The Yalobusha River–Grenada Reservoir Watershed: Sediment Movement, Accumulation and Quality in a Mississippi Intensive Agricultural Landscape

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We examined sedimentation rates, current watershed contamination contributions and potential impacts of long-term row cropping (cotton, corn, soybeans, and sweet potato) on a small river and a large downstream flood control reservoir in the loess hills of Mississippi, USA. Grenada Reservoir (impounded in 1954) has a total watershed drainage area of ~3,419 square kilometers. Although reservoir life expectancy was originally estimated at 25 years because of high erosion rates in the watershed, our study revealed that the reservoir continues to function with only slightly reduced storage capacity. Sediment delivery to the reservoir by the Yalobusha River at the most downstream measured site from 1996 to 2002, averaged 126 mg/L (range 12 to 767 mg/L, S.D.=136). Long-term sediment accumulation within the permanent pool adjacent to the dam was <1cm yr-1 except for a depositional area near tributary inflow that accumulated sediment at about 5 cm yr-1. The central area of the permanent pool experienced sediment accumulation rates that averaged <1.5 cm yr-1. Sites within the two reservoir arms fed by the two river inflows (Yalobusha and Skuna rivers) showed little or no sedimentation. Sedimentation rates near the two river inflows were also generally low. A large debris jam which formed a river plug southwest of Calhoun City accumulated sediment from the upper portion of the watershed. From 1996 to 2004 analyses were conducted in water and sediment for 8 metals and 48 pesticides/contaminants at 26 stream/river locations and 9 locations within the reservoir. In spite of long-term historical use of residual pesticides in the watershed and widespread use of currently applied agricultural compounds, concentrations in stream or reservoir sediments and overlying water were generally low and sporadic or below detection. Conversely, several metals (arsenic, lead, copper, iron, aluminum and zinc) were abundant in stream and reservoir sediments. Atrazine, a widely used triazine herbicide, was routinely found in stream water and sediment. Atrazine was also detected in reservoir water samples but at only one fifth of contributing stream concentrations. Naturally-occurring aluminum and iron were found in high concentrations. Residual pesticides were generally not detected in water but were detected in stream and reservoir sediments. Sediments within the debris jam contained concentrations of arsenic and mercury lower than watershed and reservoir locations. Debris jam sediments also held highest observed concentrations of beta-BHC but did not contain detectable amounts of several legacy pesticides that were found in both the watershed and reservoir samples. A dredged channel through the debris jam was completed in late 2003. It may affect future sediment and contaminant accumulation in the natural river channel, its floodplain, and Grenada Reservoir. Because of processes associated with transitioning from a channelized stream to a natural one, it is likely that the plug phenomenon will reoccur.

Keywords: Agriculture; contamination; sedimentation; pesticides; non-point source pollution

Introduction

The upper Yalobusha River watershed and Grenada Reservoir flood-control lake are located in north central Mississippi, USA. Flow within the watershed originates near Houston, MS, and is from east to west, with controlled outflow from the reservoir into the Yalobusha River channel below the dam just northeast of Grenada. Flow ultimately joins the Mississippi River along the western border of Mississippi via the Yazoo River that drains most of the northwestern region of the State. The reservoir was impounded in 1954. Total watershed drainage area entering Grenada Reservoir from two rivers (the upper Yalobusha to the south, and the Skuna to the north) and other direct tributaries is approximately 3,419 square kilometers. The contributing watershed associated with the upper Yalobusha River has a floodplain area of intensive agriculture, including large-scale production of sweet potatoes [Ipomoea batatus (L.) Lam.] rotated with cotton (Gossypium hirsutum L.), soybeans [Glycine max (L.) Merr.] and corn (Zea mays L.) centered around the towns of Calhoun City and Vardaman.

Channelization projects and associated channel incision that began in the early 1900s have impacted the entire study watershed. With the exception of approximately 21 km (13 miles) in the Yalobusha River upstream of Grenada Reservoir, all of the river and major tributaries of the watershed have been channelized. Original channelization projects were conducted during the 1910s and 1920s, and additional works were conducted in the late 1930s to 1950s when the Yalobusha River and Topashaw Creek, the major river tributary, became plugged with debris and sediment. Late in the 1960s the U.S. Department of Agriculture Soil Conservation Service began a major series of watershed modifications above the reservoir, including extensive clearing and dredging of many channels and installation of numerous gully erosion control structures. Also during the 1960s some dredging was done in the upper reservoir, but the extent is unknown. A major cycle of channel incision, a response to previous channelization efforts, is currently migrating up watershed streams (Simon and Thomas 2002).

