharge for site BR3, Buttahatchee River at Alabama Highway 253, Marion County, Alabama.

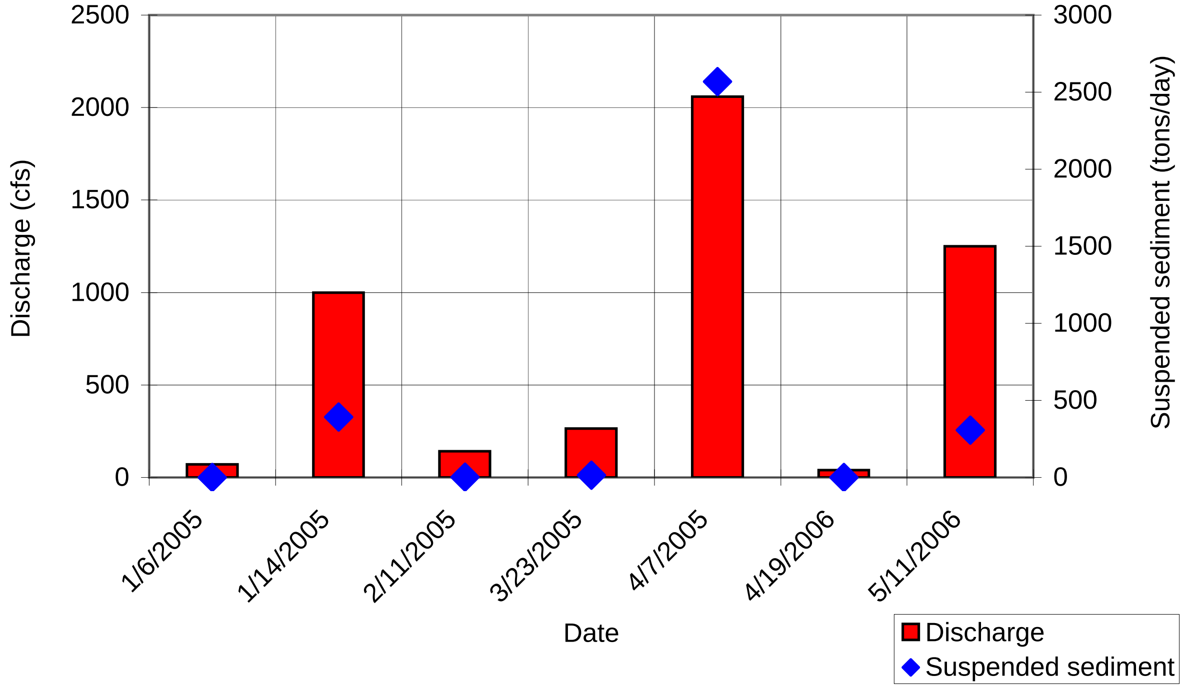


Figure 7.--Instantaneous suspended sediment loads and measured discharge for site BR4, Buttahatchee River at Alabama Highway 129, Marion County, Alabama.

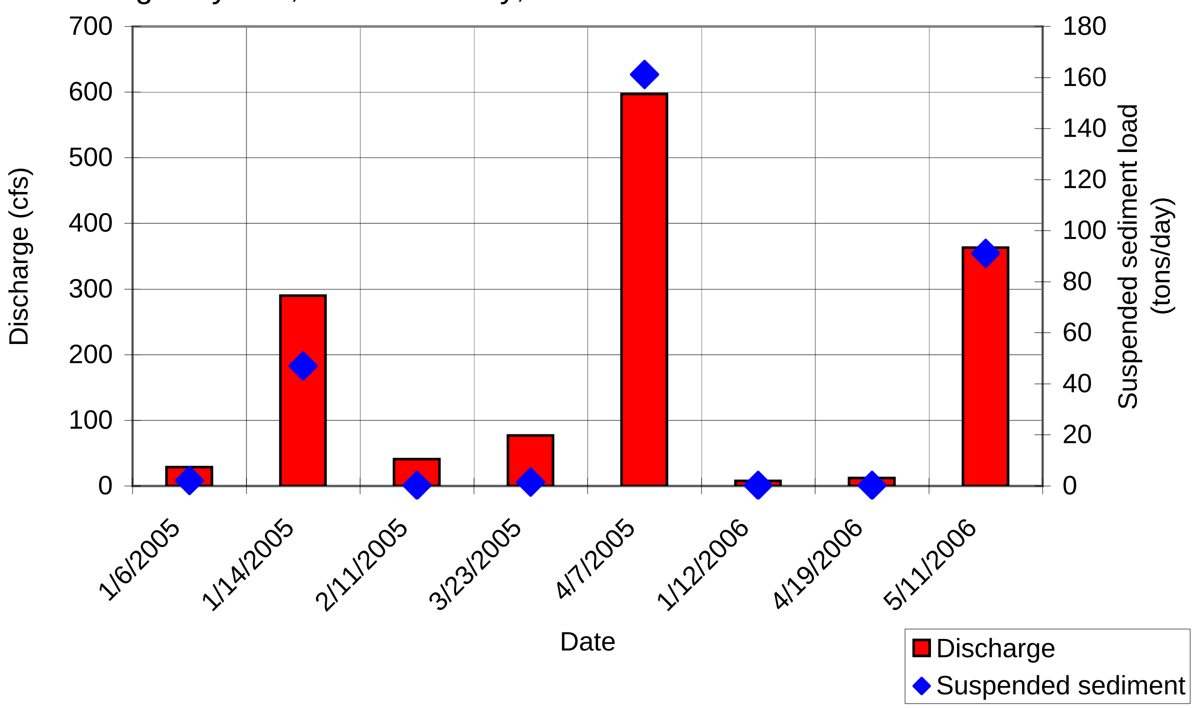


Figure 8.--Instantaneous suspended sediment loads and measured discharge for site BC1, Barn Creek at U.S. Highway 278, Marion County, Alabama.

