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Factors that contribute to turbidity on the West Fork of the White River in Arkansas

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ABSTRACT

The West Fork of the White River (WFWR) exceeds the water quality standard for turbidity (10 NTU) set by the Arkansas Department of Environmental Quality and, since 1998, the river has been on Arkansas's 303 (d) list of impaired water bodies unsuitable for aquatic life because of turbidity exceedances. To understand the factors that could be related to turbidity, total suspended solids (TSS), total inorganic suspended solids (TISS), total volatile suspended solids (TVSS), sestonic chlorophyll-a (Chl-a) concentrations, and turbidity were measured on three sample dates from nine sites on the WFWR. As the site location changed in the downstream direction, turbidity values generally increased from less than 5 NTU (nephelometric turbidity units) at upstream sites to greater than 10 NTU on average at the two most downstream sites. A similar trend was observed in TSS, TISS, TVSS and sestonic chlorophyll-a concentrations, and regression analysis showed that TISS and TVSS were significantly related to turbidity across the WFWR. The multiple regression analysis for all collected data showed that TISS alone accounted for 73% of the variation in turbidity values. Where the turbidity exceeded 10 NTU, there were select soil series (Enders-Allegheny complex and Sloan, Razort, Taloka, and Pickwick silt loams) in the riparian zone that were not present in the upstream soils matrix. The reaches of the WFWR which had both elevated turbidity values and the selected soils composed on 6% (2.2 km) of the river length, and suggested that properties of those soil series should be investigated further as a contributing factor to increased turbidity at downstream sites of the WFWR.

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MEET THE STUDENT-AUTHOR

Chris Cotton

I am originally from Vicksburg, Miss., although I have called Russellville, Ark., my home since the age of two. I graduated in May 2011 from the University of Arkansas with a Bachelor of Science in Environmental, Soil, and Water Science. While growing up in Arkansas, I developed an appreciation for the pristine scenery of the natural state and came to understand the importance of upholding the integrity of the state's natural resources. During the past four years of my academic career in the Dale Bumpers College of Agricultural, Food and Life Sciences, I have been involved in various college and department associations including various officer positions within the undergraduate Crop, Soil, and Environmental Sciences Club. I also had the opportunity to participate in the Bumpers College honors program and a student exchange program during the summer of 2010 with Brazilian Institutes in Botucatu, Spain, and Londrina, Paraná, Brazil. During the summer of 2011, I will begin preparing for a two-year commitment for the position as a high school general sciences teacher and Teach For America corps member in Kansas City, Mo.

I would like to thank Dr. Brian Haggard for his extensive help and guidance in researching and preparing my honors thesis. With the additional assistance of Dr. Wolf, Dr. Miller, and faculty and staff of the crop, soil, and environmental sciences department, I was able to successfully complete and defend my honors thesis. The research and revisions of such a project will provide a useful experience for future tasks and challenges I will face along my career path.

INTRODUCTION

The Arkansas Department of Environmental Quality (ADEQ) is required by Section 303 (d) of the Clean Water Act to identify waters which do not meet applicable water quality standards (ADEQ, 2002). The intent of water quality standards is to protect the designated beneficial uses of the states' waters, and these beneficial uses defined in Arkansas include agricultural and industrial water supply, recreation, public water supply, and aquatic life (Haggard and Scott, 2010). A variety of factors can influence whether or not designated beneficial uses are met. Two of the most common factors as defined by ADEQ (reviewed in Rogers, 2010) and nationally (U.S. EPA, 2010) are sedimentation and turbidity.

Turbidity is defined as a cloudy condition in water due to organic matter and suspended silts and clays transported from land into the water column. Soil erosion from stream banks, riparian areas, and the landscape in a watershed can contribute to increased turbidity levels in rivers. The sources of sediment include agricultural land, land undergoing urban development, and as a result of stream bank erosion, as well as natural transport. Turbidity can also result from organic matter production within the water column of streams and rivers (U.S. EPA, 1999).

