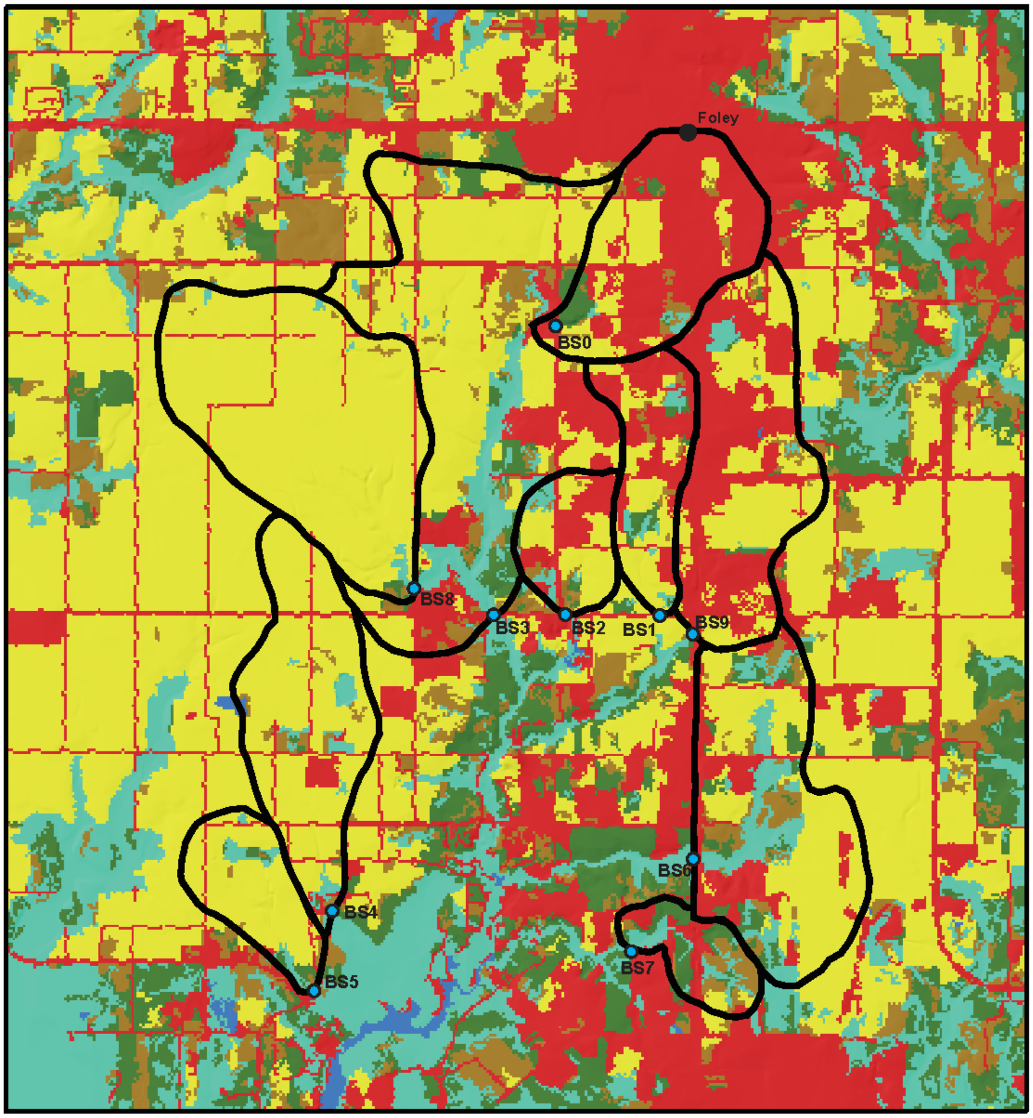
ANALYSIS OF SEDIMENT LOADING RATES AND WATER QUALITY FOR THE BON SECOUR RIVER WATERSHED, BALDWIN COUNTY, ALABAMA



GEOLOGICAL SURVEY OF ALABAMA

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ANALYSIS OF SEDIMENT LOADING RATES AND WATER QUALITY FOR THE BON SECOUR RIVER WATERSHED, BALDWIN COUNTY, ALABAMA

OPEN FILE REPORT 1409

By

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Tuscaloosa, Alabama
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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 erodible 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; Cook and others, 2009). 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.

The purpose of this project is to determine sediment loads and general surface-water quality for the Bon Secour River watershed in southwestern 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 or other water-quality impacts (fig. 1).

ACKNOWLEDGMENTS

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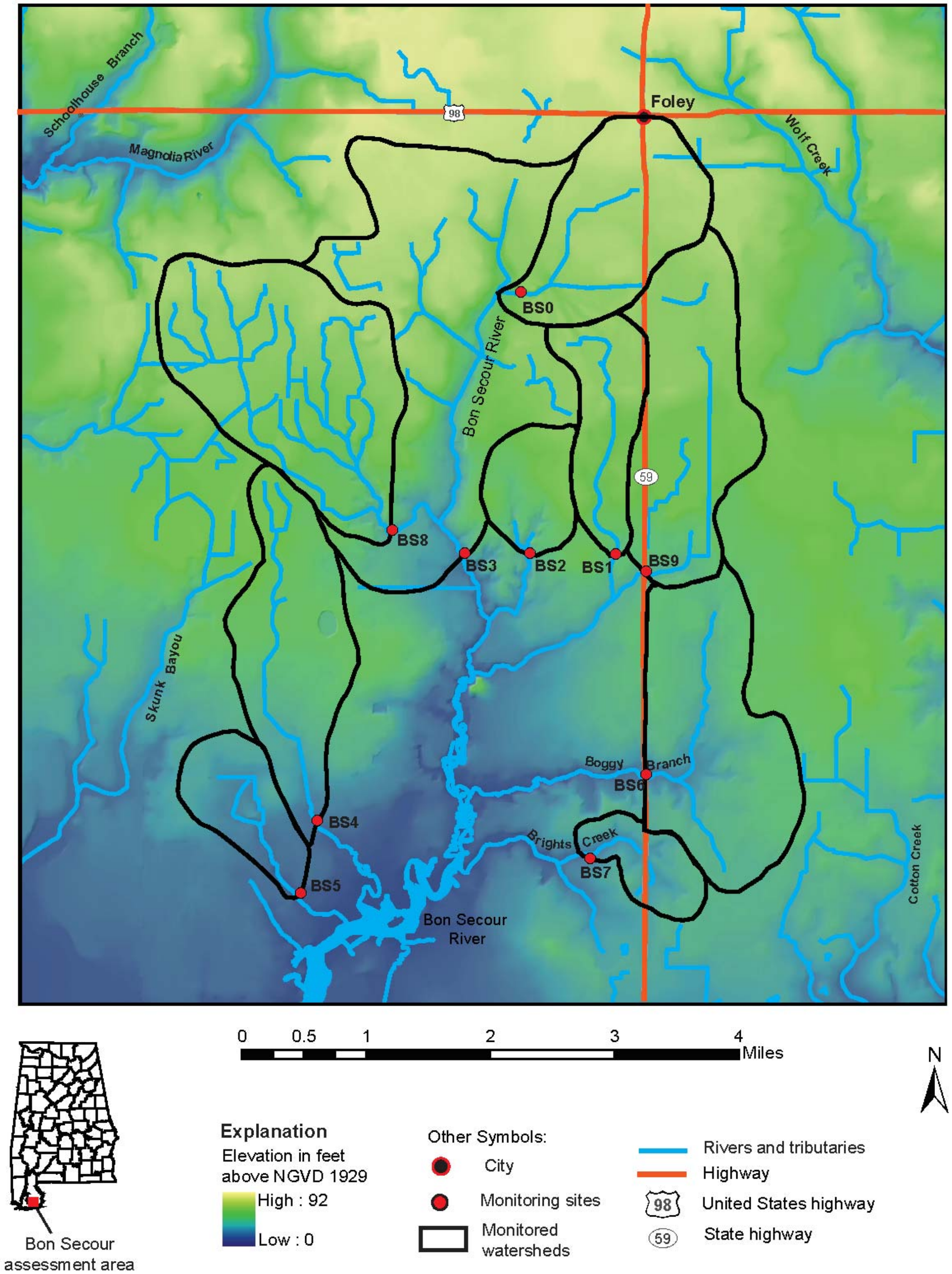

Figure 1.—Location of Bon Secour monitoring sites and monitored watersheds

MONITORED WATERSHEDS

The Bon Secour River watershed sedimentation assessment project area is approximately 58 square miles. Monitoring sites were established in 10 watersheds, varying in size from approximately 0.5 to 8.8 square miles (mi^2) (table 1). The project area and monitored watersheds are shown on plate 1. Site BS3 monitored the largest watershed (main stem Bon Secour River) and was located on Baldwin County Road 12, the last point of access upstream from tidal influence. Sites BS0 (unnamed tributary) and BS8 (Turkey Creek) were on tributaries upstream from Bon Secour River site BS3. Sites BS1 and BS2 (unnamed tributaries), BS4 (Shutt Creek), BS5 (School House Branch), BS6 (Boggy Branch), BS7 (Brights Creek), BS8 (Turkey Creek), and BS9 (unnamed tributary, were on streams with Bon Secour River confluences downstream from site BS3. Monitoring site designations, stream names, locations, and monitored areas are shown on plate 1.

Table 1.—Measured area in square miles for the Bon Secour assessment sites.