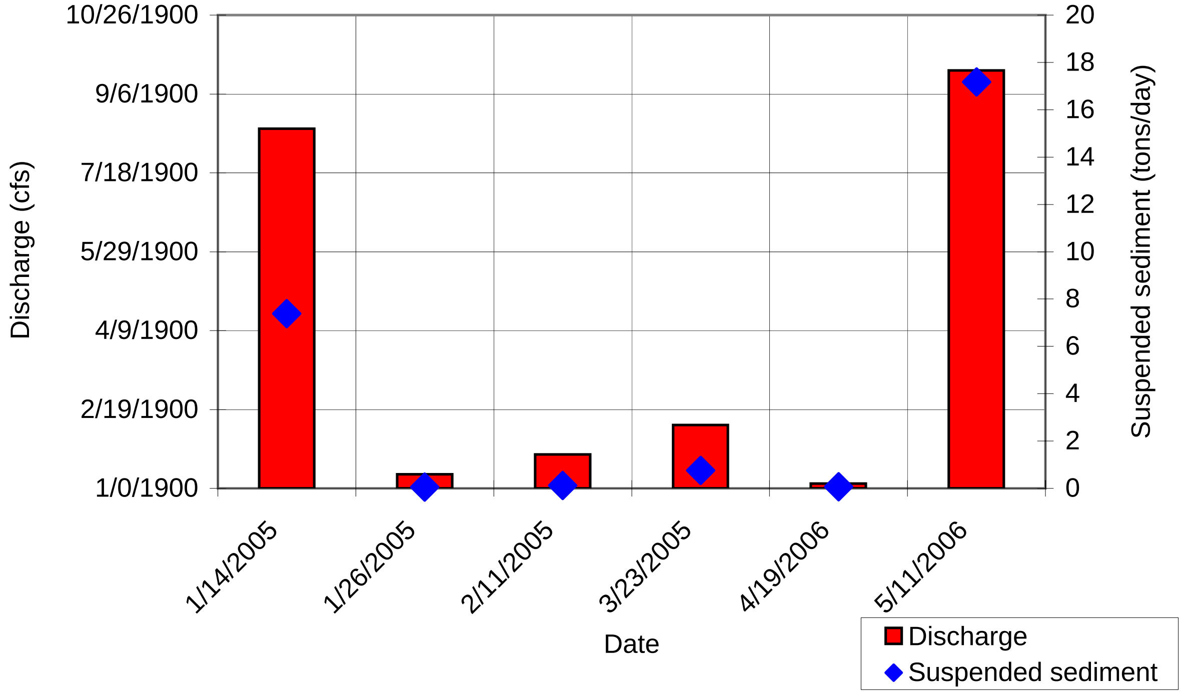


Figure 9.--Instantaneous suspended sediment loads and measured discharge for site BV1, Beaver Creek at County Road 77, Lamar County, Alabama.

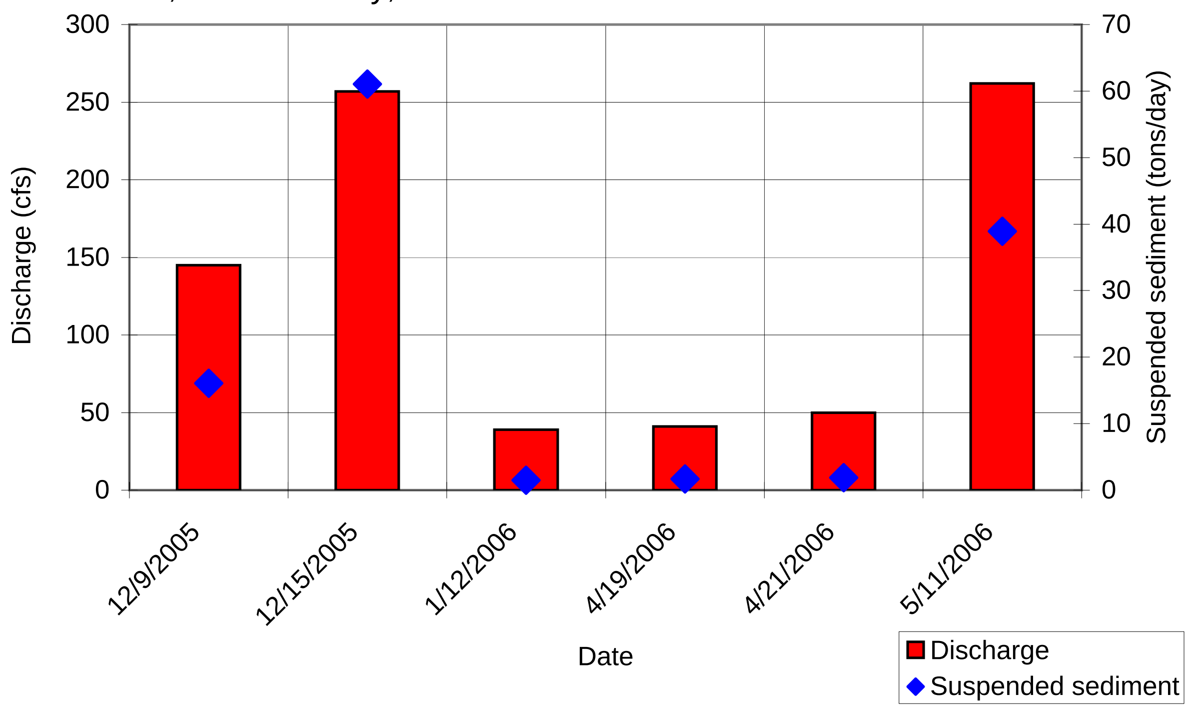


Figure 10.--Instantaneous suspended sediment loads and measured discharge for site CC1, Camp Creek at Alabama Highway 253, Marion County, Alabama.

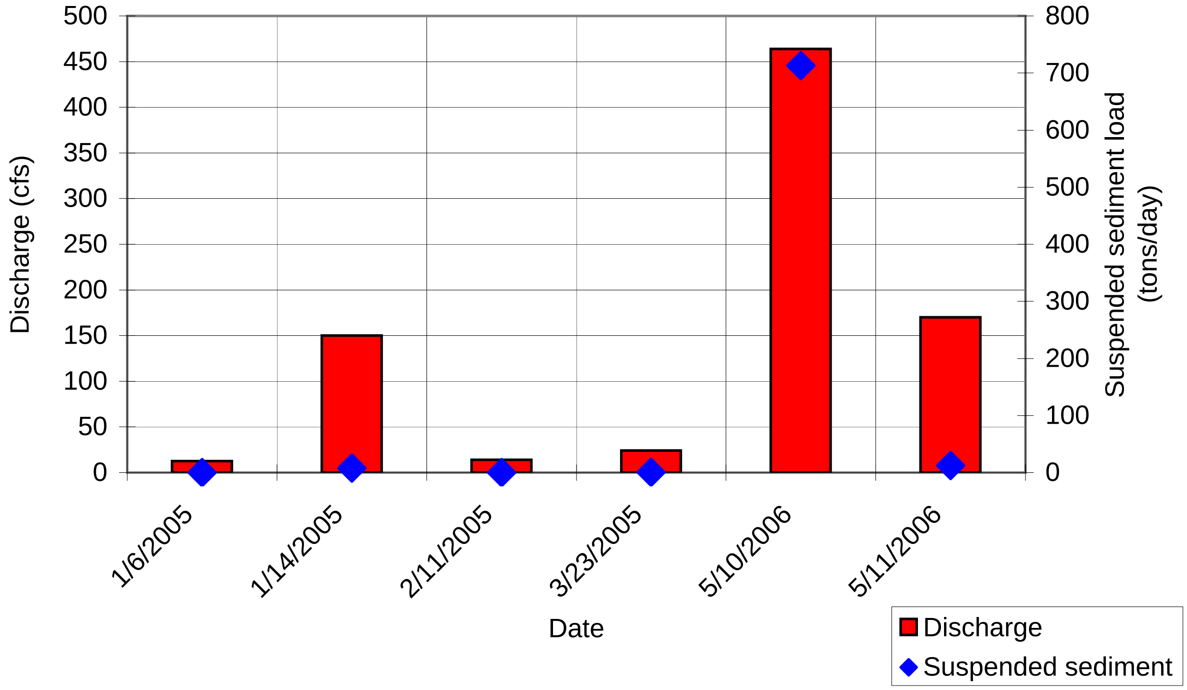


Figure 11.--Instantaneous suspended sediment loads and measured discharge for site PM1, Pearces Mill Creek at Alabama Highway 253, Marion County, Alabama.