The focus of this study was the West Fork of the White River (WFWR) in Northwest Arkansas. The objectives were (1) to determine, from collected data, where turbidity on the WFWR becomes pronounced, (2) to obtain chemical, physical, and biological data from samples collected at nine access locations and analyzed at the Arkansas Water Resources Center (AWRC) Water Quality Lab (WQL), (3), to quantify the percent river miles for each soil series present on the stream banks of the WFWR and (4) to identify factors related to the measured turbidity. This study will help watershed managers further understand the factors contributing to turbidity at WFWR, and then assist in developing and targeting remedial actions to reduce stream bank and riparian erosion.

MATERIALS AND METHODS

Site Description. The study site was the West Fork of the White River which has had a recorded decline in total fish species since the 1960s with an increase in tolerant species and a decrease in sensitive species (Formica et al., 2004). The 54-km impaired segment of the WFWR is south of Fayetteville and empties into the White River, which is a major tributary to Beaver Lake. Beaver Lake is the drinking water supply for 300,000-plus residents of Washington and Benton Counties, Ark.

Land Use and Soil Surveying. Land use distribution of the WFWR watershed area is 65% forested, 23% agriculture (mainly pasture), and 12% urban use. To better understand the composition and landscape patterns of the WFWR watershed, a state-issued soil survey for Washington County was examined (Harper et al., 1969), and a spreadsheet was compiled to record the percent and description of the soil series that were found adjacent to the river.

Water Sampling and Analysis. Water samples were collected from nine access points along the WFWR during base flow conditions in April, September, and October 2010 (Fig. 1, Table 1). At each site, an alpha type sampler was dropped from the center of each bridge on the downstream side. Once the sampler was full, water was transferred to a field-rinsed, 1-L high-density polyethylene (HDPE) bottle. Water samples were analyzed for turbidity, total suspended solids (TSS), total inorganic suspended solids (TISS), total volatile suspended solids (TVSS), and sestonic chlorophyll-a (Chl-a).

Turbidity. To determine turbidity, a WTW Turb 550 turbidimeter was used to obtain a nephelometric measurement (NTU) for samples from each site. The 1-L raw sample was vigorously shaken to mimic natural stream conditions for turbidity analysis, and a 5-mL sample was placed into a clean cuvette. The cuvette was then inserted and aligned into the optical well of the turbidimeter, and a reading for NTU was recorded. The value demonstrated the relative cloudiness of the sampled water.

Total Suspended Solids. A well-mixed sample from each site was taken from the 1-L bottles and filtered through a weighed standard glass-fiber filter (pore size = 0.7 μm). The sample (25 ml) for each site was filtered using a vacuum apparatus and was washed three times with 10 ml of distilled water. The filter was then carefully removed and transferred to an aluminum dish and dried in an oven at 103-105 °C for 1 h. After drying, the filter plus the dried residue was weighed and the total suspended solids concentration was calculated by using the following equation:

$$\text{TSS, mg/L} = \frac{(\textit{weight of filter and weight of residue, mg} - \textit{weight of filter, mg})}{\textit{sample volume, L}}$$

Total Volatile Suspended Solids. TVSS provided an estimation of the amount of suspended organic material in the sample, where the residue obtained from the TSS was ignited in this procedure to determine the amount of volatile solids in the sample. Following determination of TSS, the filter with dried residue was ignited in a muffle furnace at 550 °C. The cooled filter disk weight was recorded and used in the following equation:

$$\text{TVSS, mg/L} = \frac{(\textit{weight of filter and residue before ignition, mg} - \textit{weight after ignition, mg})}{\textit{sample volume, L}}$$

Total Inorganic Suspended Solids. To calculate the inorganic portion of the sampled solids collected in the TSS method, the concentration for the volatile solids was subtracted from the concentration of the total solids.