During the 1980s, an occlusive debris jam formed in the Yalobusha River upstream of the non-channelized portion of the river east of the reservoir. This debris jam, in excess of 2 km long and formed from eroded upstream materials, forced river flow into adjacent riparian floodplain bottomland forest and, occasionally, agricultural fields and homes. The US Army Corps of Engineers, under direction from Congress, is currently addressing this and other problems in the watershed through a system-wide approach. Tributary stabilization projects and downstream river stabilization and debris jam clearing have already been enacted. Following completion of these works, the Yalobusha River watershed is expected to become more stable over the next several decades, and movement of sediment and associated contaminants from field soil, urban areas, and streambeds should be minimized. In order to allow for future comparisons, we herein assess the sediment quality and quantity moving in the upper Yalobusha River watershed and Grenada Reservoir. This publication provides additional information and updates a previous publication by these authors (Cooper et al. 2002).

Methods

Sample collection and storage were done according to suggested American Public Health Association (APHA) methods (Greenberg et al. 1992). Suspended sediment load grab samples from the stream thalweg were collected from 13 sites on at least one hundred and two dates between October 1996 and December 2001. Values were quantified at the USDA National Sedimentation Laboratory as the difference between total solids and total dissolved solids dried at 103 – 105 degrees Celsius.

Metal and pesticide/PCB samples were collected from overlying water and bottom sediment into properly cleaned and solvent-rinsed glass sample containers according to APHA methods (but not EPA trace element methods). Analyses included concentration determinations for up to 8 metals and 48 pesticide/PCB contaminants likely to occur, given the historical and current land use (Tables 3, 4, & 5). Not all samples were tested for each analyte due to changing emphasis and resource availability.

Samples from 26 stream/river locations within the Yalobusha River watershed were taken around November 1 during 1996, 1997 and 1999 from mid water-column and the upper 10 cm of bottom sediments. Additional water column samples were taken from up to 14 of these sites on twenty-seven dates between July 1997 and April 2004. Added bottom sediment samples were taken from up to eight of the sites on nine dates ending in November 2003.

Sediment samples from Grenada Reservoir were taken at 9 locations between December 1998 and May 1999. Nearby samples were taken again at seven of these sites in November 1999, and at five of these sites in December 2002 (some sites were inaccessible because of low water). At each site, sediment cores were taken with manual coring equipment from an anchored boat. Ten-centimeter-diameter sediment cores were driven, lifted into a clean semi-tubular ruled trough, and divided into incremental 10-cm sections by depth from sediment surface for metals, pesticides, contaminants and cesium-dating analyses. One kg of sediment from each 10-cm depth increment was acquired for cesium dating that was conducted at the USDA Hydrology and Remote Sensing Laboratory. Surface sediments at seven of these sites were sampled again in November 1999. Concomitant with sediment sampling in the reservoir, water samples from mid water-column were collected for metals, pesticides and contaminants analyses.

Sediment samples from within the debris jam occluding the Yalobusha River upstream of the reservoir were collected from four transects spaced along the length of the jam on March 22, 2001, and from six additional locations on July 8, 2003. A 5-cm diameter stainless steel hand corer was used to collect samples At each transect, sediment to a maximum depth of 0.3 m was collected at three evenly spaced locations across the width of the channel and composited into a single sample. Woody and other (anthropogenic) debris within the jam prevented collection of deeper sediments. Relative location of all sampling sites is shown in Figure 1.

