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FLOW, ORGANIC, AND INORGANIC SEDIMENT YIELDS FROM A CHANNELIZED WATERSHED IN THE SOUTH CAROLINA LOWER COASTAL PLAIN[1]

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ABSTRACT: Many small streams in coastal watersheds in the southeastern United States are modified for agricultural, residential, and commercial development. In the South Carolina Lower Coastal Plain, low-relief topography and a shallow water table make stream channelization ubiquitous. To quantify the impacts of urbanization and stream channelization, we measured flow and sediment from an urbanizing watershed and a small forested watershed. Flow and sediment export rates were used to infer specific yields from forested and nonforested regions of the urbanizing watershed. Study objectives were to: (1) quantify the range of runoff-to-rainfall ratios; (2) quantify the range of specific sediment yields; (3) characterize the quantity and quality of particulate matter exported; and (4) estimate sediment yield attributable to agriculture, development, and channelization activities in the urbanizing watershed. Our results showed that the urban watershed exported over five times more sediment per unit area compared with the forested watershed. Sediment concentration was related to flow flashiness in the urban watershed and to flow magnitude in the forested watershed. Sediments from the forested watershed were dominated by organic matter, whereas mineral matter dominated sediment from the urban stream. Our results indicated that a significant shift in sediment quality and quantity are likely to occur as forested watersheds are transformed by urbanization in coastal South Carolina.

(KEY TERMS: streamflow; watersheds; sediment; urbanization; turbidity; stormwater management.)

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INTRODUCTION

In coastal watersheds in the southeastern United States (U.S.), minimal relief and a shallow water table typify the landscape. To accommodate a growing population influx (Culliton *et al.*, 1990; Vernberg and Vernberg, 2001; Exum *et al.*, 2005), many first-order streams have been modified (Craig and Kuenzler, 1983; Shankman, 1996) and the landscape subjected to tree removal and land grading (Phillips, 1995) to allow for arable land as well as residential and commercial development. Modifications include stream channelization, ditching, and deepening of existing stream networks to lower the groundwater table (Choate, 1972; Schilling *et al.*, 2004), primarily to reduce the frequency and magnitude of overbank flows (Simon and Hupp, 1992). Shallow first-order

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wetland streams characterized by an assortment of instream woody material, complexity of flow regimes, and frequent overbank flows that spill onto broad forested floodplains (Hunt, 1967) have been transformed to deep, straight, and flat-bottomed channels designed to confine all but the most infrequent flows (Brookes, 1988). A consequence of anthropogenically imposed disturbance to fluvial form is a shift in fluvial functioning that transpires over decades, a process that would otherwise occur over a geologic time span (Simon *et al.*, 2007).

The impacts of development on riparian function have been widely documented in various geographic settings and at multiple spatial scales (e.g., Martens, 1968; Krug and Goddard, 1986; Booth, 1990; Schueler, 1994; Booth and Jackson, 1997; Walsh *et al.*, 2005; White and Greer, 2006). In the southeastern U.S., the impacts of urbanization on coastal watersheds have been shown to have adverse consequences (Mallin *et al.*, 2000; Tufford *et al.*, 2003; Meyer *et al.*, 2005; Van Dolah *et al.*, 2008; O'Driscoll *et al.*, 2010).

Given suitable geomorphic conditions, stream networks that are subjected to channelization will undergo gradual changes in morphology to achieve a stable end configuration (Schumm *et al.*, 1984; Simon and Hupp, 1986; Jayakaran and Ward, 2007). Suitable conditions for dynamic stability include adequate stream power, availability of sediments, initial constructed width (Landwehr and Rhoads, 2003; Jayakaran *et al.*, 2005), and the ability for vegetation to stabilize channel structure (Thorne, 1982; Wynn and Mostaghimi, 2006). A critical step toward the effective rehabilitation and better management of degraded streams is to quantify flow and sediment characteristics for stream channels occupying the continuum between disturbance and dynamic stability (Simon *et al.*, 2007).

The overarching goal of this study was to estimate the impacts of land cover change on flow and sediment yields from an urbanizing coastal plain watershed in South Carolina. We also sought to determine the quality of suspended particulate matter in the water column with differing land cover. To do this, we monitored flow and suspended sediment exports from two streams in northeastern South Carolina. These streams have comparable low-gradient topography, soils, and climatic conditions yet differing drainage areas. One stream was a first-order stable channel in a forested watershed (1.57 km^2); the other was a second-order channelized stream draining an urbanizing watershed (46.10 km^2) with a quarter of its drainage area remaining forested. Flow and suspended sediment measurements offered insight into the range of hydrologic and reach-scale processes across the development spectrum, specifically with respect to the channel form, streamflow, and sediment export (e.g., Wahl *et al.*, 1997; Simon and Klimetz, 2008). We used specific flow and sediment yields (loads per unit drainage area) from the forested watershed to infer potential yields from the forested areas of the urbanizing watershed. By subtracting forest-attributable yields from those measured at the outlet of the urbanizing watershed, we estimated flow and sediment yields in the urbanizing watershed that might be attributable to agriculture, commercial development, and stream channelization. We also examined the quality of suspended material exported from the two watersheds in terms of organic and mineral constituents of suspended sediment export.

The comparison of flows and sediment export were undertaken with the following objectives: (1) to quantify the range of runoff-to-rainfall ratios; (2) to quantify the range of specific sediment yields; (3) characterize the quantity and quality of particulate matter exported from the two watersheds; and (4) to estimate sediment yield attributable to agriculture, development, and channelization activities in the urbanizing watershed.