Sestonic Chlorophyll-a. The U.S. EPA standard method 446 (Arar, 1997) was used to estimate concentration of Chl-a in the samples, and provided the relative abundance of algal cells in the water samples (Aminot and Rey, 2000). A 500-ml sample was vacuum filtered onto a glass-fiber filter. The filter was macerated and placed in 5 ml of 90% acetone aqueous solution to extract chlorophyll from the algal cells. The extract was centrifuged, placed in a cuvette, and analyzed using a *Beckman-Coulter* DU 720 spectrophotometer (Miami, Fla.) which measured the absorbance of the samples at wavelengths of 750, 664, 647,and 630 nm. The trichromatic method followed used Jeffery and Humphrey's equation (Jeffery and Humphrey, 1975 as cited in Arar, 1997) to determine Chl-a concentrations as follows (Arar, 1997):

$$\text{Chl-a, μg/L} = (11.85 * (E664 - E750) - 1.54 * (E647 - E750) - 0.08 * (E630 - E750)) * Ve/L * Vf$$

Where:

E# = absorbency at specified wavelength
L = Cuvette light-path in cm
Ve = Extraction volume in ml
Vf = Filtered volume in L

Statistical Analysis. To statistically analyze the concentrations of TSS, TVSS, TISS, and sestonic chlorophyll-a in relation to the increased NTU values observed in the WFWR, linear regression analyses were conducted for monthly data. From these analyses, the following information was collected for each parameter for the data points of each month: slope, intercept, R^2, and P-value The formula used in the regression was:

$$NTU = constant + (B_0 * X)$$

Where *NTU* is turbidity units, B_0 is the regression coefficient or slope, and *X* represents the independent variable including TSS, TISS, TVSS and sestonic chlorophyll-a. A multiple linear regression of turbidity was also conducted for data across all sampling months using multiple variables, including TISS and TVSS. The following formula was used:

$$NTU = constant + (B_1 * TISS) + (B_2 * TVSS)$$

Where *NTU* is turbidity units, B_1 and B_2 are regression coefficients, and *TISS* and *TVSS* are the dependent factors.

RESULTS AND DISCUSSION

Turbidity. On average, turbidity values was least at the upstream sites 1-7, with mean values less than 10 NTU

(Fig. 2). Turbidity generally increased in the downstream direction of the West Fork of the White River. Turbidity over the sampling period was greatest at site 8 at river km 31, averaging over 15 NTU during base flow. This monitoring program showed that the standard of 10 NTU was exceeded at sampling sites 8 and 9 from river km 31-36. These sampling sites comprise 5 kilometers or just fewer than 17% of the sampled river length.

The average TSS concentrations were less at the sites upstream (site 1-7) compared with that measured at the downstream sites 8 and 9 (Fig. 3). Average TSS was least at site 2 at river km 8 (average of 2.4 mg/L); whereas, the greatest average was 13.2 mg/L at site 8 at river km 31. The trends in both turbidity and TSS concentrations were similar across the WFWR, increasing in the downstream direction. The TSS is comprised of TISS and TVSS and differences determine if the suspended solids causing turbidity in the stream were from inorganic or organic sources. Mean TISS concentrations ranged from 1.6 mg/L at site 2 to 10.9 mg/L at site 8. The mean TVSS concentrations were less compared to those observed for TISS, ranging from 0.6 mg/L at sites 3 and 5 to 2.3 mg/L at site 8 (Fig. 3).

The lowest average concentration for sestonic chlorophyll-a was 1.2 µg/L at site 3, and the greatest average recorded was at site 9 with a concentration of 6.9 µg/L (Fig. 4). These data showed general concentration increase for all measured parameters in the samples collected further downstream (relative to upstream), and turbidity at the two most downstream sites was of most concern relative to exceeding water quality standards.

Regression Analysis. The TSS and TISS regressions against turbidity showed the greatest R^2 values for each individual month, suggesting that the inorganic portion of the suspended material explained most of the variation in turbidity across the WFWR (data not shown). However, TVSS concentrations were also an important determinant in the variability of turbidity across these sites when all data were combined for the regression analysis. Sestonic chlorophyll-a concentrations were not significantly related to turbidity measurements during each of the three months nor were concentrations significantly related to turbidity when all data were pooled together ($P > 0.05$).