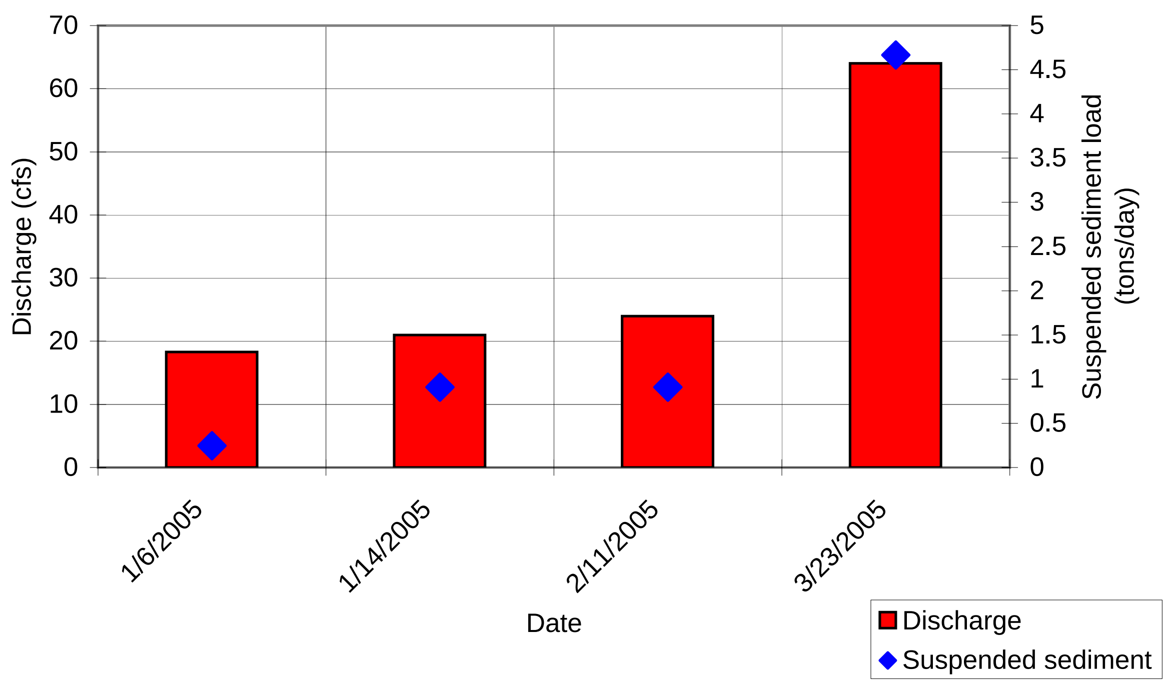


Figure 12.--Instantaneous suspended sediment loads and measured discharge for site WB1, West Branch Buttahatchee River at Alabama Highway 129, Marion County, Alabama.

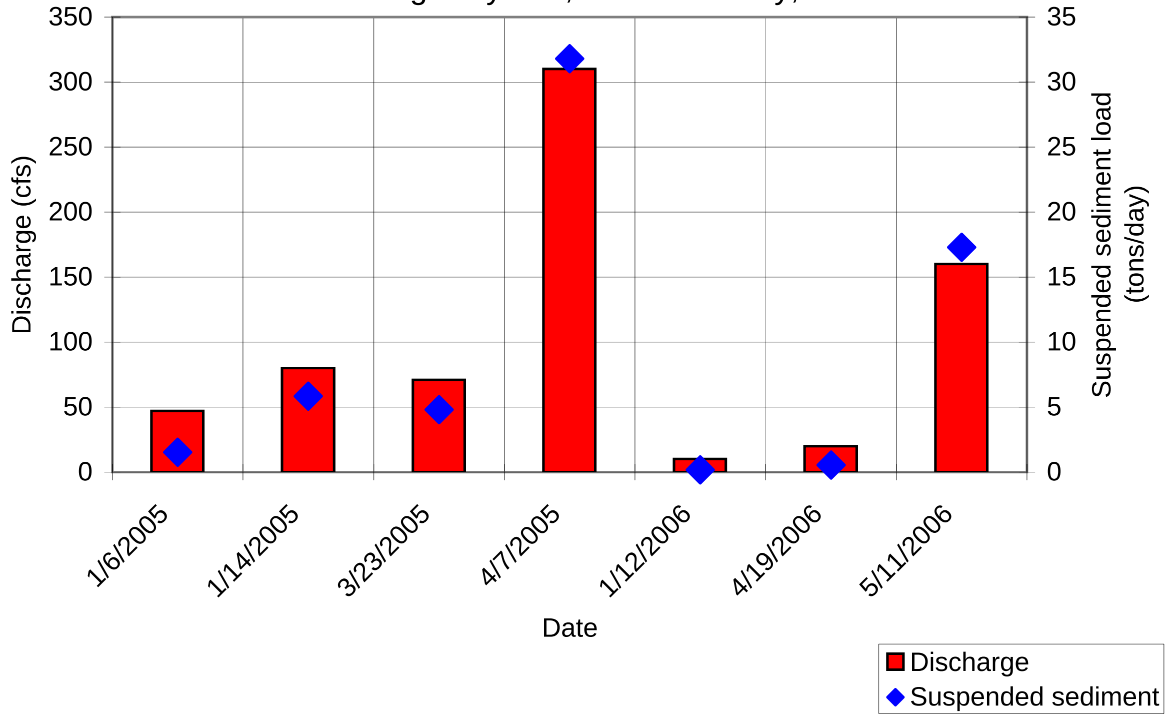


Figure 13.--Instantaneous suspended sediment loads and measured discharge for site WC1, Williams Creek at Old Highway 43, Marion County, Alabama.

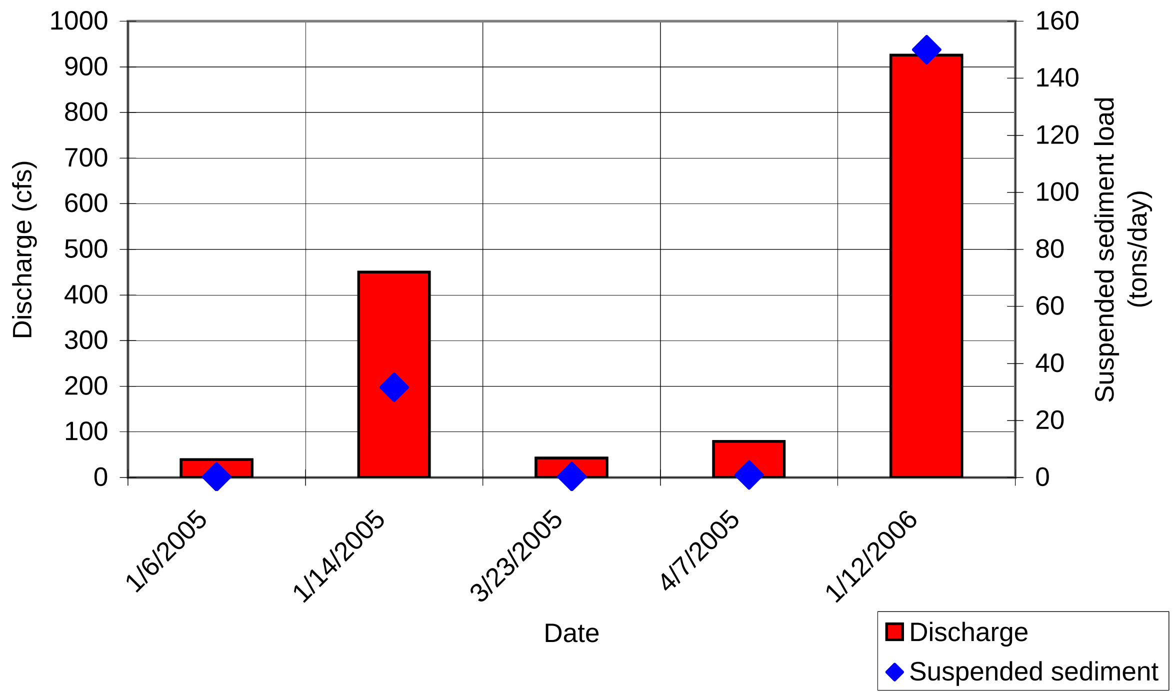


Figure 14.--Instantaneous suspended sediment loads and measured discharge for site Wd1, Woods Creek at County Road 98, Marion County, Alabama.