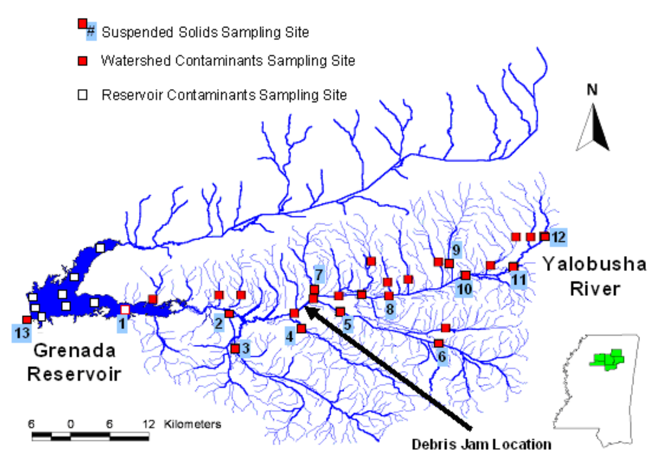

Figure 1. Grenada Reservoir drainage system, including Grenada Reservoir, Yalobusha River Watershed (South) and Skuna River Watershed (North), with sampling locations indicated by rectangles, and suspended solids collections sites by number (#).

Table 1. Methods used and method detection limits (MDL) for quantifying metal concentrations during this study. Information for pesticides is given in the text.

Analyte	Method	MDL ($\mu g\ L^{-1}$ or $\mu g\ kg^{-1}$)
Mercury	EPA 245.1	0.1
Arsenic	EPA 206.2	1
Copper	EPA 200.7	3
Chromium	EPA 200.7	2
Lead	EPA 200.7	15
Zinc	EPA 200.7	3
Aluminum	EPA 200.7	60
Iron	EPA 200.7	2

Analyses for some pesticides were conducted in part (Table 5) at the USDA-ARS National Sedimentation Laboratory using gas chromatographic methods (Bennett et al. 2000) with both method detection and level of quantification limits equal to or less than 0.1 μg kg-1. Other analytes, including a 25 priority pollutant scan and all metals, were quantified at the University of Louisiana Monroe Soil-Plant Analysis Laboratory using ASTM and USEPA approved methods. Priority pollutants in water and sediment were tested according to EPA method SW 846:8140 with a detection limit of 1 μg kg-1. Methods and detection limits for metals analyses were as indicated in Table 1.

Results and Discussion

Suspended Sediment

The overall mean concentration of total suspended solids (TSS) in the Yalobusha River watershed, including all thirteen sites we monitored on the Yalobusha River, its tributaries, and including the reservoir spillway outlet, was 80 mg/L. The overall standard deviation for the thirteen sites was 146, with an overall standard error of 3.73. The median value for all TSS data was 42 mg/L.

Mean concentrations for each site are given in Table 2. Unweighted overall average maximum concentration for all sites was 1061 mg/L, with maxima of about 1500 mg/L for three sites (tributary sites 6 and 3, and river site 10). These concentrations were associated with major storm events. Individual maximum concentrations at the other ten sites were mostly below 1000 mg/L. Individual site minima of zero were observed for nine sites. Seasonal averages for all sites showed summer (62 mg/L), and fall (65 mg/L) to have almost identical concentrations as expected. Winter, with minimum ground cover and maximum rainfall, had higher suspended sediment concentrations (95 mg/L), followed by spring (87 mg/L).

Table 2. Mean concentration of total suspended solids (TSS) observed at 13 sites within the Yalobusha River and Grenada Reservoir Watershed and its outflow, years 1996-2001. (note: asterisk * denotes site downstream of debris jam; caret ^ indicates site influenced seasonally by Grenada Reservoir inundation.)

Site Name	Location	Mean TSS ($mg\ L^{-1}$)
12	Tributary of River	104
9	Tributary of River	53
6	Tributary of River	76
5	Tributary of River	48
4	Tributary of River	50
7	Tributary of River	60
3	Tributary of River	84
11	Yalobusha River	127
10	Yalobusha River	105
8	Yalobusha River	69
2	Yalobusha River *	134
1	Yalobusha River ^	84
13	Grenada Reservoir Outlet	57

Tributary sites had an unweighted average concentration of 68 mg/L, while riverine sites were higher, at 104 mg/L. The reservoir outlet channel mean concentration of suspended solids was 57 mg/L, and three of seven tributary sites had a lower mean concentration for our study period. Site 4 on Shutispear Creek, potentially the least channelized of all the Yalobusha River tributaries, had not only one of the lowest mean TSS concentrations at 50 mg/L but also a standard error of only 7 mg/L.