The multiple regression analysis suggested that TISS and TVSS accounted for 85% of the variability in turbidity across these sampling sites and dates at the WFWR. It was noted that both B_1 and B_2 held positive values, thus it can be further concluded that increases in either TISS or TVSS resulted in increased turbidity. To further confirm this, the R^2 values showed that TISS explained 73% of the variation in turbidity, and TVSS explained an additional 12% (data not shown). Therefore, the multiple regression analyses suggested that TISS accounted for the majority of variability in turbidity in the water column.

Soils. To provide further detail concerning the inorganic materials possibly causing turbidity in the WFWR, riparian soil series along the river were evaluated. The dominant soil series throughout the WFWR was Cleora fine sandy loam, occupying 66.4% of the measured riparian zone, with a slight erosion hazard and low runoff potential; 13 other soil series comprise the remaining 33.6% of the land area. The sites of major concern for high turbidity levels were downstream from site 7, representing the last 11 km of the sampled section of the WFWR. As turbidity increased downstream, the presence of select soil series (including Enders-Allegheny complex, Sloan, Razort, Taloka, and Pickwick silt loams) also increased (data not shown).

The erosivity hazard index for the soils at these sites were highest for the Pickwick silt loam which constituted 0.305 km between sites 8 and 9. The Taloka silt loams, covering 0.25 km between sites 8 and 9, have a moderate erosion hazard. The Razort silt loam which is present for 0.32 km between sites 7 to 8, had a moderate runoff potential, but only a slight erosion hazard. The presence of these soils potentially could be related to the increased downstream turbidity and inorganic material in the WFWR due to the higher erosivity hazards and runoff potentials compared to those of the dominant Cleora fine sandy loam series.

From this study, we observed that turbidity measurements increased as the WFWR near Fayetteville flowed downstream. The measured turbidity was significantly related to TSS concentrations, and more specifically to concentrations of TISS and TVSS. Regression analyses showed that TISS had a greater influence on turbidity over the three sampling dates. These findings were consistent with results found in previous studies conducted on the WFWR in 2004 and 2006 which determined that TSS concentrations were mostly inorganic in composition (Formica et al., 2004). Additionally, logarithmic regression equations relating turbidity to TSS concentrations were developed (U.S. EPA, 2006). As turbidity and TISS concentrations in the water column increased downstream, there was an observed occurrence of select soil series (Enders-Allgeheny complex, Sloan silt loam, Razort loam, Taloka silt loam, and Pickwick silt loam) which were characterized as having moderate to high erosion hazards and runoff potentials.

In 2004, a study was conducted for the Arkansas Natural Resource Commission on the siltation and turbidity of the WFWR (Formica et al., 2004). These researchers found that stream bank erosion was estimated to contribute 13,962 Mg annually of suspended sediment to the WFWR, accounting for 66% of the annual TSS load. Additionally, turbidity and TSS data were collected over two years and a regression analysis showed that TSS explained over 75% of the variability in turbidity with a slope of 1.202. In the current study, regression values were consistent during the six month sampling period with a slope of 0.915 and a R^2 value of 0.781. This observation indicates that TSS explains the majority (78%) of the variability in turbidity both spatially (upstream and downstream) and temporally (across different studies).

A similar study of the Illinois River near Fayetteville was conducted from 2005-2007 by the U.S. Geological Survey to quantify the percentages of organic and inorganic materials in the water column (Galloway, 2008). It was noted that there was significant relation between TSS concentrations and turbidity measurements in the Illinois River. However, the Illinois River had mean TVSS concentrations (3.1 mg/L) that were three times greater than those found in the current study of the WFWR (TVSS = 1.03 mg/L). However, mean sestonic Chl-a concentrations were relatively similar between the Illinois River (3.1 µg/L) and the WFWR (2.9 µg/L). In both systems, the inorganic material was the largest part of TSS measured in the water column, given that the mean values of TISS were 4 mg/L on the Illinois River and 5.2 mg/L on the WFWR (Galloway, 2008).