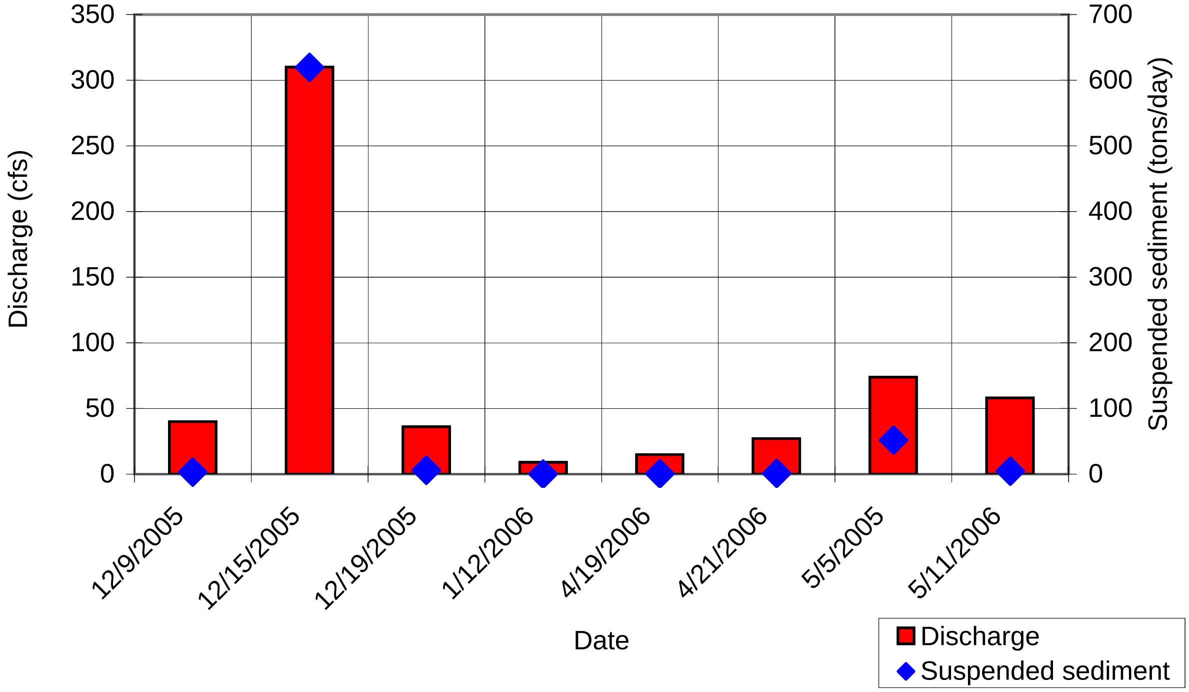
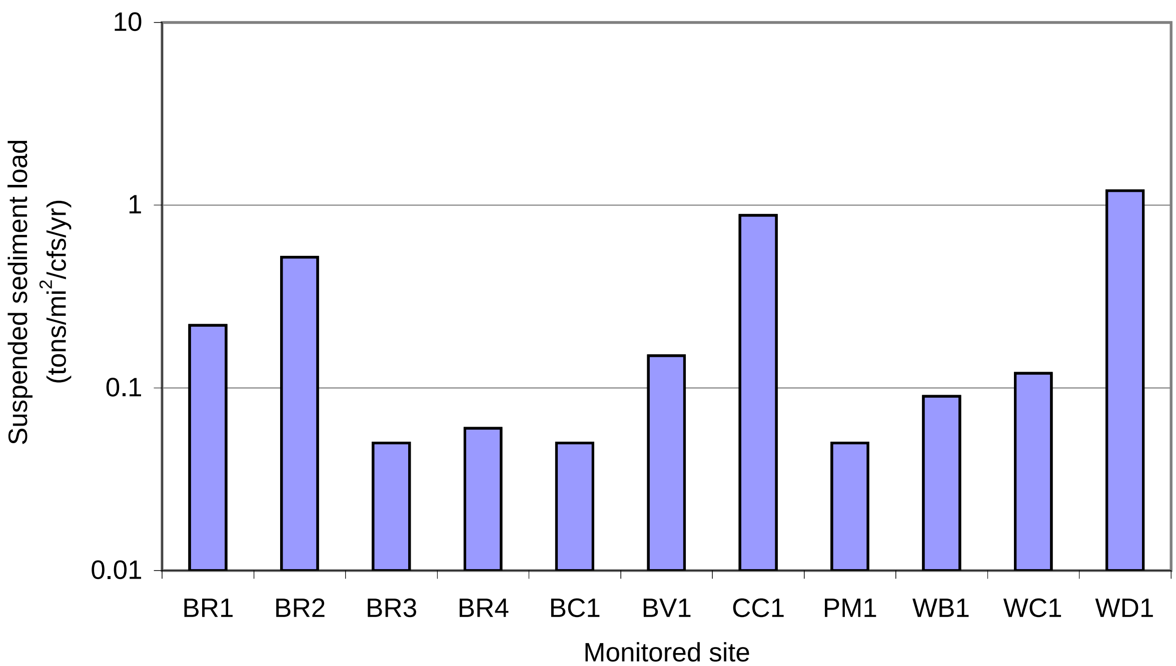


Figure 15.--Calculated mean instantaneous suspended sediment loads normalized with respect to area, discharge, and time for selected sites in the Buttahatchee River watershed.



from these main stem sites. However, normalization of the data (mean values normalized with respect to area, discharge, and time) clearly shows that sites BR1, BR2, Bv1, CC1, and Wd1 transport the largest suspended loads (fig. 15, table 7).

The computer model Regr_Cntr.xls (Regression with Centering) was used to estimate suspended sediment loads at nine of eleven monitored sites. The largest annual suspended sediment loads were measured at sites BR3 (232,124 tons per year (t/yr)), BR2 (99,430 t/yr), Wd1 (35,774 t/yr), and Bv1 (33,389 t/yr) (fig. 16). Decreasing suspended sediment loads were estimated downstream from main stem site BR3 (fig. 3, fig. 16, table 8). This occurs as the suspended load settles out of the water column due to decreasing stream flow velocity as the Buttahatchee River crosses the Fall Line and transitions from an upland Cumberland Plateau stream to a coastal plain stream. The coastal plain portion of the river has a relatively large bedload compared to the upland portion of the stream. When the annual suspended loads are normalized with respect to watershed area, sites Wd1 (1,379 tons per square mile per year ($t/mi^2/yr$)), BR2 (576 $t/mi^2/yr$), and Bv1 (389 $t/mi^2/yr$) contribute the largest volume (fig. 17, table 8).