Monitoring site numbers	Monitored stream name and site location	Monitored watershed area (mi^2)
BS0	Unnamed tributary to Bon Secour River at South Hickory Street	1.7
BS1	Unnamed tributary to Bon Secour River at County Road 12	0.9
BS2	Unnamed tributary to Bon Secour River at County Road 12	0.6
BS3	Bon Secour River at County Road 12	8.8
BS4	Shutt Creek at Bon Secour Highway	1.8
BS5	School House Branch at Bon Secour Highway	0.8
BS6	Boggy Branch at Alabama Highway 59	2.3
BS7	Brights Creek at Viola Road	0.5
BS8	Turkey Creek at County Road 65	2.9
BS9	Unnamed tributary to Bon Secour River at Alabama Highway 59	2.1

LAND USE

Land use is directly correlated with water quality, hydrologic function, ecosystem health, biodiversity, and the integrity of streams and wetlands. When natural landscapes are converted to urban, permeable soils are covered with impervious surfaces such as roads, sidewalks, parking lots, and buildings. Impervious surfaces or cover is defined as all hard surfaces of watersheds that are impermeable to rainfall infiltration. Increased imperviousness leads to higher volumes and flow velocities of storm water runoff, which can have devastating effects on local hydrology including increased flooding, stream bank erosion, degraded aquatic habitat, reduced groundwater recharge, and increased surface-water pollution (Schueler, 1992). Subwatersheds within the Bon Secour project area are dominated by agriculture, but in the past decade a large part of the land cover has transitioned to urban and residential.

Land use classification and change within the Bon Secour project area was determined using the National Land Cover Database (NLCD) raster dataset. The NLCD was created by the Multi-Resolution Land Characteristics (MRLC) Consortium, which is led by the United States Geological Survey (USGS). Both the 2001 and 2011 NLCD datasets were used to compare land use change and classifications over a decade within the study extent. The 2001 NLCD is a 16-class land cover classification scheme that has been applied consistently across the United States at a spatial resolution of 30 meters and is based primarily on a decision-tree classification of circa 2001 Landsat satellite data. The 2011 NLCD is the most recent national land cover product and is based on the circa 2011 Landsat satellite data. It has the same classes and resolution as the 2001 NLCD, by providing the capability to assess wall-to-wall, spatially explicit, national land cover changes and trends across the United States from 2001 to 2011 (Jin and others, 2013).

Land use in the project area was subdivided into six classified groups defined as developed, forested, agricultural, grassland/shrub/scrub, wetlands, and open water (table 2). Land use for the years 2001 and 2011 are shown on plates 3 and 4, respectively. Land use and vegetative cover in the Bon Secour watershed is characterized as coastal plain, dominated by agriculture, urban and residential development along roadways and extending south and southwestward from the city of Foley in the northern part of the study area, and floodplains with wetland and forest vegetation along Bon Secour River and its tributaries (plate 4).

The primary land use in the watershed is agriculture which is heavily concentrated in the western and southeastern sections of the study area. Agricultural uses include some pasture land, but mainly row crops consisting of corn, cotton, soybeans, peanuts, and sod. The majority of crops are planted year round as double

Table 2.—Land use data for the Bon Secour sedimentation assessment sites (2011 NLCD).

Monitoring Site	Open Water %	Developed %	Forested %	Grassland/scrub/shrub %	Agriculture %	Wetlands %
BS0	0	66.2	4.1	4.7	23.7	1.3
BS1	0	46.7	4.7	3.4	39.9	5.3
BS2	0	36.2	4.1	6.7	43	10
BS3	0	23.6	3.8	5.3	61.3	5.9
BS4	0.5	10.1	0.5	3.9	80	5.5
BS5	0	6.3	5.2	2.8	78	7.7
BS6	0.1	21.1	7.5	9.4	45	17.1
BS7	0	26.9	24.5	23.3	7.2	18
BS8	0	3.3	0.5	1.2	93.6	1.4
BS9	0.1	54.6	1	2.1	40	2.3

crops and winter wheat is grown in winter and early spring. A turf (sod/grass seed) farm is located in the west-central portion of the watershed. Double crops, winter cover vegetation, and long growing seasons decrease the amount of time the land is bare and limits erosion from agricultural land.

Average land use change was calculated for the entire project area from 2001 to 2011. Significant changes were observed in the “developed” category, which increased by 7.8 percent, and the agriculture category, which decreased by 7.6 percent (fig. 2). It can be inferred that the decrease in agriculture and increase in developed classes correlate as crop lands were likely converted into urban and residential use. As previously mentioned, urbanization increases the amount of impervious surfaces in a watershed, leading to intensified flood events, stream bank erosion, and sedimentation.

The watershed upstream from site BS0 is comprised mainly of developed land (66 percent) due to its location within the city of Foley where urban land use is most prominent (fig. 3). There was a 13 percent increase in developed land use in this watershed from 2001 to 2011. Agriculture is the second largest land use category for BS0, which decreased 10.8 percent. There were also small decreases in forested land (0.6 percent), grassland/shrub/scrub (0.6 percent), and wetlands (1 percent). There is no open water in the watershed.

The watershed upstream from site BS1 consists largely of developed land (46.7 percent) (fig. 4). It is located in the southern portion of Foley, where commercial and

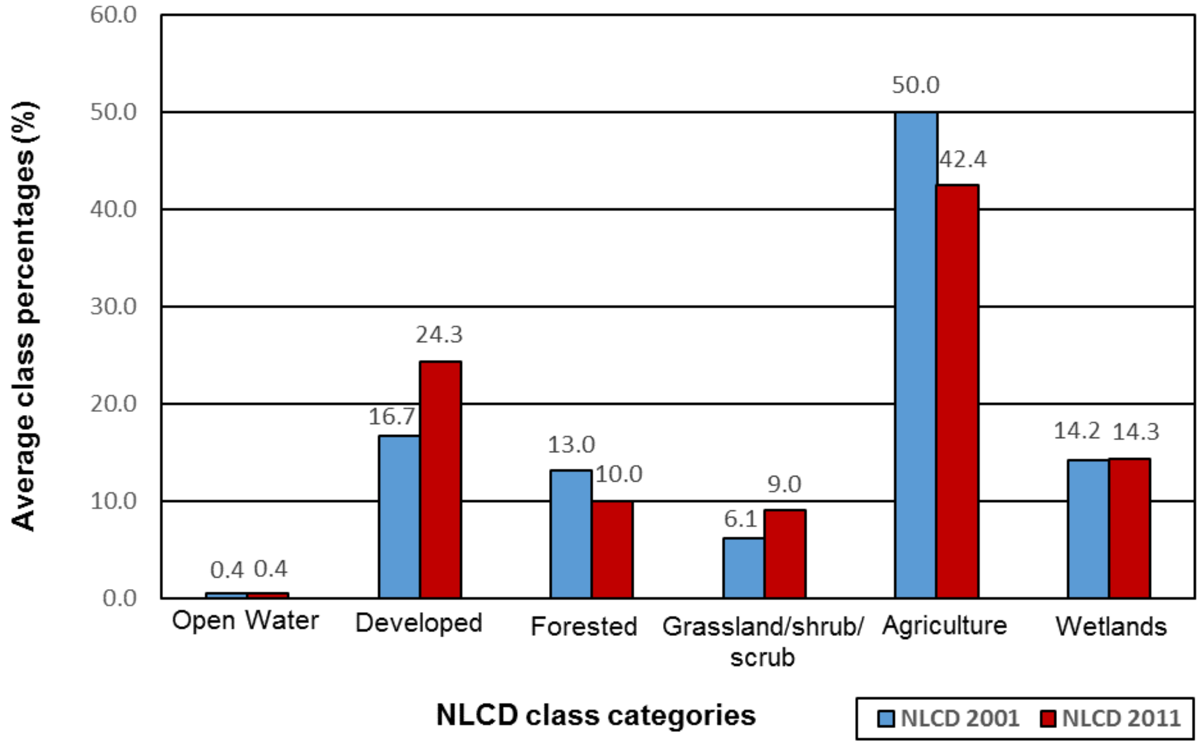

Figure 2.—Changes in average NLCD land use classes from 2001 to 2011 for the entire project area.

residential areas extended south of the city. There was a 29.6 percent increase in developed land use from 2001 to 2011. Agriculture is the second largest land use category for BS1, which decreased 20.5 percent. There were also small decreases in forested land (2.2 percent) and grassland/shrub/scrub (7.6 percent). Wetlands increased by 0.7 percent. There is no open water in the watershed.

The watershed upstream from site BS2 is comprised mainly of agriculture (43 percent) (fig. 5). There was a 20.8 percent decrease in agricultural land use from 2001 to 2011. Developed land (36.2 percent) is the second largest land use category for BS2, which increased 25.4 percent. There were also small decreases in forested land (1 percent), grassland/shrub/scrub (2.7 percent), and wetlands (1 percent). There is no open water in the watershed.

The watershed upstream from site BS3 includes the headwaters of Bon Secour River. It is located in the western portion of the study area which is comprised of heavy agriculture and row crops classified as agriculture (61.3 percent) (fig. 6). There was a

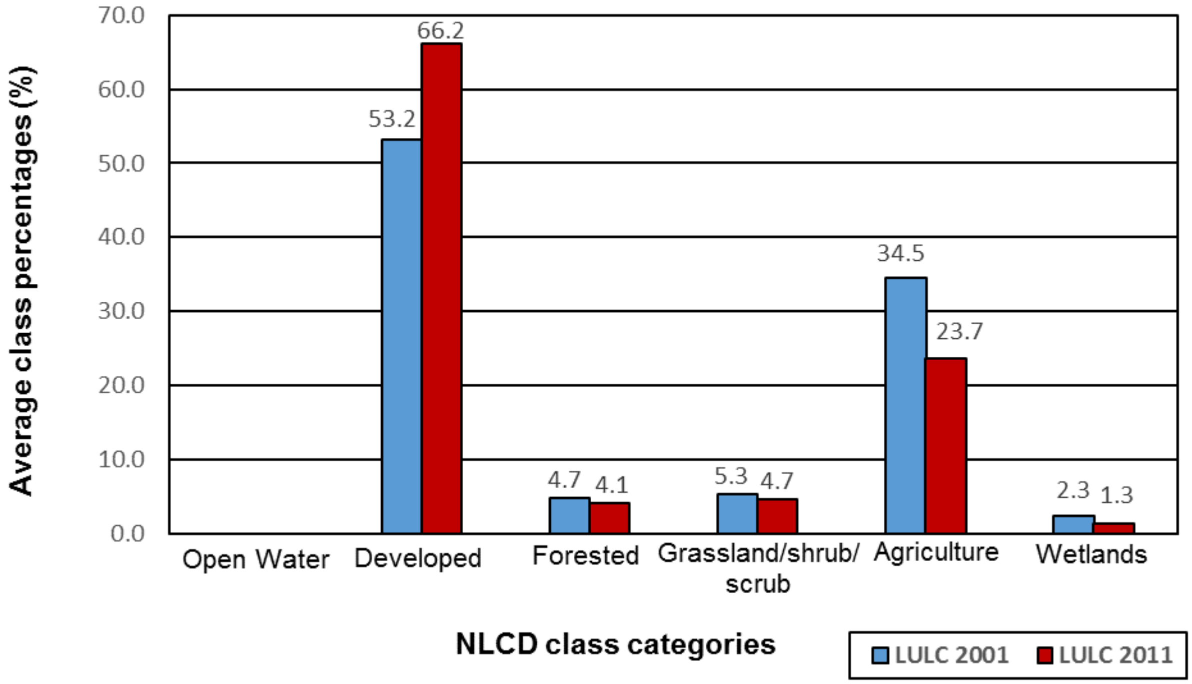

Figure 3.—Changes in average NLCD land use classes from 2001 to 2011 for site BS0.