Formica et al. (2004) used a soil survey to map potential areas of concern for sediment loss due to agricultural pasture land use in the WFWR watershed. It was concluded that soils with a slope of 8-16% in the Enders association were responsible for 65% of the sediment loss from riparian pasture land at the WFWR. This is consistent with the riparian soils information gathered in the current study which indicated that increased percentages of Enders-Allegheny soil series had increased records of turbidity and TSS. Further evaluation of the select soil series (Enders-Allegheny complex and Sloan, Razort, Taloka, and Pickwick silt loams) present upstream from sites with the greatest turbidity measurements could provide an understanding of which soils contribute more silts and clays into the water column.

The current study suggests that select soil series at downstream sites (Enders-Allegheny complex and Sloan, Razort, Taloka, and Pickwick silt loams) may contribute to the elevated turbidity at the WFWR. Prior to the current study, the Watershed Conservation Resource Center (WCRC) restored and redesigned the fluvial channel and banks near site 1 on the WFWR and concluded that riparian vegetation, bank stabilization, and constructed floodplains reduced sediment loads by 96% at this site (WCRC, 2011). Conservation management practices such as riparian buffer strips and vegetation can help reduce soil erosion by decreasing surface water velocity and depositing suspended sediments (Henley et al., 2000). Efforts by the WCRC provide an effective model for stream bank restoration on the WFWR, and soils found downstream could benefit from similar management (Fig. 5).While this conservation effort reduced sedimentation at an upstream site, data in the current study provided that turbidity limits were still being exceeded downstream which may further support the hypothesis that the soil series composition has an effect on the turbidity values on the WFWR.

CONCLUSIONS

With the results from this study, we provided an analysis of factors in the WFWR that can affect turbidity and water quality. We examined water quality conditions from three samples at nine sites along 36 km of the WFWR over a six month period. It was concluded that only the two furthest downstream sites had conditions that exceeded turbidity standards (10 NTU). In general, the turbidity increased as the location of the sampling site changed in the downstream direction. To examine factors that could possibly be causing the high turbidity, TSS, TISS, TVSS, and Chl–a were measured from the samples, and all parameters tested show an increase in concentrations as the sample site location moved in the downstream direction. Linear regression analyses showed that TISS and TVSS concentrations were significantly related to changes in turbidity. A multiple linear regression showed that TISS and TVSS together explained 85% of the variation in turbidity, and 73% of the variance in turbidity was influenced by TISS alone. Thus, inorganic materials comprised the majority of suspended solids in the water column. At downstream sites that exceeded the water quality standard (>10 NTU), there were select soils (Enders-Allegheny complex and Sloan, Razort, Taloka, and Pickwick silt loams) in the riparian zone which were not as prevalent at the upstream sites. The segments of the WFWR which were found to exceed turbidity and had the select soils represents only 2.2 km (6%) of the studied stream reach. Past restoration efforts on the WFWR showed results of lowered turbidity upstream, although the downstream sites exceeded the turbidity limit in the current study. The observed soil types which were identified at those sampling sites with higher turbidity values should be investigated further for physical factors that attribute to suspended solids so that further data can be collected and contribute in the progress towards a management plan for lowering turbidity in the WFWR.

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Table 1. Site description of sampling locations on the West Fork of the White River

Site No.	Description	Distance (km) from site 1	Latitude, degrees	Longitude, degrees	Elevation (m)
1	Brentwood Mt. Rd.	0	35.85545	-94.109650	462
2	Woolsey Rd.	8	35.88368	-94.165782	451
3	West Fork Main	14	35.92812	-94.184479	427
4	Dye Creek Rd.	16	35.94138	-94.186562	404
5	Greenland Main	19	35.98113	-94.173714	389
6	Wilson Hollow	22	36.01485	-94.142342	370
7	Black Oak Rd.	25	36.01897	-94.123222	367
8	Dead Horse Mt. Rd.	31	36.05080	-94.118584	361
9	Harvey Dowell Rd.	36	36.05382	-94.083092	354