Mean TSS concentrations exceeded 100 mg/L for only four sites; three being the uppermost of our sampling sites in the watershed (sites 12, 11, and 10) and the lowermost true riverine site, (site 2). Lower observed mean concentrations in the intervening sites are likely due to sediment storage occurring upstream of the debris jam. Once past the impounding influence of the debris jam, the TSS concentration in the river channel was again elevated as erosive tributaries (including Lickup, Savannah and Sabougla Creeks) entered the river.

The capacity for up-stream storage occurring in the region above the debris jam, and its potential for remobilization, has recently been studied by Bennett et al. (2005). Their estimates indicate that only about 16% of eroded upstream sediments are stored in Grenada Reservoir, and 8% or less are exported from the reservoir. With an estimated 76% or more of sediments eroded from the upper Yalobusha River tributaries and the river channel (an estimated 10 million tons or more) still stored above the reservoir, contaminants harbored in that sediment are a concern. Not only does sediment accumulate upstream of the debris jam, observations revealed that large amounts of sediment are deposited in the river floodplain where the jam causes high flows to overtop spoil levees.

Bennett et al. (2005) also used multiple methods to estimate point sedimentation rates at several locations within Grenada Reservoir, finding values in general agreement to those obtained earlier by the present authors (Cooper et al. 2002), and from which they calculated that the reservoir has lost only about 3% of its storage capacity during the 50 years it has been in service. During this time, they (Bennett et al. 2005) estimate that 0.036 km^3 of sediment have been impounded with the reservoir.

Metals

Metal concentrations in water samples were often an order of magnitude or even less than concentrations in sediments. Mean water and sediment concentrations for metals in the study area are given in Table 3. Mercury was detectable in watershed water with only 12% frequency, and reservoir water at a 24% frequency; detected concentrations were predominately quite low. This resulted in very low mean concentrations of mercury for both the watershed and reservoir sites. Mean surface water concentrations of other metals of potential concern were near their minimum detection levels, and only iron and aluminum (both elements that naturally occur in high concentration in soils of the watershed) were observed at elevated levels in the water. None of the metals concentrations listed in water exceeded EPA drinking water standards.

Analyses for metal concentrations in sediments revealed moderate arsenic and mercury concentrations. Reservoir mean sediment concentrations of mercury and zinc were somewhat elevated over other watershed levels. Again, iron and aluminum were abundant.

Pesticides

Pesticides were detected in stream water samples at only a 13% frequency (652 of 5,027 potential detections) which was comparable to metal occurrence. Of the 25 priority pollutant scan analytes (Table 4), only six were detected. For those six analytes, detections were rare and at such small concentrations that four had mean concentrations of 0.001 $\mu g\ L^{-1}$ or less. Of current-use and other pesticides for which we sought determination (Table 5), only one compound, atrazine (a herbicide used on corn and cotton), was found to have a mean concentration above 1 $\mu g\ L^{-1}$ in stream waters. All others were below 0.1 $\mu g\ L^{-1}$, and often below 0.01 $\mu g\ L^{-1}$.

In Grenada Reservoir, pesticides in water were also detected in only 13% of analyses (93 of 697 potential detections). Here, none of the 25 priority pollutant compounds were detected in reservoir water. Of current-use and other pesticides we sought, atrazine was again the compound with highest observed mean concentration (0.317 $\mu g\ L^{-1}$) but at approximately one-fifth of the level observed in the watershed samples. All other pesticides had a mean concentration below 0.1 $\mu g\ L^{-1}$ except for the herbicides cyanazine (0.131 $\mu g\ L^{-1}$) and metolachlor (0.118 $\mu g\ L^{-1}$).

In watershed stream sediment samples, only 332 (of 2524 potential; 13% detection rate) results of analyses showed detectable pesticides in measurable quantities. Within the priority pollutant scan, seventeen compounds were detected in measurable quantities; however, none of the PCBs or chlordane were detected. BHC

Table 3. Mean concentration ($\mu g\ L^{-1}$ water or $\mu g\ kg^{-1}$ sediment) of metals in watershed components of the Yalobusha River and Grenada Reservoir.