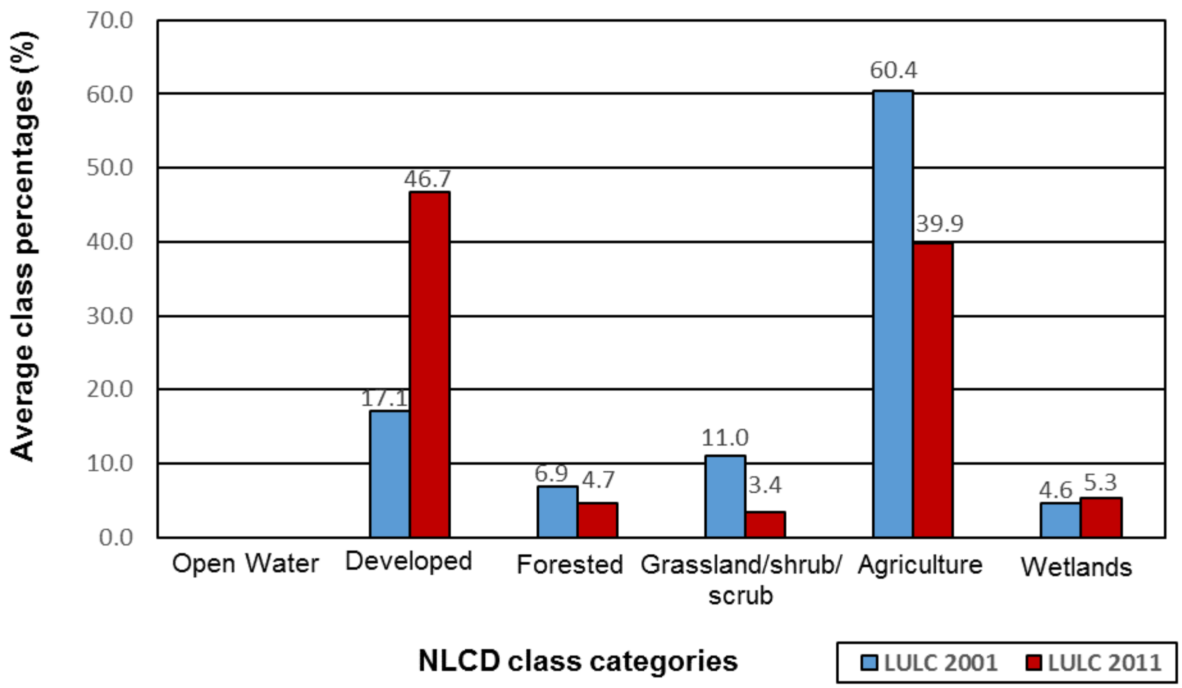

Figure 4.—Changes in average NLCD land use classes from 2001 to 2011 for site BS1.

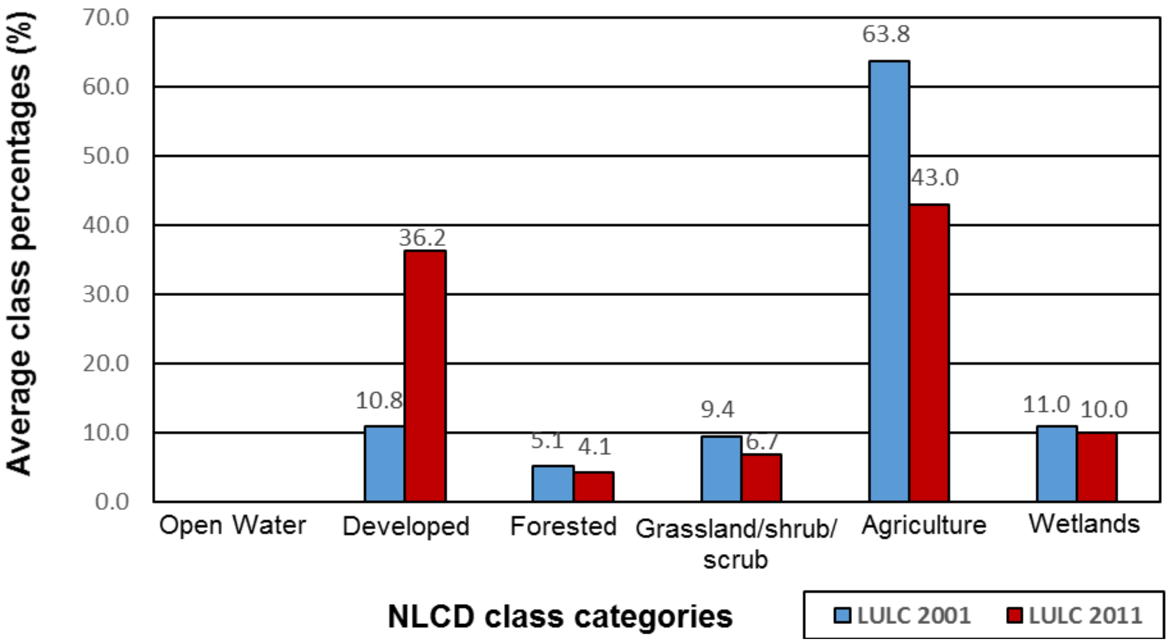

Figure 5.—Changes in average NLCD land use classes from 2001 to 2011 for site BS2.

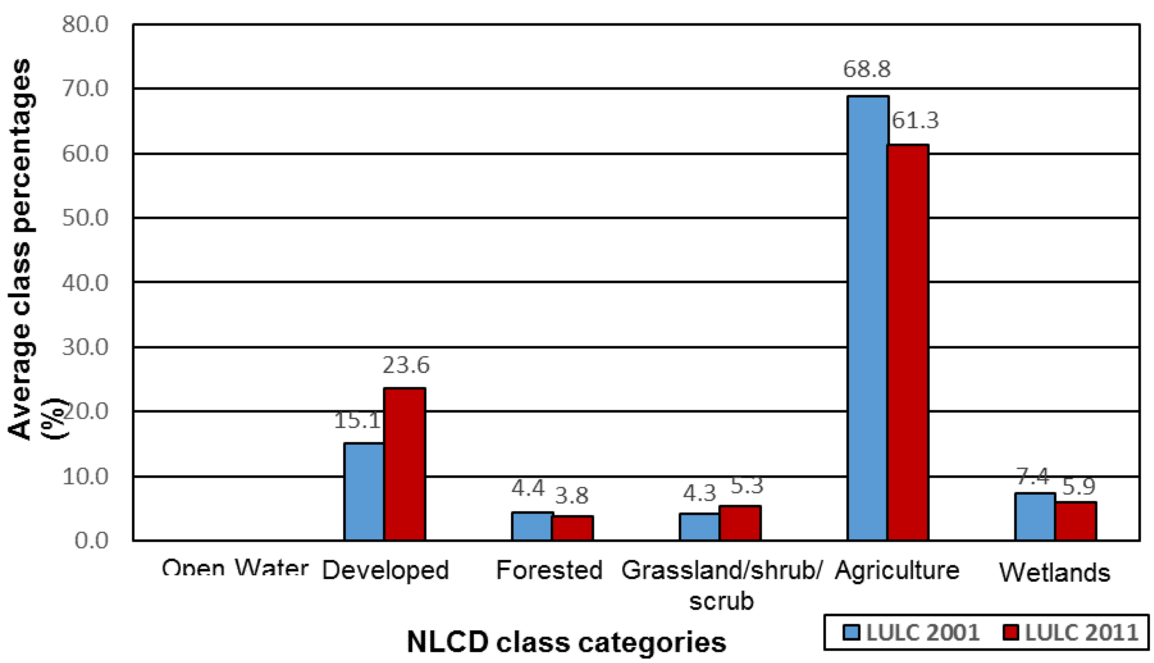

Figure 6.—Changes in average NLCD land use classes from 2001 to 2011 for site BS3.

7.5 percent decrease in agricultural land use from 2001 to 2011. Developed land (23.6 percent) is the second largest land use category for the watershed, which increased 8.5

percent. There were also small decreases in forested land (0.6 percent) and wetlands (1.5 percent). Grassland/shrub/scrub increased by 1 percent. There is no open water in the watershed.

The watershed upstream from site BS4 is located in the southwest portion of the major agricultural area in the western extent of the study area. It is comprised mainly of agriculture (80 percent) (fig. 7). There was a 3.7 percent decrease in agricultural land use from 2001 to 2011. Developed land (10.1 percent) is the second largest land use category for BS4 and increased by 3 percent. There was a small decrease in forested land (0.3 percent). Both open water (0.5) and grassland/shrub/scrub (1 percent) experienced slight increases. Wetlands remained the same at 5.5 percent.