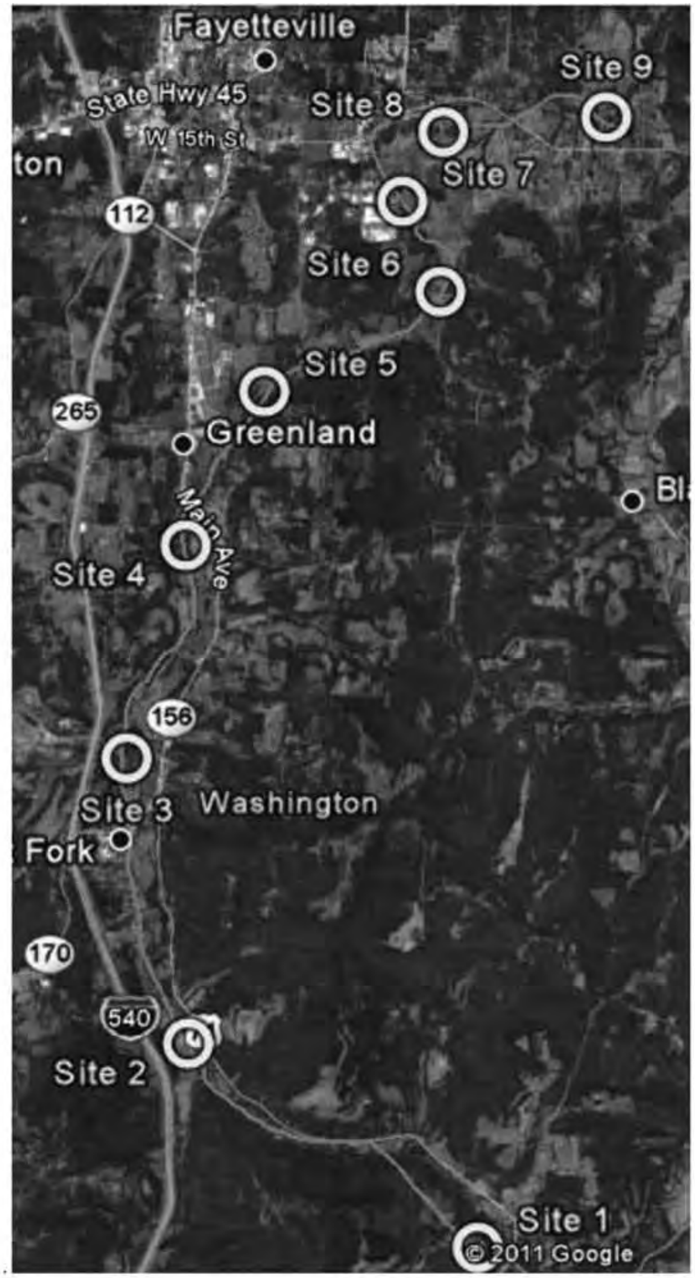

Fig. 1. Sampling sites on the West Fork of the White River southeast of Fayetteville, Ark. (Image courtesy of GoogleEarth 2011).