	Water		**Sediment**		
	Watershed	Reservoir	Watershed	Reservoir	Debris Jam
Mercury	< 0.1	< 0.1	43.1	67.3	34.8
Arsenic	3	4	2686	2553	1834
Copper	10	30	9751	11714	5405
Chromium	3	2	5618	10561	7921
Lead	14	6	21817	21128	5928
Zinc	24	35	16286	44679	24111
Aluminum	3873	2260	3063430	12219000	14437500
Iron	4093	1801	9635468	17329187	12119600

Table 4. Mean concentration (μg L-1 water or μg kg-1 sediment) of 25 priority pollutant insecticides and PCBs in watershed components of the Yalobusha River and Grenada Reservoir. ND = not detected.

	Water		Sediment		
	Watershed	Reservoir	Watershed	Reservoir	Debris Jam
Arochlor 1016	ND	ND	ND	ND	ND
Arochlor 1221	ND	ND	ND	ND	ND
Arochlor 1232	ND	ND	ND	ND	ND
Arochlor 1242	ND	ND	ND	ND	ND
Arochlor 1248	ND	ND	ND	ND	ND
Arochlor 1254	ND	ND	ND	ND	ND
Arochlor 1260	ND	ND	ND	ND	ND
BHC-ALPHA	ND	ND	0.641	0.169	ND
BHC-BETA	ND	ND	26.219	27.558	68.622
BHC-DELTA	ND	ND	1.081	ND	0.295
BHC-GAMMA	ND	ND	0.603	ND	1.47
CHLORDANE	ND	ND	ND	ND	ND
TOXAPHENE	ND	ND	0.061	ND	ND
DDD 4,4′	ND	ND	3.253	3.310	7.608
DDE 4,4′	ND	ND	9.626	6.062	4.620
DDT 4,4′	ND	ND	0.607	10.406	4.070
ΣDDT	ND	ND	4.495	6.593	5.433
ALDRIN	< 0.001	ND	15.429	1.506	1.784
DIELDRIN	< 0.001	ND	1.521	ND	ND
ENDRIN	ND	ND	0.191	5.468	ND
ENDRIN ALDEHYDE	ND	ND	0.020	1.018	ND
ENDOSULFAN I	< 0.001	ND	0.016	0.127	0.100
ENDOSULFAN II	0.002	ND	3.879	ND	0.191
ENDOSULFAN SULFATE	ND	ND	0.106	ND	ND
HEPTACHLOR	0.001	ND	0.981	2.563	0.947
HEPTACHLOR EPOXIDE	0.015	ND	3.855	0.163	ND

(beta) (lindane) had the highest concentration of any analyte in watershed sediments, with a mean of 26.2 μg kg^{-1}. Aldrin (an organochlorine banned in 1974) was also present in high enough concentrations to have a mean value of 15.4 μg kg^{-1} in our samples. ΣDDT, endosulfan II, heptachlor epoxide, dieldrin, and BHC (delta) all had mean concentrations in sediment greater than 1 μg kg^{1}. Many of the other current-use pesticides were detected in stream sediments, but only atrazine (3.698 μg kg^{-1}) and fluometuron (1.379 μg kg^{-1}) had mean concentrations above 1.0 μg kg^{-1}.

Sediments of Grenada Reservoir yielded 126 detections of pesticides (of 846 potential; 15% detection rate). Again, no PCBs were detected, nor were seven other analytes in the priority pollutant scan. Ten of the 25 priority pollutants were measurable, with BHC and ΣDDT again having highest observed mean concentrations in our samples. However, four other banned compounds had mean concentrations above 1.0 μg kg^{-1}, including aldrin, endrin, endrin aldehyde, and heptachlor. Not surprisingly, atrazine (322.26 μg kg^{-1}) was observed to have the highest mean concentration of pesticide analytes in reservoir sediments, but two other commonly used herbicides, alachlor and metolachlor, had mean concentrations well above 100 μg kg^{-1}. Additionally, methyl parathion, trifluralin, chlorpyrifos, and cyanazine all had mean concentrations above 1.0 μg kg^{-1}. Only two current-use pesticides were not detected in measurable quantities in reservoir sediments.