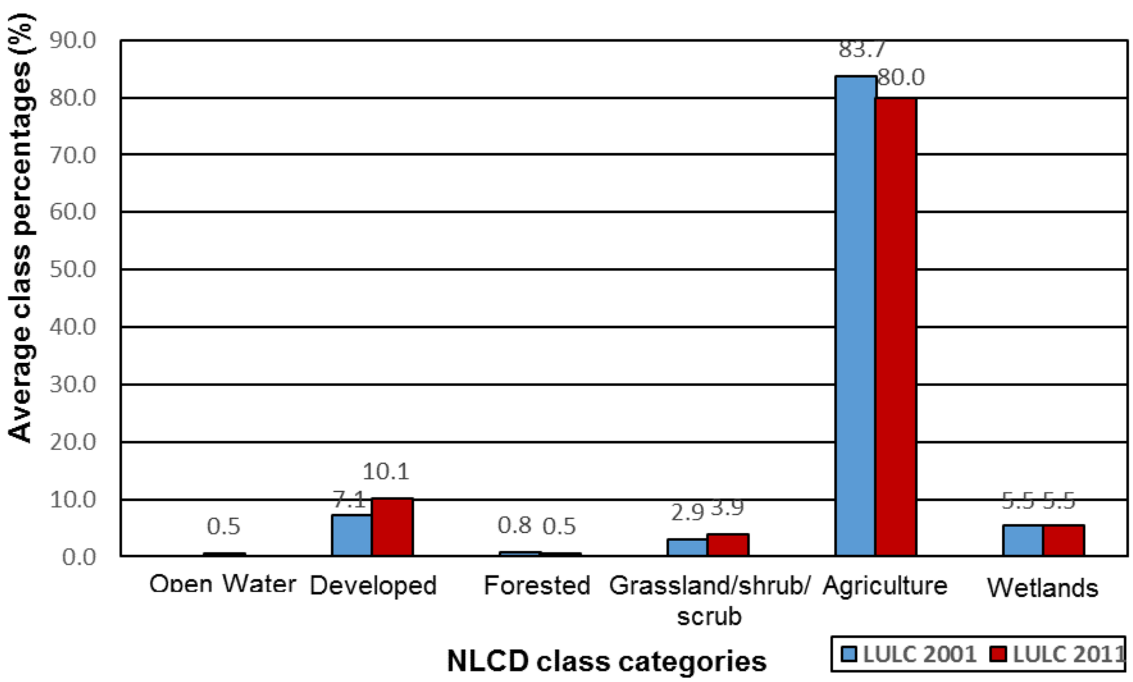

Figure 7.—Changes in average NLCD land use classes from 2001 to 2011 for site BS4.

The watershed upstream from site BS5 is located to the southwest of BS4 in the major agricultural area of the study extent. It is comprised mainly of agriculture (78 percent) (fig. 8). There was a 1 percent decrease in agricultural land use from 2001 to 2011. Wetlands (7.7 percent) is the second largest land use category for BS5 and increased by 2.8 percent. There was a small decrease in developed land (0.3 percent)

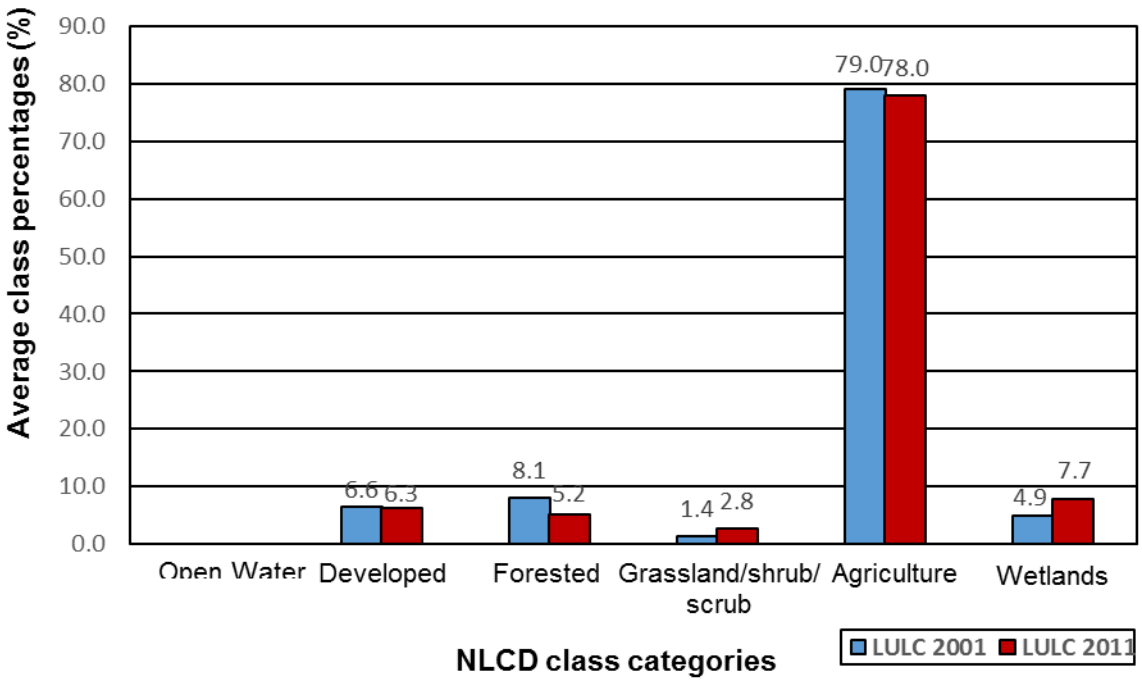

Figure 8.—Changes in average NLCD land use classes from 2001 to 2011 for site BS5.

and forested land (2.9 percent). Grassland/shrub/scrub increased by 1.4 percent. There is no open water in the watershed.

The watershed upstream from site BS6 is located in the southeastern portion of the study area south of BS9. It is comprised mainly of agriculture (45 percent) (fig. 9). Agricultural land use decreased 6.8 percent from 2001 to 2011. Developed land (21.1 percent) is the second largest land use category for BS6 and increased by 12.4 percent. Forested land (2.9), grassland/shrub/scrub (1.4), and wetlands (1.2) experienced slight decreases within the decade. Open water increased by 0.1 percent.

The watershed upstream from site BS7 is located in the southeastern portion of the study extent south of BS6. It is comprised mainly of developed land (26.9 percent) (fig. 10). Developed land use increased slightly by 0.9 percent from 2001 to 2011. Forested land (24.5 percent) is the second largest land use category for BS7 and decreased by 11.8 percent. Grassland/shrub/scrub increased by 1.2 percent, wetlands increased by 11.3 percent, and agriculture decreased by 1.6 percent. There is no open water in the watershed.

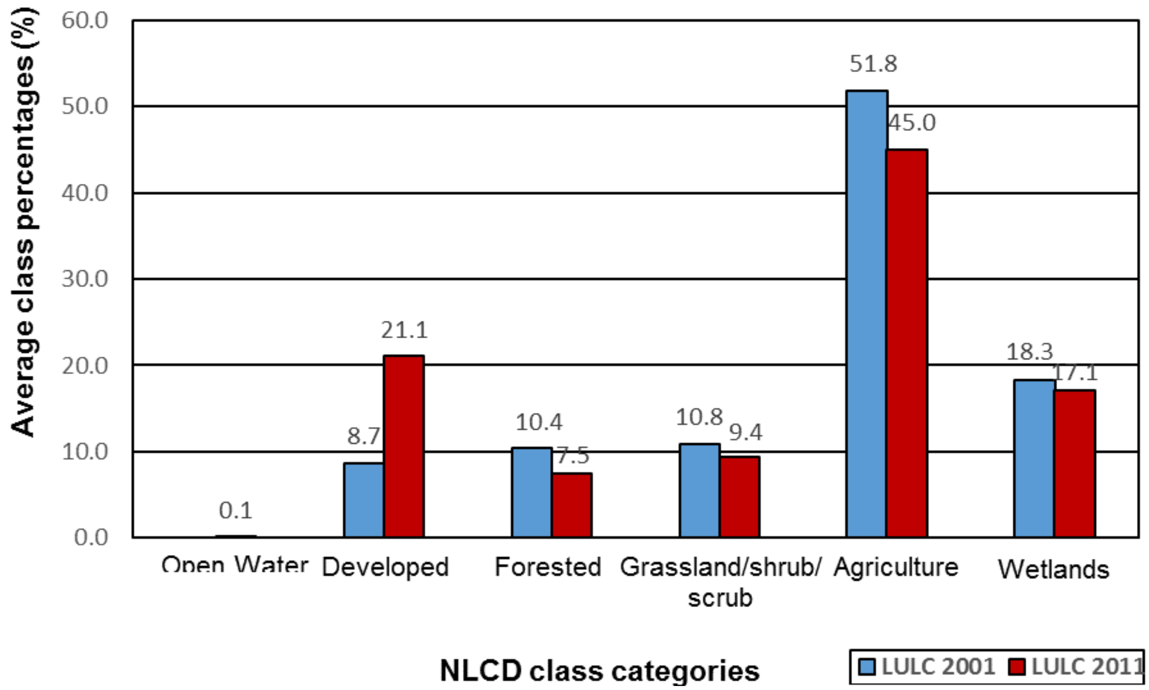

Figure 9.—Changes in average NLCD land use classes from 2001 to 2011 for site BS6.