Stream bed sediment loads were measured for seven sites (BR2, Bv1, CC1, PM1, WB1, WC1, and Wd1) in the Buttahatchee River watershed during 2005 and 2006. All other monitoring sites are underlain by Pottsville Sandstone where total sediment loads are assumed to be partially or totally suspended. The maximum bedload measured during the monitoring period was 157 tons per day (t/d) at site BR2. Figures 18 through 24 portray stream bed sediment loads measured during the project.

Table 7.—Calculated mean instantaneous suspended sediment loads normalized with respect to area, discharge, and time for monitored sites in the Buttahatchee River watershed

Station number	Monitoring Site	Normalized suspended sediment loads ($t/mi^2/cfs/yr$)
BR1	Buttahatchee River	0.22
BR2	Buttahatchee River	0.52
BR3	Buttahatchee River	0.05
BR4	Buttahatchee River	0.06
BC1	Barn Creek	0.05
Bv1	Beaver Creek	0.15
CC1	Camp Creek	0.88
PM1	Pearces Mill Creek	0.05
WB1	West Branch Buttahatchee River	0.09
WC1	Williams Creek	0.12
Wd1	Woods Creek	1.2

Table 8.—Estimated annual suspended sediment loads for sites in the Buttahatchee River watershed.

Station number	Monitoring Site	Estimated annual suspended sediment load (t/yr)	Normalized estimated annual suspended sediment load ($t/mi^2/yr$)
BR1	Buttahatchee River	961	212
BR2	Buttahatchee River	99,430	576
BR3	Buttahatchee River	232,124	184
BR4	Buttahatchee River	19,458	122
BC1	Barn Creek	3,803	50
Bv1	Beaver Creek	9,140	242
CC1	Camp Creek	33,389	389
WB1	West Branch Buttahatchee River	1,137	96
Wd1	Woods Creek	35,774	1,379

Figure 16.--Estimated annual suspended sediment loads from 2005 and 2006 data for selected sites in the Buttahatchee River watershed.

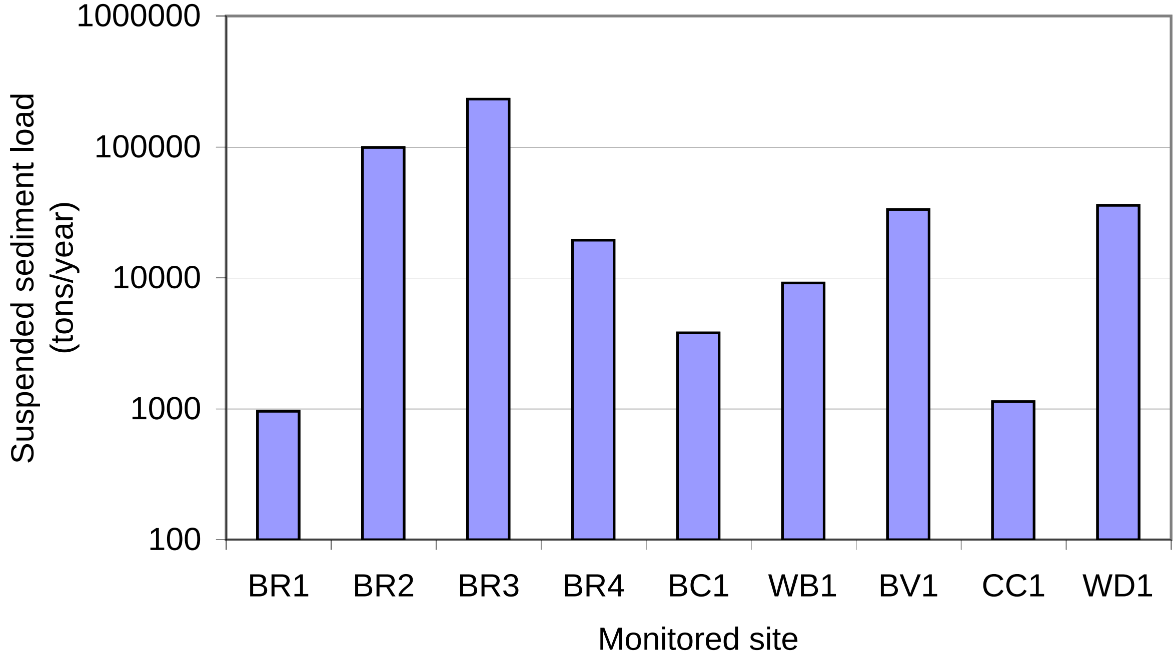


Figure 17.--Estimated normalized annual suspended sediment loads from 2005 and 2006 data for selected sites in the Buttahatchee River watershed.

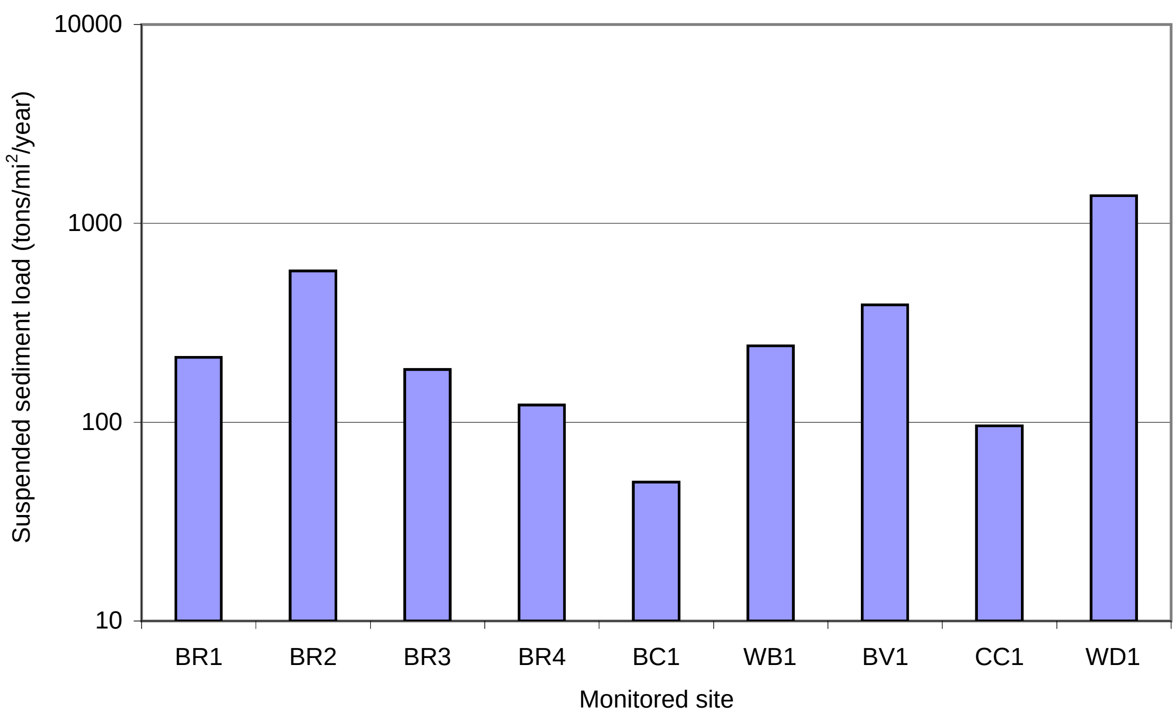


Figure 18.--Measured stream discharge and bedload sediment for site BR2, Buttahatchee River at County Road 16, Lamar County, Alabama.