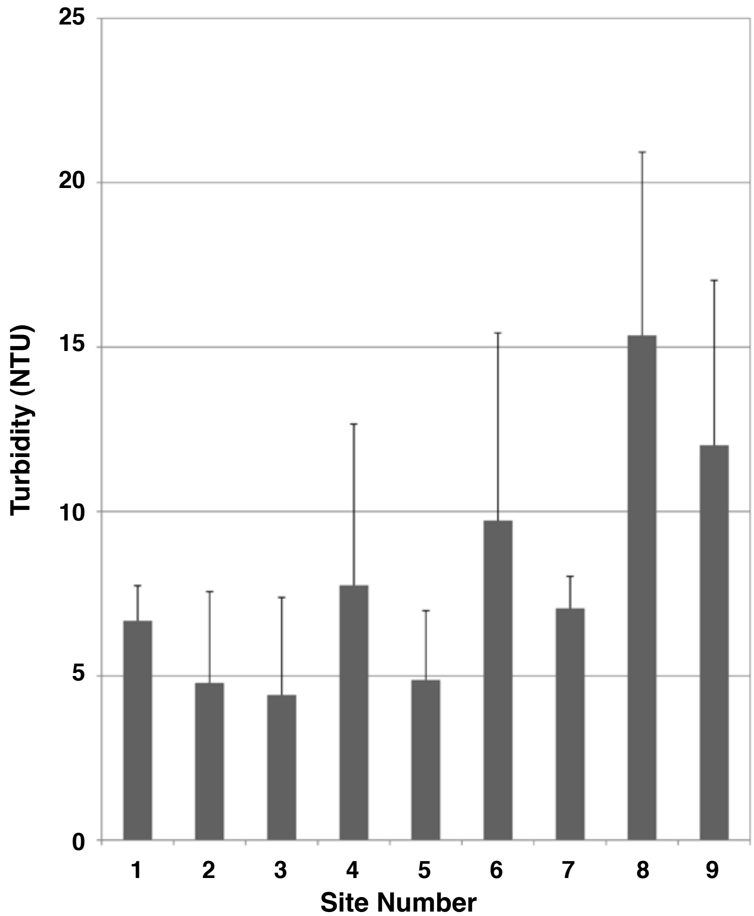

Fig. 2. Average turbidity (NTU) at the West Fork of the White River and the error bars are corresponding standard deviation amongst samples at each site (1-9) across three sampling dates. See Table 1 for site descriptions.