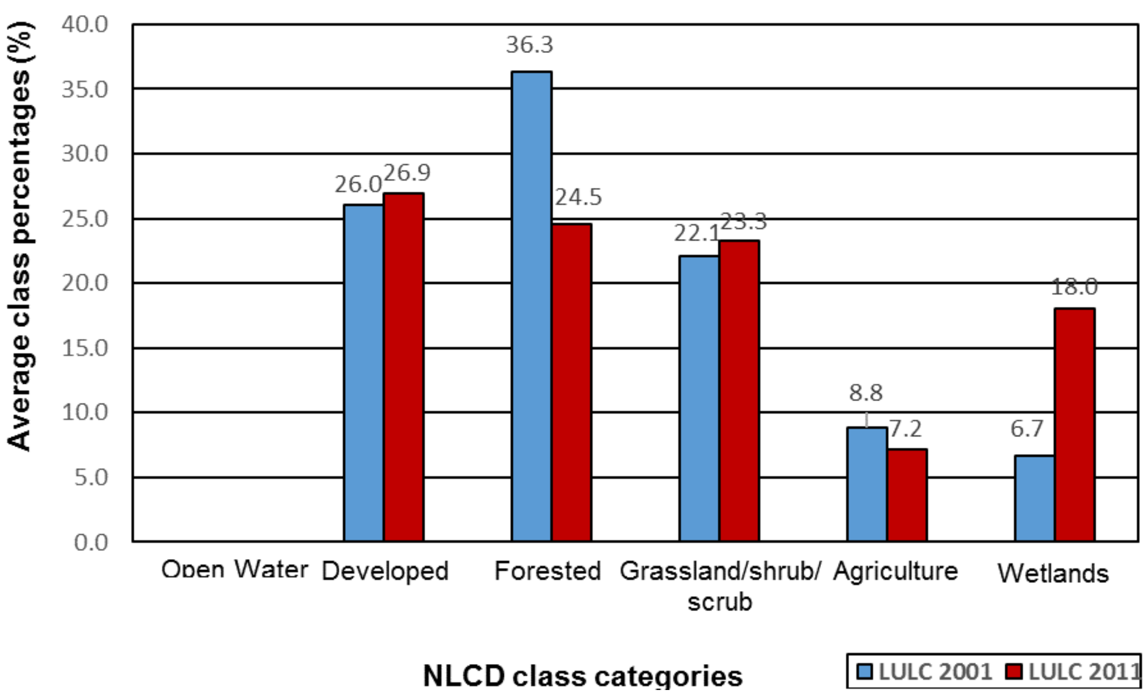

Figure 10.—Changes in average NLCD land use classes from 2001 to 2011 for site BS7.

The watershed upstream from site BS8 is located in the western portion of the study extent within the main agricultural area. It is almost entirely comprised of agricultural land (93.6 percent) (fig. 11). Agricultural land use decreased slightly by 1.1 percent from 2001 to 2011. Developed land (3.3 percent) is the second largest land use category for BS8 and remained constant over the past decade. Grassland/shrub/scrub increased by 0.9 percent, wetlands increased by 0.5 percent, and forested land decreased by 0.4 percent. There is no open water in the watershed.

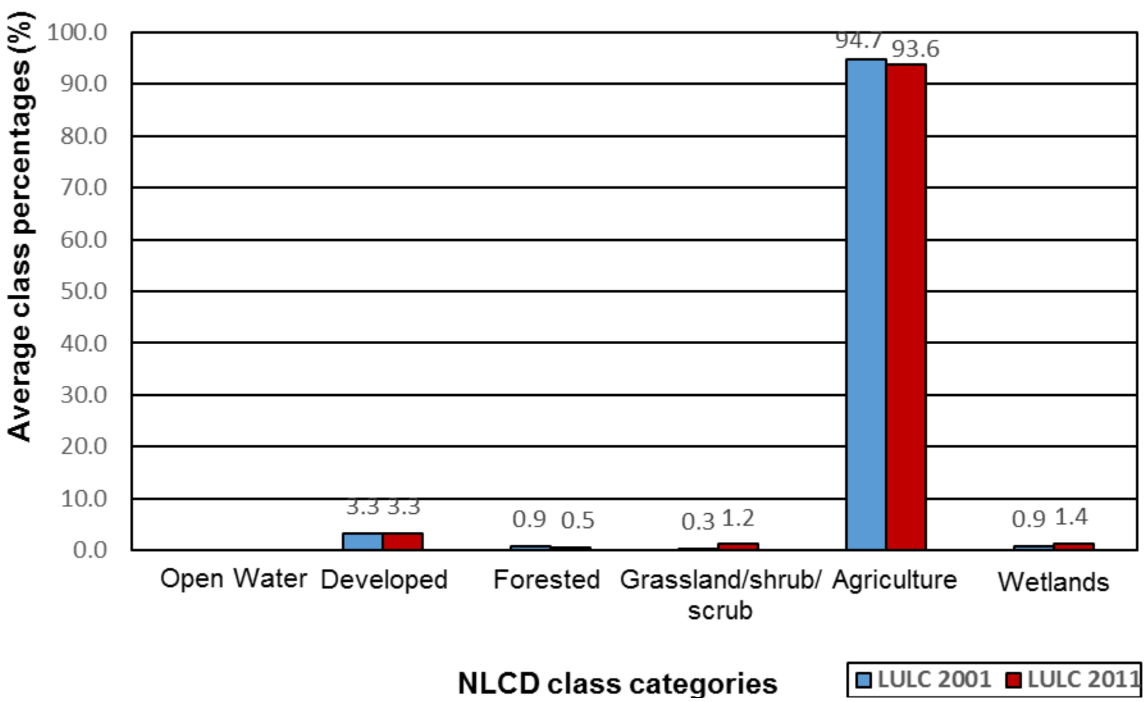

Figure 11.—Changes in average NLCD land use classes from 2001 to 2011 for site BS8.

The watershed upstream from site BS9 is located in the northeastern portion of the study extent. It is comprised mainly of developed land (54.6 percent) because it is located in the southern outskirts of the city of Foley where urban land use is prominent. There was a 26.7 percent increase in developed land use from 2001 to 2011 (fig. 12). Agriculture is the second largest land use category for BS9 and decreased by 18.7 percent. There were also small decreases in forested land (3.4 percent), grassland/shrub/scrub (3 percent), and wetlands (1.5 percent). Open water remained constant over the decade at 0.1 percent.

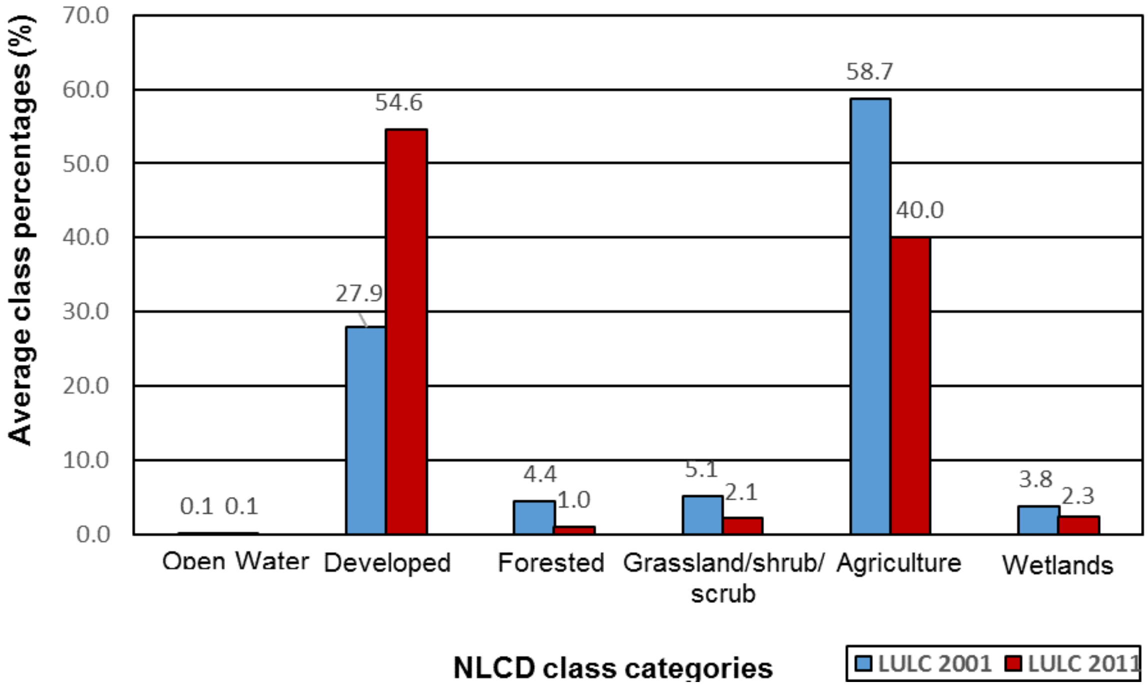

Figure 12.—Changes in average NLCD land use classes from 2001 to 2011 for site BS9.

STREAM-FLOW CONDITIONS

Precipitation, stream gradient, geology, and land use are all important factors that influence discharge, sediment transport, and water quality of streams. Water quality conditions in the Bon Secour watershed are segregated by particular stream segments based on instream conditions that are influenced by topography and soils, impervious surfaces, construction activities, and associated erosion prevention and runoff management efforts. Estimates of sediment loads are based on measured sediment and stream discharge. Stream discharge at sites BS1 and BS2 (unnamed tributaries) is intermittent and extremely flashy, resulting from the relatively small catchments and intensity of individual rainfall events. Discharge at sites BS0 (unnamed tributary), BS6 (Boggy Branch), and BS9 (unnamed tributary) originates as runoff from the city of Foley and is extremely flashy, characterized by minimal base flow due to expansive impervious surfaces, resulting in small discharge and low flow velocities (BS0 is intermittent) during dry periods and relatively large discharge and high velocities during storm events.

Site BS3 (Bon Secour River at Baldwin County Road 12) was outfitted with an Ott Orpheus Mini pressure transducer and data logger, which recorded water levels at 30 minute intervals from February 19, 2013 to May 22, 2014. Manual discharge measurements were made periodically and combined with water levels to produce a rating table for the site that was used to calculate average daily discharge. Site 3 discharge data, along with measured discharge and watershed drainage area upstream from each monitoring site were used to estimate average daily discharge for all monitored streams (table 2). Evaluation of discharge for each monitored watershed indicates that land use and size of areas covered by impervious surfaces are the major influences on volume and velocity of stream flow. With the exception of site BS3 (main stem of Bon Secour River), discharge for sites BS0, BS6, and BS9 have the largest discharge and when normalized with respect to drainage area (cubic feet per second per square mile (cfs/mi^2)of drainage area, these sites have more than three times higher discharge than any other monitored site (table 2). Site BS0, a concrete channelized stream with headwaters in downtown Foley, had an average stream-flow velocity of 7.8 feet per second (ft/s), which is more than twice that of any other monitored site (table 2).

Sediment transport conditions in the Bon Secour 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 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 3).

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

Table 3.—Measured stream flow characteristics for monitored sites in the Bon Secour River watershed.