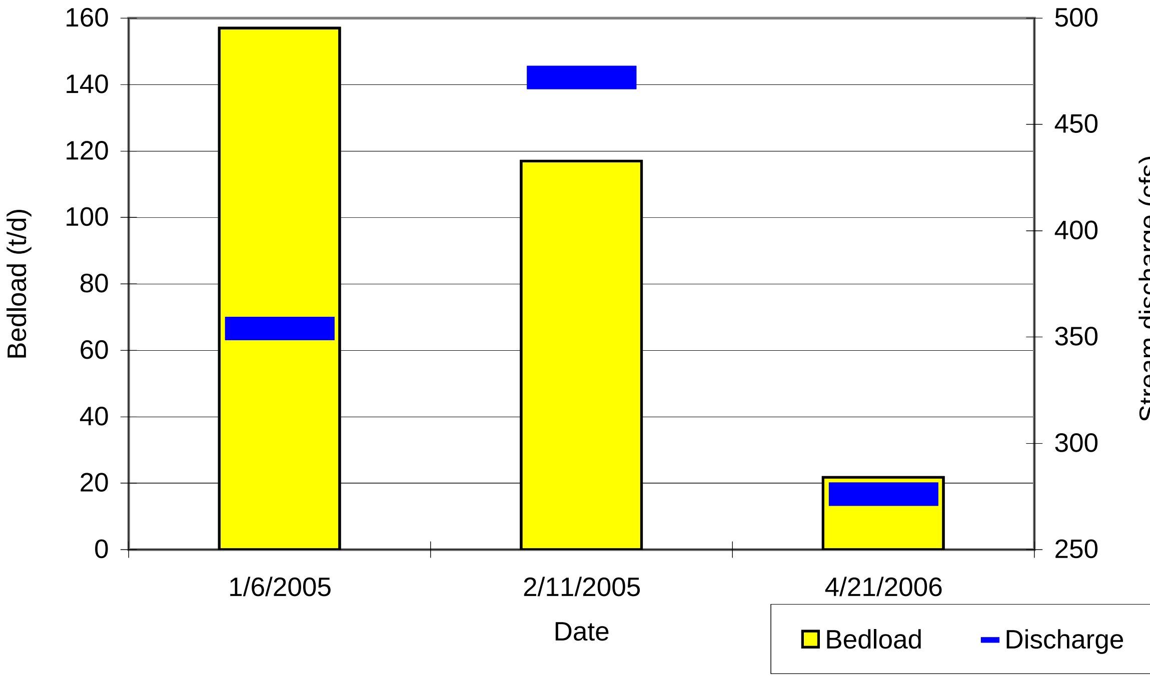


Figure 19.--Measured stream discharge and bedload sediment for site Bv1, Beaver Creek at County Road 77, Lamar County, Alabama.

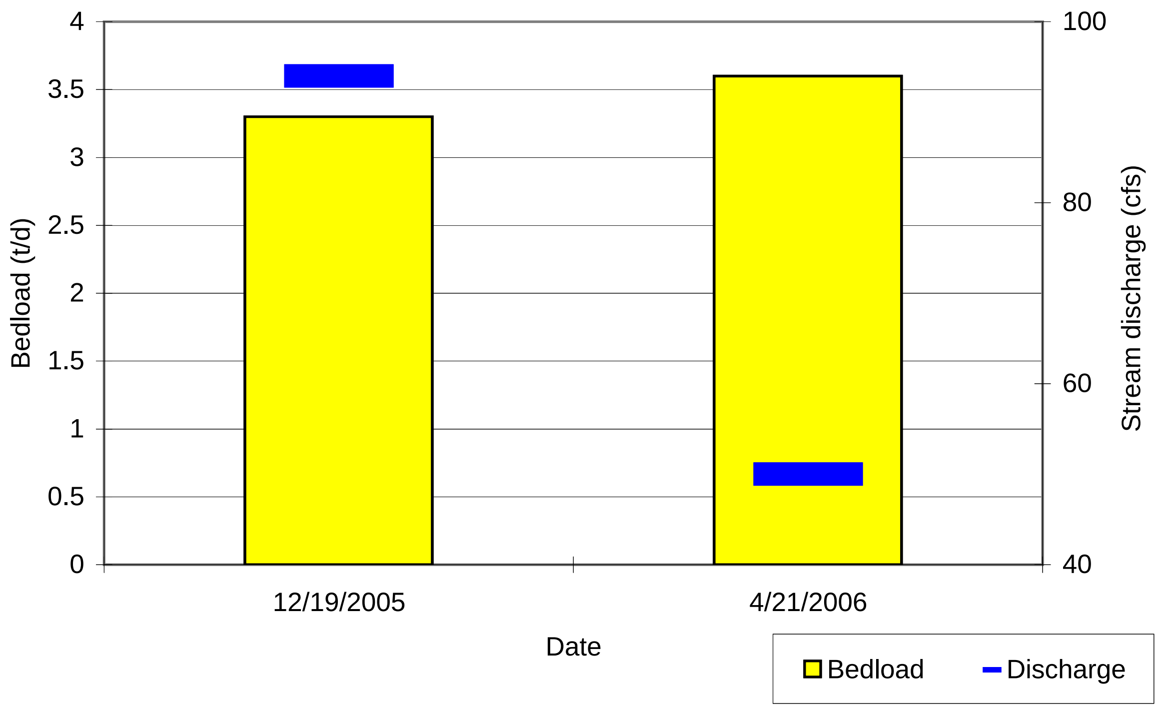


Figure 20.--Measured stream discharge and bedload sediment for site CC1, Camp Creek at Alabama Highway 253, Marion County, Alabama.