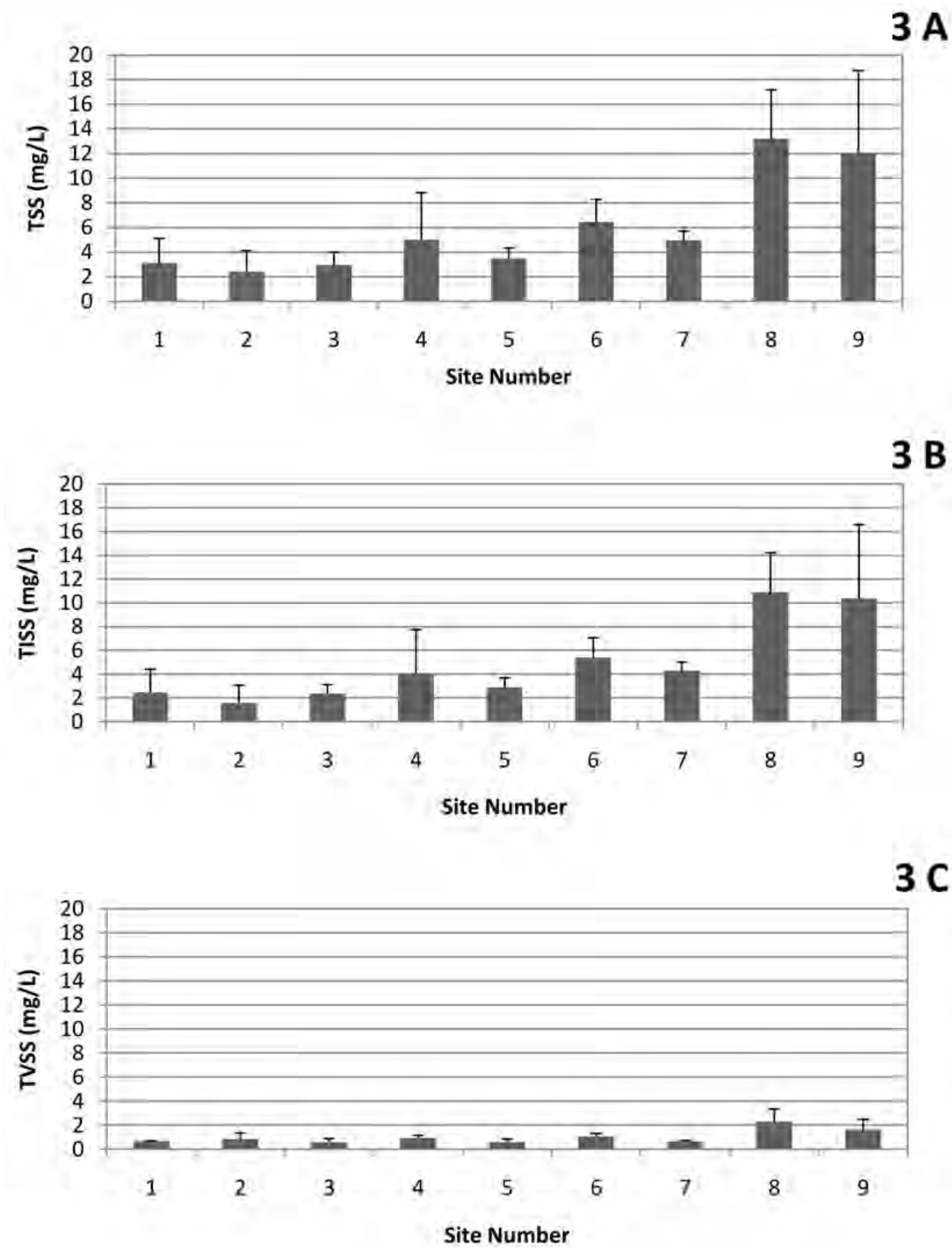

Fig. 3. A. Total suspended solids (TSS), **B.** total inorganic suspended solids (TISS), and **C.** total volatile suspended solids (TVSS) at the West Fork of the White River and the error bars are corresponding standard deviation amongst samples at each of nine sites averaged across the three sampling dates. See Table 1 for site descriptions.

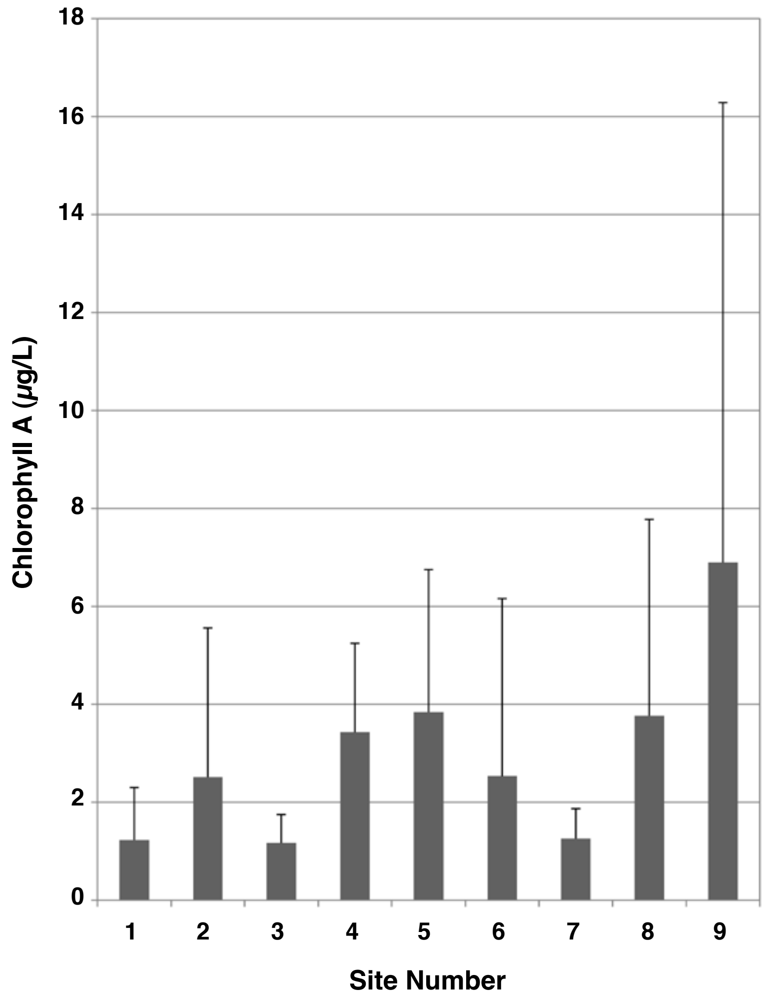

Fig. 4. Average sestonic chlorophyll a concentrations at the West Fork of the White River, and the error bars are corresponding standard deviation amongst samples at each of nine sites averaged across the three sampling dates. See Table 1 for site descriptions.

Fig. 5. West Fork of the White River at Dead Horse Mountain Road (site 8) with visible stream bank erosion and turbid water conditions along a Razort-Sloan-Enders soils complex.