Site	Average daily discharge (cfs)	Maximum average daily discharge (cfs)	Minimum average daily discharge (cfs)	Maximum flow velocity (ft/s)	Average daily runoff (cfs/mi^2)
BS0	25	467	0	7.8	14.5
BS1	1.4	37	0	3.4	1.6
BS2	1.0	33	0	3.5	1.7
BS3	41	572	6.8	0.9	4.7
BS4	1.8	25	0.3	1.2	1.0
BS5	2.6	47	0.5	1.9	3.3
BS6	24	470	0.2	0.8	10.4
BS7	1.8	25	0.3	1.0	3.6
BS8	9.6	135	1.6	1.3	3.3
BS9	29	572	0.2	1.5	13.8

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. Without human impact, erosion rates in the watersheds, called the geologic erosion rate, would be 64 t/mi^2/yr (Maidment, 1993). This value allows comparison of estimated sediment transport rates in monitored streams in the Bon Secour River watershed.

Land surface disturbance related to agriculture and urbanization are the primary causes of excessive erosion and sedimentation in the Bon Secour River watershed. The monitored watersheds are underlain by highly erodible soils formed from Citronelle Formation sediments. These soils combined flashy runoff from increasing areas of impervious surfaces and channelized routing of storm water, result in sediment transport in excess of baseline conditions (geologic erosion rate) in most streams in the Bon Secour watershed. 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.

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 a temporary GSA stream-flow monitoring station located on Bon Secour River at Baldwin County Road 12. Estimated suspended sediment loads for each monitored site are shown in table 4. Sites BS3, BS0, and 9 had the largest loads with 12,936, 6,592, and 1,321 tons per year (t/yr), respectively. Normalizing suspended loads with respect to unit watershed area permits comparison of monitored watersheds. Table 3 shows normalized suspended sediment loads, with sites BS0, BS3, and BS9 having the largest loads with 3,878, 1,470, and 629 tons per mi^2 per year ($t/mi^2/yr$), respectively.

Table 4.—Measured turbidity, total suspended solids (TSS), and estimated suspended sediment loads for monitored streams in the Bon Secour River watershed.

Site no.	Average turbidity (NTU)	Maximum turbidity (NTU)	Average TSS (mg/L)	Maximu m TSS (mg/L)	Estimated suspended sediment load (t/yr)	Estimated normalized suspended sediment load ($t/mi^2/yr$)
BS0	194	725	108	494	6,592	3,878
BS1	102	318	18	32	15	17
BS2	94	300	40	221	67	112
BS3	162	615	101	308	12,936	1,470
BS4	134	441	134	192	22	12
BS5	162	555	45	120	77	97
BS6	88	291	14	50	47	127
BS7	113	220	58	109	11	21
BS8	249	498	198	400	831	287
BS9	258	720	48	115	1,321	629

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 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. 13) (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. However, bed sediment is of minimal importance in the monitored watersheds as all monitored sites except BS3 and BS4 are characterized by stream channelization and discharge conditions that cause sediment to be suspended and therefore the total sediment loads for these sites are included previously as suspended loads (table 4).

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 5 gives average daily discharge, maximum stream-flow velocity, annual bed sediment loads, and normalized annual bed sediment loads for sites BS3 and BS4. Sites BS3 and BS4 had estimated bed sediment loads of 539 and 276 tons per year (t/yr), respectively. After normalization of bed sediment loads, sites BS3 and BS4 had loads of 61 and 153 t/mi ^{2}/yr, respectively.


Figure 13.—Bed sediment measured in Bon Secour River site BS3.

Table 5.—Measured discharge, stream-flow velocity, and estimated bed sediment loads for monitoring sites on selected streams in the project area.

Site no.	Average daily discharge (cfs)	Maximum stream-flow velocity (ft/s)	Estimated annual bed sediment loads (t/yr)	Estimated Normalized annual bed sediment loads ($t/mi^2/yr$)
BS3	41	0.9	539	61
BS4	1.8	1.2	276	153

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 6.

Table 6.—Total estimated sediment loads for monitored streams.

Monitored site	Estimated geologic erosion rate total sediment load (t/yr)	Estimated total annual sediment load (t/yr)	Estimated normalized total annual sediment load (t/mi ^{2}/yr)	Estimated normalized total annual sediment load (cubic yards/yr)
0	109	6,592	3,878	12,207
1	58	15	17	28
2	38	67	112	124
3	563	13,475	1,531	24,953
4	115	296	165	548
5	51	77	97	143
6	147	47	127	87
7	32	11	21	20
8	186	831	287	1,539
9	134	1,321	629	2,446

The largest total annual sediment load (13,475 t/yr) was estimated for site BS3 (table 6). This is not surprising since site BS3 (main stem Bon Secour River) has the largest drainage area and represents the cumulative load for streams monitored at sites BS0, BS3, and BS8.

The largest total sediment load for a tributary was site BS0 (unnamed tributary with headwaters in downtown Foley) with 6,592 t/yr. When the data are normalized, allowing comparison of sediment loads with respect to unit drainage areas, site BS0 had the largest load (3,878 t/mi^2/yr) (table 6). Table 6 also shows total sediment loads for each of the monitored stream segments in cubic yards per year.

When normalized total sediment loads are compared with land use trends for each of the monitored watersheds, causes of excessive erosion and sediment transport become apparent. Excluding site BS3, which shows cumulative loads from multiple tributaries, watersheds with the two largest sediment loads (BS0 and BS9) had the largest area of developed land. The third largest load (BS8) was dominated by agricultural land use, which was primarily turf farming. Other watersheds (sites BS4, BS5, and BS6) with dominant agricultural land use (row crop) had relatively small sediment loads (tables 2, 6).

Comparisons of sediment loads from other watersheds are helpful in determining the severity of erosion problems in a watershed of interest. Figure 14 shows that land use is a dominant factor in erosion and sediment loading in streams. Estimates of sediment loads from 30 streams throughout Alabama shown in figure 14 indicate that streams with the largest sediment loads estimated in the Bon Secour River watershed

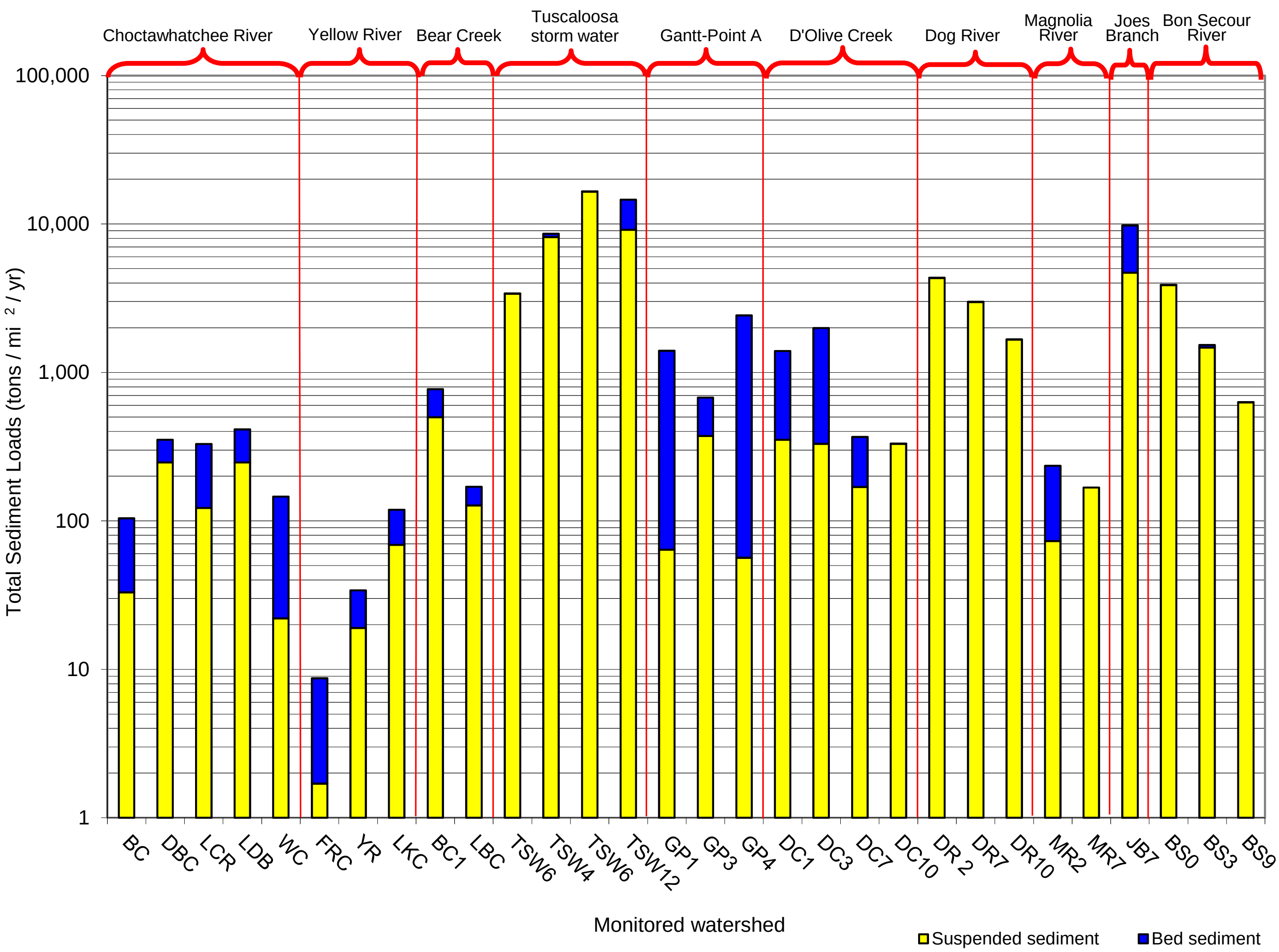

Figure 14.—Estimates of sediment loads from 30 streams throughout Alabama.

are comparable to other urban and transitional urban watersheds in Baldwin and Mobile Counties (D'Olive Creek, Dog River, and Joes Branch) (Cook and others, 2002) and city of Tuscaloosa watersheds in the west-central part of the state (Cook, 2005). Watersheds with land use that results in smaller sediment loads includes the

Choctawhatchee River, Bear Creek, and Magnolia River, which is dominated by agriculture, Gantt-Point A Reservoir tributaries on the Conecuh River where sediment loads are influenced by unpaved roads, and Yellow River, which is forested.