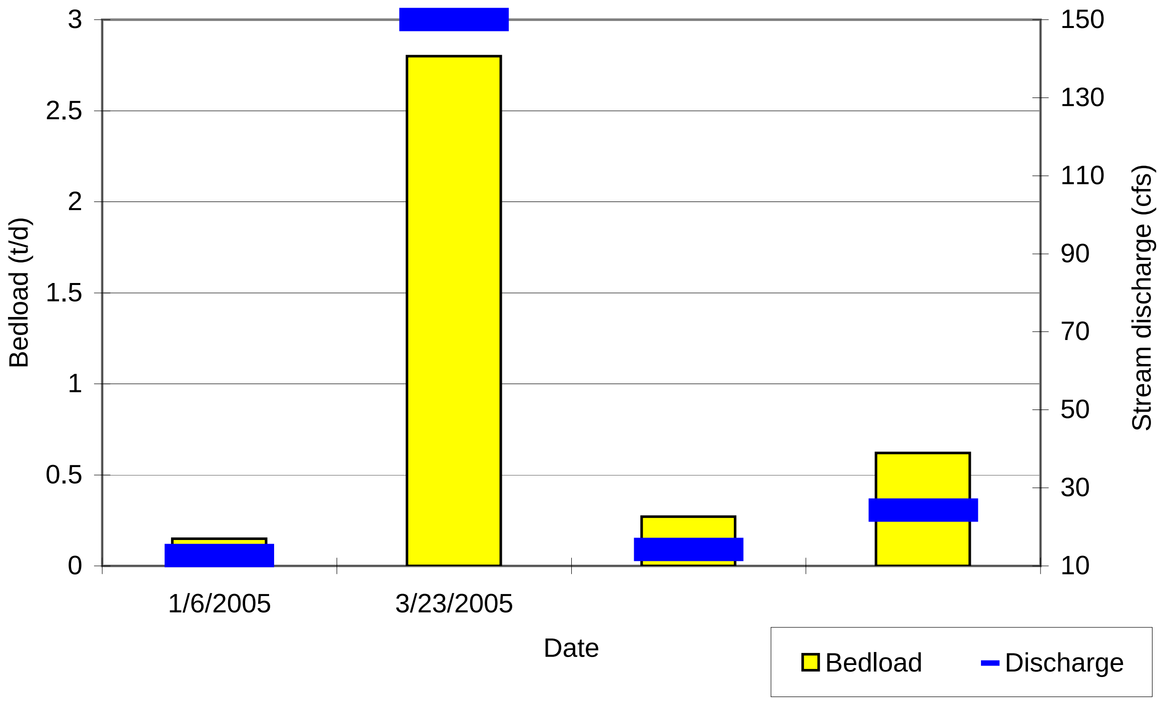


Figure 21.--Measured stream discharge and bedload sediment for site PM1, Pearces Mill Creek at Alabama Highway 253, Marion County, Alabama.

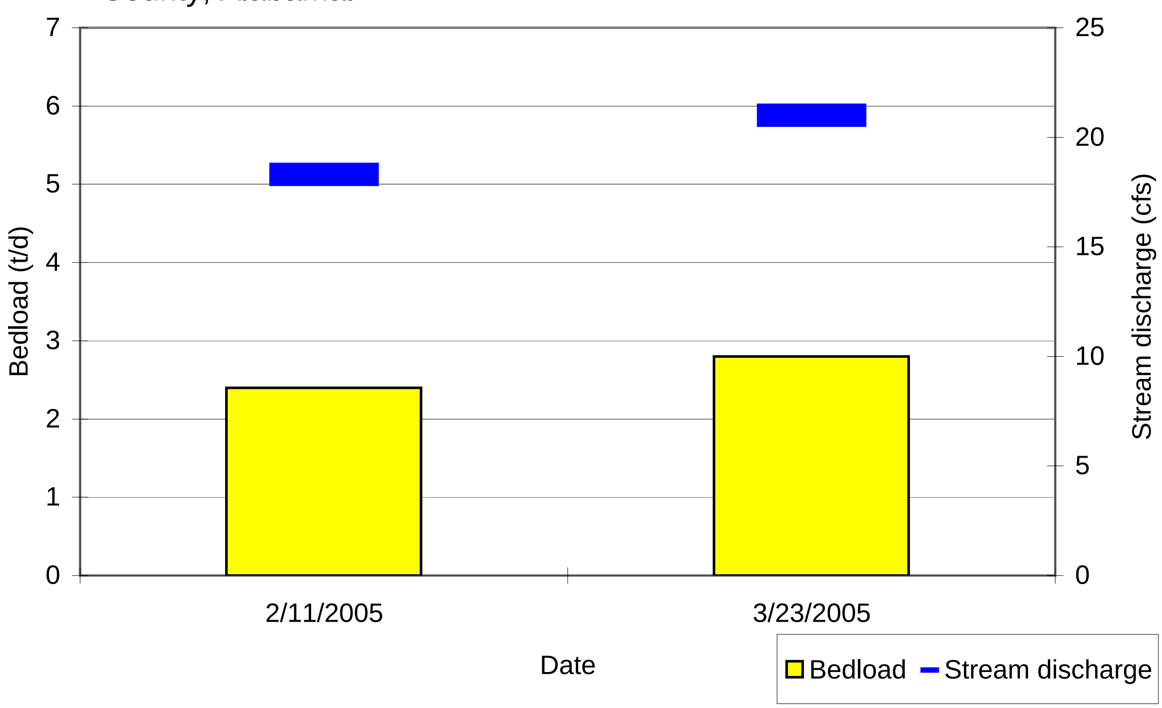


Figure 22.--Measured stream discharge and bedload sediment for site WB1, West Branch Buttahatchee River at Alabama Highway 129, Marion County, Alabama.

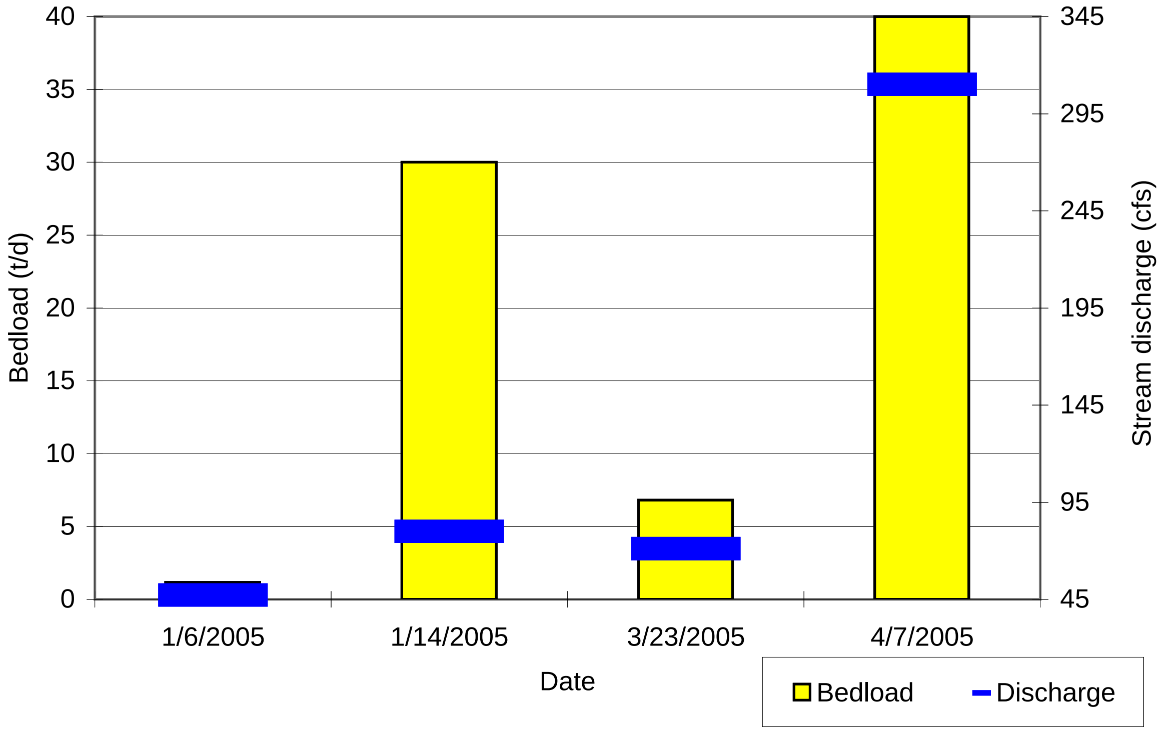


Figure 23.--Measured stream discharge and bedload sediment for site WC1, Williams Creek at old Highway 43, Marion County, Alabama.