Sediments in the debris jam showed similar occurrence of measurable pesticides as samples from other areas, with a 14% detection rate (46 of 328 potential). Here, as in the other sediments, BHC and DDT analytes were found in highest concentrations (Table 4). Aldrin (1.784 μg L^{-1}) was the only other compound found with a mean concentration above 1.0 μg kg^{-1}, though heptachlor was nearly so (0.947 μg L^{-1}. Still, only eleven of the 25 priority pollutants were measured in our samples from the debris jam. Furthermore, only four of the thirteen other pesticides we sought at the jam were detected, with atrazine yet again having the highest observed

Table 5. Mean concentration (μg L-1 or μg kg-1) of current-use and other pesticides in watershed components of the Yalobusha River and Grenada Reservoir. ND = not detected. X = not tested.

Herbicides in BOLD	**Water**		**Sediment**		
Insecticides in NORMAL	**Watershed**	**Reservoir**	**Watershed**	**Reservoir**	**Debris Jam**
ALACHLOR	**0.011**	**ND**	**0.863**	**157.381**	**ND**
ALDICARB	ND	X	ND	X	X
ATRAZINE	**1.513**	**0.317**	**3.698**	**322.257**	**3.697**
BIFENTHRIN	0.011	0.016	0.364	0.120	0.173
CHLORFENAPYR	0.014	0.059	0.413	ND	ND
CHLORPYRIFOS	0.002	< 0.001	0.023	12.528	ND
CYANAZINE	**0.007**	**0.131**	**0.994**	**1.523**	**ND**
CYFLUTHRIN	0.028	X	0.002	X	X
CYHALOTHRIN-LAMBDA	0.007	0.008	0.656	0.324	ND
DELTAMETHRIN	ND	X	X	X	X
FIPRONIL	0.001	0.003	ND	X	0.913
FIPRONIL SULFONE	0.004	ND	0.195	X	1.814
FLUOMETURON	**ND**	**ND**	**1.379**	**ND**	**X**
METHOXYCHLOR	ND	X	0.089	X	X
METHYL PARA-THION	0.015	0.014	0.626	55.977	ND
METOLACHLOR	**0.090**	**0.118**	**0.005**	**127.388**	**ND**
METRIBUZIN	**ND**	**X**	**X**	**X**	**X**
MIREX	0.021	X	0.658	X	X
NORFLURAZON	**0.021**	**X**	**0.658**	**X**	**X**
PENDIMETHALIN	**0.001**	**0.001**	**0.223**	**0.148**	**ND**
TEFLUTHRIN	ND	X	X	X	X
TRALOMETHRIN	0.055	X	ND	X	X
TRIFLURALIN	**0.001**	**0.031**	**0.018**	**27.210**	**ND**

mean concentration (3.697 $\mu g\ L^{-1}$), a concentration similar to other locations in the watershed outside of the reservoir. The other three detected compounds were bifenthrin, fipronil and fipronil sulfone.

Conclusions

The Yalobusha River drainage upstream of Grenada Lake is representative of mixed cover, hill-land watersheds that empty into the Mississippi River floodplain. Watersheds like this one experience runoff and associated contaminants from both agriculture and municipalities. In addition to field erosion, deeply incised streams in the watershed provide an additional source of suspended sediment.

As expected, runoff in winter and spring provided the highest concentrations of suspended sediments. All concentrations above 800 mg/L were detected from late November through February. In-stream sediment sources provided additional material so that wet seasons were almost identical to each other in elevated suspended sediment concentrations, while dry seasons had considerably lower mean concentrations of moving sediments.

In addition to the river, its tributaries, and Grenada Lake, a large obstruction, a debris dam, in the channelized portion of the river bordering Grenada Lake provided insight into riverine (lotic) and lake (lentic) effects on sediment, metals, and pesticides. The debris dam slowed water so that sediments settled in both the main river stem and wetlands/floodplain to either side on the main channel. The same depositional phenomenon occurred in the reservoir. Overall, sediment deposition in the reservoir was not cause for concern.

Metals and pesticides were detected in 12-15% of water and sediment samples in all sampling habitats. Atrazine (corn and cotton herbicide) was ubiquitous; BHC (beta), an organochlorine insecticide, had concentrations which were high in all sediments. As expected, DDT, its derivatives and Aldrin were also evident in sediments.

Overall, pesticide and metal concentrations were well below levels of concern. A few insecticides and herbicides had sporadically high concentrations, especially in sediments, which merit future scrutiny. Atrazine was ubiquitous.

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