NUTRIENTS

Excessive nutrient enrichment is a major cause of water-quality impairment. Excessive concentrations of nutrients, primarily nitrogen and phosphorus, in the aquatic environment may lead to increased biological activity, increased algal growth, decreased dissolved oxygen concentrations at times, and decreased numbers of species (Mays, 1996). Nutrient-impaired waters are characterized by numerous problems related to growth of algae, other aquatic vegetation, and associated bacterial strains. Blooms of algae and associated bacteria can cause taste and odor problems in drinking water and decrease oxygen concentrations to eutrophic levels. Toxins also can be produced during blooms of particular algal species. Nutrient-impaired water can dramatically increase treatment costs required to meet drinking water standards. Nutrients discussed in this report are nitrate (NO_3-N) and phosphorus (P-total).

NITRATE

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

Six sites were sampled for nitrate in the Bon Secour watershed between November 2013 and January 2014 (fig.15). All sites were sampled during or immediately after a precipitation event resulting in elevated stream discharges. Five sites show elevated nitrate levels above the 0.5 mg/L standard with site BS4, sampled on November 1, 2013 the highest at 2.59 mg/L (fig.15). This may be expected, since 80 percent of the land is used for agriculture. Site SB6, sampled on January 13, 2014, had the lowest, with a nitrate level of 0.115 mg/L (fig.15).

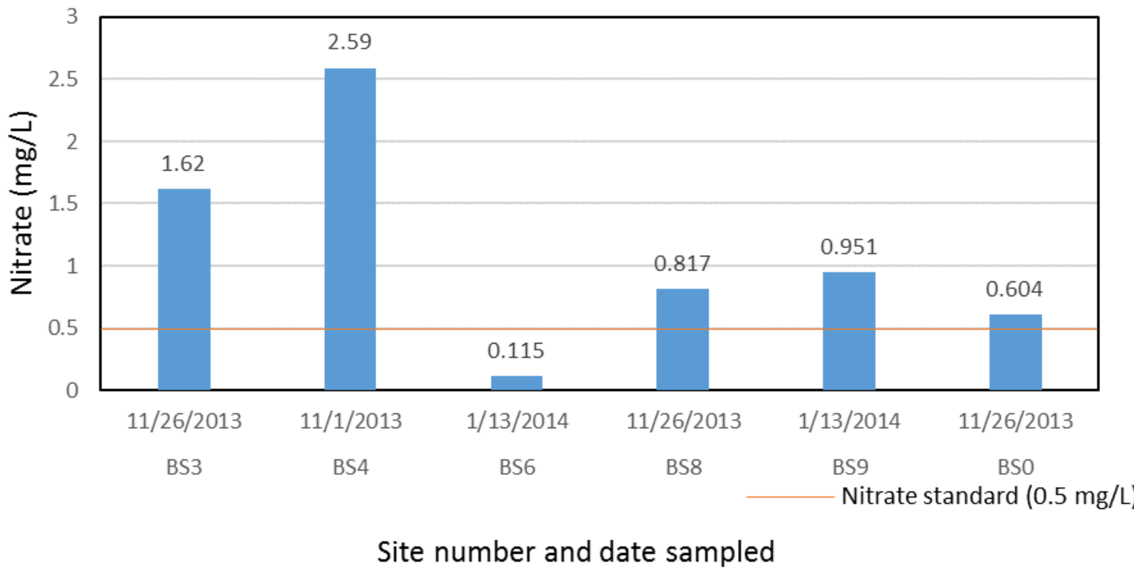

Figure 15.—Nitrate concentrations at selected sites in the Bon Secour watershed.

PHOSPHORUS

Phosphorus in streams originates from the mineralization of phosphates from soil and rocks or runoff and effluent containing fertilizer or other industrial products. The principal components of the phosphorus cycle involve organic phosphorus and inorganic phosphorus in the form of orthophosphate (PO_4) (Maidment, 1993). Orthophosphate is soluble and is the only biologically available form of phosphorus. Since phosphorus strongly associates with solid particles and is a significant part of organic material, sediments influence water column concentrations and are an important component of the phosphorus cycle in streams.

The natural background concentration of total dissolved phosphorus is approximately 0.025 mg/L. Phosphorus concentrations as low as 0.005 to 0.01 mg/L may cause algae growth, but the critical level of phosphorus necessary for excessive algae is around 0.05 mg/L (Maidment, 1993). Although no official water-quality criterion for phosphorus has been established in the United States, phosphorus should not exceed 0.05 mg/L in any stream or 0.025 mg/L within a lake or reservoir in order to prevent the development of biological nuisances (Maidment, 1993). In many streams phosphorus is the primary nutrient that influences excessive biological activity. These streams are termed “phosphorus limited.”

Six sites were sampled for phosphorus in the Bon Secour watershed between November 2013 and January 2014 (fig.16). All sites were sampled during or immediately after a precipitation event resulting in elevated stream discharges. Five sites show elevated phosphorus levels above the 0.05 mg/L standard with site BS8, sampled on November 26, 2013 the highest at 0.699 mg/L (fig.16). Site BS4 sampled on November 1, 2013, was the lowest with a phosphorus level of 0.043 mg/L (fig.16).

METALLIC CONSTITUENTS

The USEPA compiled national recommended water quality criteria for the protection of aquatic life and human health in surface water for approximately 150 pollutants. These criteria are published pursuant to Section 304(a) of the Clean Water Act (CWA) and provide guidance for states and tribes to use in adopting water quality standards (USEPA, 2009). The criteria were developed for acute (short-term exposure) and chronic (long-term exposure) concentrations. Table 7 shows selected metals and their measured and recommended acute and chronic maximum concentrations.

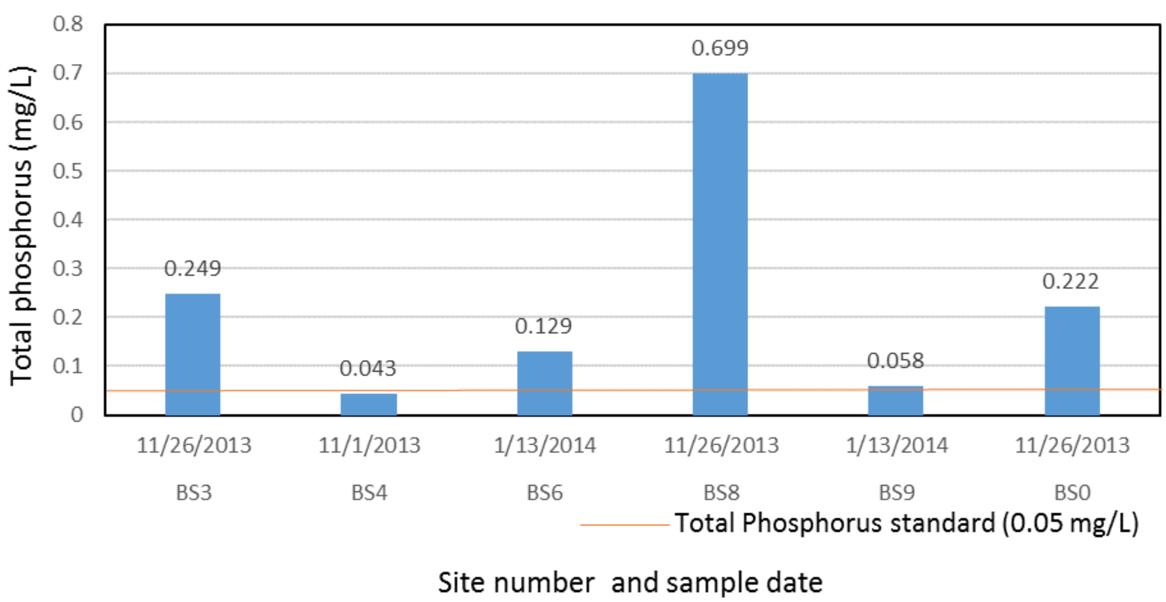

Figure 16.—Phosphorus concentrations at selected sites in the Bon Secour watershed.

Numerous metals are naturally present in streams in small concentrations. However, toxic metals in streams are generally anthropogenic in origin. Water samples collected from sites BS0, BS3, BS4, BS6, BS8, and BS9 were analyzed for selected metallic constituents. Table 7 compares concentrations of samples collected with the USEPA recommended criteria for protection of aquatic life. The acute protection standard was exceeded in three samples: aluminum at site BS8, copper at site BS9, and zinc at site BS3. Elevated concentrations of aluminum are common in Alabama streams and is related to erosion of clays that naturally contain high concentrations of aluminum. The chronic standard for aluminum was exceeded at all sites except site BS9 and the chronic standard for lead was exceeded at all sites except sites BS6 and BS9. The only other chronic standard exceeded was for zinc at site BS3. In addition to aluminum, lead, copper and zinc, other metals detected in the streams included arsenic, chromium, iron, mercury, nickel, and selenium (table 7). Iron occurs commonly in Alabama streams. However, although in small concentrations, arsenic, chromium, mercury, nickel, and selenium are probably related to industrial components of urban runoff.

Although not included in USEPA criteria, barium, manganese, and magnesium were also detected in water samples collected at all sites. These constituents are common in Alabama streams and are a result of dissolution or erosion of rocks and sediment.

Although not a metallic constituent, pH is included in table 7 due to its importance in the occurrence and solubility of metals. Concentrations of hydrogen ions control speciation of other constituents, influence dissolution and precipitation of chemical elements, and determine whether the water will support aquatic life. Aquatic organisms are sensitive to pH change and require a pH of 6.5 to 9. pH in study area streams was consistently low at all sites and below the USEPA chronic standard criteria in most instances.

Another nonmetallic constituent detected in collected water samples is boron. Although no water quality criteria for boron has been established, concentrations as small as 1 mg/L may be toxic to plant life (Hem, 1985). Boron is naturally associated with igneous rocks and is present in active volcanic areas. In areas without a natural

Table 7.—Concentrations of metallic constituents detected in water samples at selected monitoring sites in the Bon Secour project area.