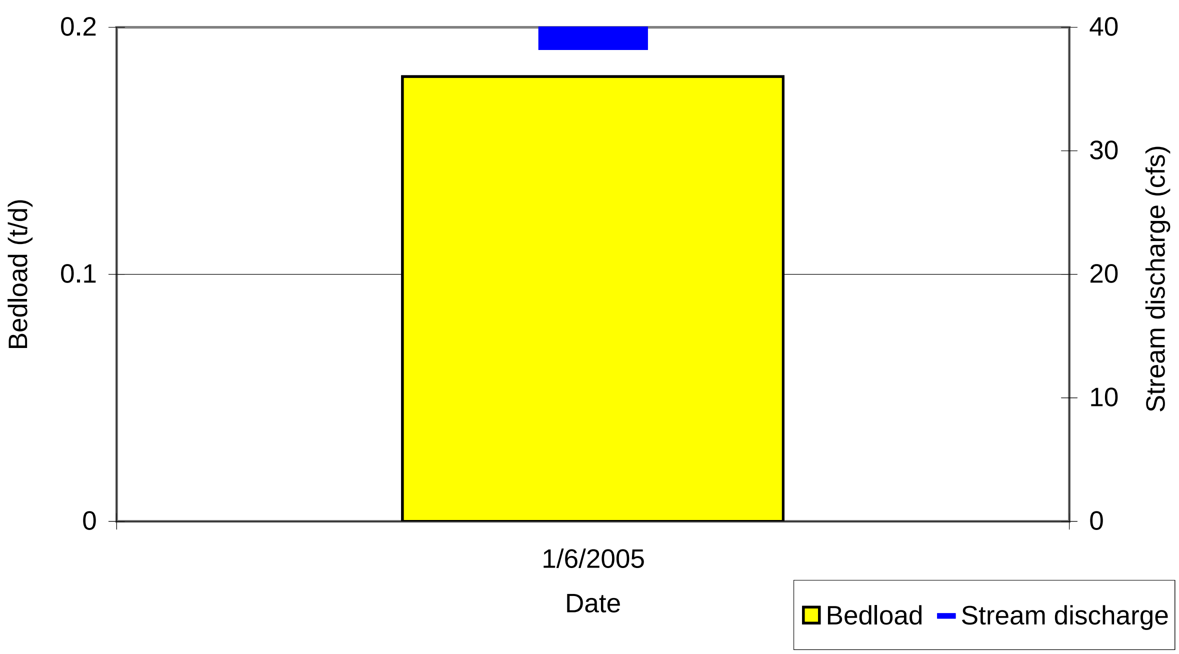
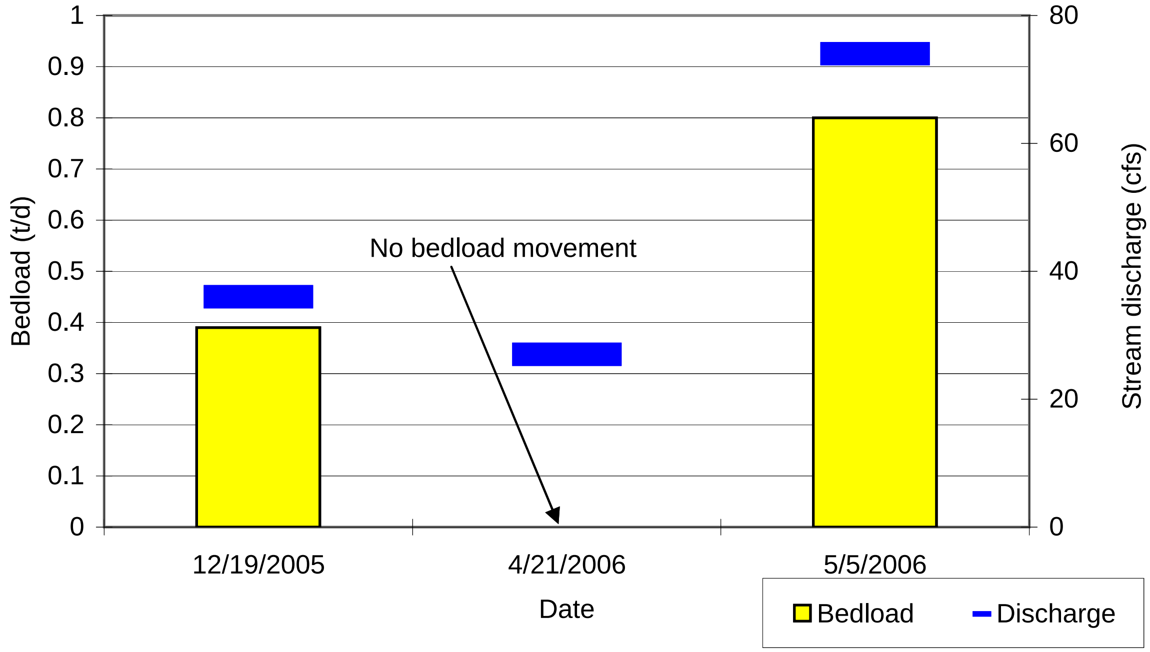


Figure 24.--Measured stream discharge and bedload sediment for site Wd1, Woods Creek at County Road 98, Marion County, Alabama.



SUMMARY AND RECOMMENDATIONS

The most diverse and abundant mussel populations in a recent upper Tombigbee tributary study were strongly associated with streams containing high quality gravel and gravel/sand substrate, stable riparian buffer zones, and moderate flow (McGregor and Haag, 2004). Channelized streams and streams with heavy agricultural, silvicultural, or other anthropogenic impacts usually yielded poor faunas and in some cases were completely devoid of native mussels. The Buttahatchee River was second to the Sipsey River in diversity and abundance during that study. A valuable mussel fauna remains in the Buttahatchee River system. That fauna includes the only known population of one federally listed endangered species, other listed species with declining distributions, and additional species of conservation concern in Alabama and Mississippi.

Several recent publications document the historic presence of an adequate pool of potential host fishes in the Buttahatchee River system. However, those publications were generally based on museum records and the current distribution and abundance of fishes is relatively unknown.

A single sample of bed sediment evaluated for toxic metals in the bed sediment yielded values generally lower than those in other regional streams known to harbor healthy, reproducing mussel populations. This finding suggests that, if the sample is indeed indicative of the watershed as a whole, toxicity would not be a major factor in reintroduction of freshwater mussels in the Buttahatchee system.

Investigations of sediment loading in the Buttahatchee River watershed indicate that suspended sediment probably comprises a major portion of the total sediment load transported by the river. Recent evaluations of sediment loading rates in the mainstem

Buttahatchee and tributaries document an ongoing elevated sedimentation event in the headwaters that, left unchecked, could continue to suppress the mussel and fish faunas and would likely influence future mussel propagation and reintroduction efforts.

As a result of information found during this analysis and information found through review of relevant literature sources, we make the following recommendations for successful propagation and reintroduction of mussels into and from the Buttahatchee River system:

- Continued presence of stable populations of suitable host fishes for species of recovery potential should be verified before reintroducing mussels that would fail through attrition in the absence of those hosts.
- During this study analysis of a single sample of bed sediment yielded values of metals known to be toxic to freshwater mussels to be generally lower than those in other stream systems with viable mussel faunas; however, it should not be inferred that this result reflects conditions throughout the system, and a more comprehensive evaluation of sediment toxicity throughout the watershed should be executed before that determination can be made.
- Additional sampling to further refine the rates and sources of sediment loading should be a primary objective. A plan to monitor habitat recovery efforts should be implemented and such efforts evaluated for success. Reintroduction should not commence until a suitable level of recovery has been documented.

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