Metallic constituent	USEPA standards for protection of aquatic life (µg/L[a])		Concentrations (µg/L)					
	Acute	Chronic	BS0	BS3	BS4	BS6	BS8	BS9
Aluminum	750	87	95	104	341	160	1590	86
Arsenic	340	150	0.6	1.13	0.52	0.48	12.6	0.68
Cadmium	2	0.3	BDL [b]	BDL	BDL	BDL	BDL	BDL
Chromium (Cr_3) [c]	570	74	1.72	0.98	BDL	4.62	2.39	1.76
Copper	4.7	n/a	BDL	BDL	BDL	BDL	BDL	9
Cyanide	22	5.2	BDL	BDL	BDL	BDL	BDL	BDL
Iron	n/a	1,000	52.2	662	296	81.4	492	221
Lead	65	2.5	4.9	3.5	4.5	2.1	2.6	2.4
Mercury	1.4	0.8	0.02	0.07	BDL	0.01	BDL	0.02
Nickel	470	52	29	BDL	BDL	BDL	12	BDL
Selenium	n/a	5	BDL	1.8	BDL	BDL	2.1	BDL
Silver	3.2	n/a	BDL	BDL	BDL	BDL	BDL	BDL
Zinc	120	120	90.3	272	18.3	26.8	90	37.2
	pH range		pH range					
pH	n/a	6.5-9.0	5.3-6.7	5.6-6.8	5.3-6.7	5.3-6.3	5.6-6.4	5.1-6.5

[a] µg/L = micrograms per liter.
[b] BDL = below detection limit.
[c] Chromium reported as total chromium and is assumed to be primarily Cr_3.

source, it may originate from cleaning wastes and may be present in sewage and industrial wastes (Hem, 1985). Boron was detected in each sample collected at all sites. The largest concentration (49 µg/L) was detected at site BS8.

ORGANIC CONSTITUENTS

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

Total organic carbon (TOC) analysis is a well-defined and commonly used methodology that measures the carbon content of dissolved and particulate organic matter present in water. Many water utilities monitor TOC to determine raw water quality or to evaluate the effectiveness of processes designed to remove organic carbon. Some wastewater utilities also employ TOC analysis to monitor the efficiency of the treatment process. In addition to these uses for TOC monitoring, measuring changes in TOC concentrations can be an effective surrogate for detecting contamination from organic compounds (e.g., petrochemicals, solvents, pesticides). Thus, while TOC analysis does not give specific information about the nature of the threat, identifying changes in TOC can be a good indicator of potential threats to a hydrologic system (USEPA, 2005). Typical TOC values for natural waters vary from 1 to 10 mg/L (Mays, 1996). TOC concentrations from water samples collected from study area sites all fall within typical values for natural waters (table 8).

Table 8.—Measured TOC concentrations at selected sites.

Monitoring sites	Total Organic Carbon (mg/L)
BS0	5.0
BS3	6.3
BS4	3.9
BS6	3.8
BS8	9.7
BS9	2.8

Phenols are used in the production of phenolic resins, germicides, herbicides, fungicides, pharmaceuticals, dyes, plastics, and explosives (Bevans, 1998). Phenols may occur in domestic and industrial wastewaters, natural waters, and potable water supplies. The USEPA has set its water quality criteria, which states that phenols should be limited to 10,400 µg/L (micrograms per liter) (10.4 mg/L) in lakes and streams to protect humans from the possible harmful effects of exposure (USEPA, 2009). Phenols cause acute and chronic toxicity to freshwater aquatic life. Study area streams were found to have no phenols above the laboratory minimum detection level of 3 µg/L.

Concentrations of oil and grease were determined for water samples collected from selected sites. Oil and grease includes fatty matter from animal and vegetable

Table 9.—Measured Oil and Grease concentrations at selected sites.

Monitoring sites	Oil and grease (mg/L)
BS0	BDL
BS3	BDL
BS4	7.4
BS6	BDL
BS8	BDL
BS9	BDL

sources and from hydrocarbons of petroleum origin. Site BS4 had an oil and grease concentration of 7.4 mg/L, while all other sites were found to have no concentrations greater than the minimum detection level of 5 mg/L (table 9).

SUMMARY

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.

The Bon Secour Sedimentation Assessment project area is approximately 58 square miles. Monitoring sites were established in 10 watersheds, varying in size from approximately 0.5 to 8.8 mi^2. Land use in the project area was subdivided into six classified groups defined as developed, forested, agricultural, grassland/shrub/scrub, wetlands, and open water. Land use for the years 2001 and 2011 were classified to permit comparisons to determine land use change in the watershed. Significant changes were observed in the “developed” category, which increased by 7.8 percent and the agriculture category which, decreased by 7.6 percent. Urban contributions of contaminants to surface-water bodies is normally significant. Monitor sites BS0 and BS9 were established to evaluate runoff from the city of Foley. The watersheds upstream from sites BS0 and BS9 are comprised mainly of urban and residential land, with 66 percent and 54.6 percent, respectively in the developed classification. There was a 26.7

percent increase in developed land use in the watershed upstream from site BS9 between 2001 and 2011.

Precipitation, stream gradient, geology, and land use are all important factors that influence discharge, sediment transport, and water quality of streams. Site BS3 (Bon Secour River at Baldwin County Road 12) was outfitted with an Ott Orpheus Mini pressure transducer and data logger, which recorded water levels at 30 minute intervals from February 19, 2013, to May 22, 2014. Manual discharge measurements were made periodically and combined with water levels to produce a rating table for the site that was used to calculate average daily discharge. Site 3 discharge data, along with measured discharge and watershed drainage area upstream from each monitoring site were used to estimate average daily discharge for all monitored streams. Evaluation of discharge for each monitored watershed indicates that land use and size of areas covered by impervious surfaces are the major influences on volume and velocity of stream flow. With the exception of site BS3 (main stem of Bon Secour River), discharge for sites BS0, BS6, and BS9 have the largest discharge and when normalized with respect to drainage area (cfs/mi^2), these sites have more than three times higher discharge than any other monitored site. 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). Sites BS3, BS0, and BS9 had the largest loads with 12,936, 6,592, and 1,321 t/yr, respectively. Normalizing suspended loads with respect to unit watershed area permits comparison of monitored watersheds. Normalizing suspended sediment loads shows that sites BS0, BS3, and BS9 have the largest loads with 3,878, 1,470, and 629 t/mi^2/yr.

Sites BS3 and BS4 were the only sites with measurable bed sediment. All other sites had stream beds that caused most sediment to be suspended so that total loads for those sites is included in the suspended loads. Sites BS3 and BS4 had estimated bed sediment loads of 539 and 276 t/yr, respectively. After normalization of bed sediment loads, sites BS3 and BS4 had loads of 61 and 153 t/mi^2/yr, respectively. The largest total annual sediment load (13,475 t/yr) was estimated for site BS3, which was expected since this site was on the main channel of Bon Secour River. When normalized total sediment loads are compared with land use trends for each of the monitored watersheds, causes of excessive erosion and sediment transport become apparent. Excluding site BS3, which shows cumulative loads from multiple tributaries, watersheds with the two largest sediment loads (BS0 and BS9) had the largest area of developed land. The third largest load (BS8) was dominated by agricultural land use, which was primarily turf farming. 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 30 streams throughout Alabama indicate that streams with the largest sediment loads estimated in the Bon Secour River watershed are comparable to other urban and transitional urban watersheds in Baldwin and Mobile Counties (D'Olive Creek, Dog River, and Joes Branch) and in the city of Tuscaloosa in the west-central part of the state.

Six sites were sampled for nitrate in the Bon Secour watershed between November 2013 and January 2014. All sites were sampled during or immediately after a precipitation event resulting in elevated stream discharges. Five sites show elevated nitrate levels above the 0.5 mg/L standard with site BS4, sampled on November 1, 2013 the highest at 2.59 mg/L. This may be expected, since 80 percent of the land is used for agriculture.

Six sites were sampled for phosphorus in the Bon Secour watershed between November 2013 and January 2014. All sites were sampled during or immediately after a precipitation event resulting in elevated stream discharges. Five sites show elevated phosphorus levels above the 0.05 mg/L standard with site BS8, sampled on November 26, 2013 the highest at 0.699 mg/L. The dominant land use (about 94 percent) for the watershed upstream from site BS8 is agriculture.

Numerous metals are naturally present in streams in small concentrations. However, toxic metals in streams are generally anthropogenic in origin. Water samples collected from sites BS0, BS3, BS4, BS6, BS8, and BS9 were analyzed for selected metallic constituents and compared to the USEPA recommended criteria for protection of aquatic life. The acute protection standard was exceeded in three samples: aluminum at site BS8, copper at site BS9, and zinc at site BS3. Elevated concentrations of aluminum are common in Alabama streams and are related to erosion of clays that naturally contain high concentrations of aluminum. The chronic standard for aluminum was exceeded at all sites except site BS9 and the chronic standard for lead was exceeded at all sites except sites BS6 and BS9. The only other chronic standard exceeded was for zinc at site BS3. In addition to aluminum, lead, copper and zinc, other metals detected in monitored streams included arsenic, chromium, iron, mercury, nickel, and selenium. Iron occurs commonly in Alabama streams. However, although in small concentrations, arsenic, chromium, mercury, nickel, and selenium are probably related to industrial components of urban runoff.

Previous surface-water quality assessments performed by the Geological Survey of Alabama have determined that urban runoff has the most deleterious impacts on streams and habitats. During this assessment, the quality of water in Bon Secour River and a number of its tributaries was found to be profoundly influenced by agricultural and urban land uses. Without intervention, as more agricultural, forested and wetland areas are converted to residential and urban land uses, water quality and biological habitats will continue to degrade. Implementation of best management practices designed to prevent erosion from cleared lands and to slow and treat urban runoff can slow and reverse negative water-quality impacts and restore habitats in the Bon Secour River watershed and Mobile Bay that provide the quality of life enjoyed by area residents.

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