Land Use Effects on Streamflow, Flashiness, and Sediment Exports

The effects of land use change with particular focus on drainage and urbanization have shown that stream form adjusts in response to perturbations affecting flow and sediment rates. Lane's classic relationship (Lane, 1955) suggests that with changing flow rates and associated return periods, an imbalance is imposed upon stream equilibrium that requires an adjustment of channel form and a consequent change in sediment transport regime for the restoration of dynamic equilibrium. Simon and Darby (1997) showed by numerical modeling that, with the imposition of a particular flow with half of the sediment capacity available for transport, streams with sandy banks are prone to bank failure, whereas streams that are less prone to bank failure (high clay content) tend to deepen and incise. The evolution of destabilized channels from the point of disturbance to a state of dynamic stability has been well documented and is described in several channel evolution models (Schumm *et al.*, 1984; Simon and Hupp, 1986).

Flows tend to become flashier in urbanizing watersheds due to the installation of drainage networks designed to enhance the rate at which incident precipitation is conveyed from landscape to receiving streams. A metric of stream flashiness is the Richards-Baker Flashiness Index (RBFI) (Baker *et al.*, 2004). The RBFI can range from 0.1 to 1.2

(based on streams in Indiana, Michigan, and Ohio); where RBFI is inversely proportional to watershed size and directly proportional to groundwater input. Forested watersheds that receive high rainfall, have saturated soils, and experience shallow groundwater position can also have flashy streams (e.g., Ramírez *et al.*, 2009). Stream flashiness can be further influenced by drainage modifications on the landscape, such as channelization and subsurface drainage (Baker *et al.*, 2004), increased imperviousness (Nagy *et al.*, 2012), as well as modifications to stormwater drainage systems that increase surface runoff and decrease time of concentration (Walsh *et al.*, 2005). Stream channel incision as a function of increased runoff can further amplify flashiness as more water is confined within the incised channel (Shields *et al.*, 2010).

Quantifying the transport of suspended sediment is a critical step in assessing the fluvial function of stream systems, including stream response to changes in the landscape and climate. Sediment yields from a watershed are determined by the volume of runoff and the concentration of sediment in the runoff (Langbein and Schumm, 1958). Factors altering either of these two parameters can result in changes in the sediment transport regime of a stream. Sediment yield has been linked to stream channel erosion (Trimble, 1997), rainfall intensity (Kayhanian *et al.*, 2008), catchment geomorphology represented by the hypsometric integral (Gert and Jean, 2001), and land use change (Walling, 1999). Specific sediment yield has been shown to decrease with increasing drainage area (Dendy and Bolton, 1976; Schumm, 1977; Borah *et al.*, 2008). Therefore, one would expect to see an attenuation of specific sediment yields with increasing drainage area if climate and geological conditions were consistent. A deviation from this trend would suggest anthropogenic influence.

Relative Contributions of Organic and Mineral Fractions to Suspended Sediment as a Function of Land Use

Suspended sediments in the water column comprise mineral and organic fractions that, respectively, provide insight into distinct physical and biological processes. Organic material (OM) in the water column exists in a particulate phase, a dissolved phase, and as large woody debris — all three components play important roles as sources of energy, nutrients, and habitat to aquatic ecosystems (Hynes, 1970; Cummins, 1974). In modified channels, the disconnection of the main channel from its floodplain, and the elimination of forest canopy, can limit not only the rate and timing of allochthonous OM inputs to a drainage network but also inhibit the movement of invertebrates and woody debris from headwaters to downstream reaches (Wipfli *et al.*, 2007).

MATERIALS AND METHODS

We conducted the study in two watersheds that are representative of either end of the development spectrum encountered in northeastern South Carolina (Figure 1). Crabtree Canal (CC) watershed (12-digit hydrologic unit code: 030402060803) is located within Horry County and contains the city of Conway (Pop $\approx$ 18,000). Upper Debidue Creek (UDC) is located in a relatively undeveloped coastal watershed (12-digit hydrologic unit code: 030402080402) in Georgetown County. The two watersheds are only 50 km apart, but lie in two different Level III Ecoregions (Griffith *et al.*, 2002). CC is a second-order stream that lies in the Middle Atlantic Coastal Plain Ecoregion (Level III). It drains a 46.10-km^2 watershed whose land cover/land use (LULC) based on the 2006 National Land Cover Dataset is 23.0% developed, 35.3% forested, 17.2% pasture or cultivated crops, and 24.6% wetlands. Population numbers have increased rapidly in Horry County over the past three decades with the county ranking 27th highest of 683 coastal counties nationwide in terms of projected population growth rates between 1980 and 2020 (NOAA, 2013). The dominant soil types in the CC watershed are poorly draining Eulonia loamy fine sands in the upper elevations, Wahee fine sandy loams mid slope, and Meggett loams in the riparian zones. All three soils are hydrologic class C/D (drained/undrained). CC was originally a hardwood swamp that was channelized in the 1960s by the U.S. Army Corps of Engineers to prevent flooding of croplands and the city of Conway. The channelization was extended in the 1980s to cover a total of 19 km and now serves as a major conduit by which urban stormwater is conveyed to the Waccamaw River. A U.S. Geological Survey (USGS) real-time gaging station (USGS 02110701) is located at the watershed outlet. Downstream sections of the CC watershed are influenced by tidal and backwater effects imposed by the larger Waccamaw River. Backwater and tidal effects extend 1.4 km upstream of the gage to a 1.2-m rise in streambed elevation coincident with a highway culvert that limits further upstream influence. Downstream of the gage, the stream flows for 0.32 km in a confined channel then discharges into the Kingston Lake swamp system — a riparian

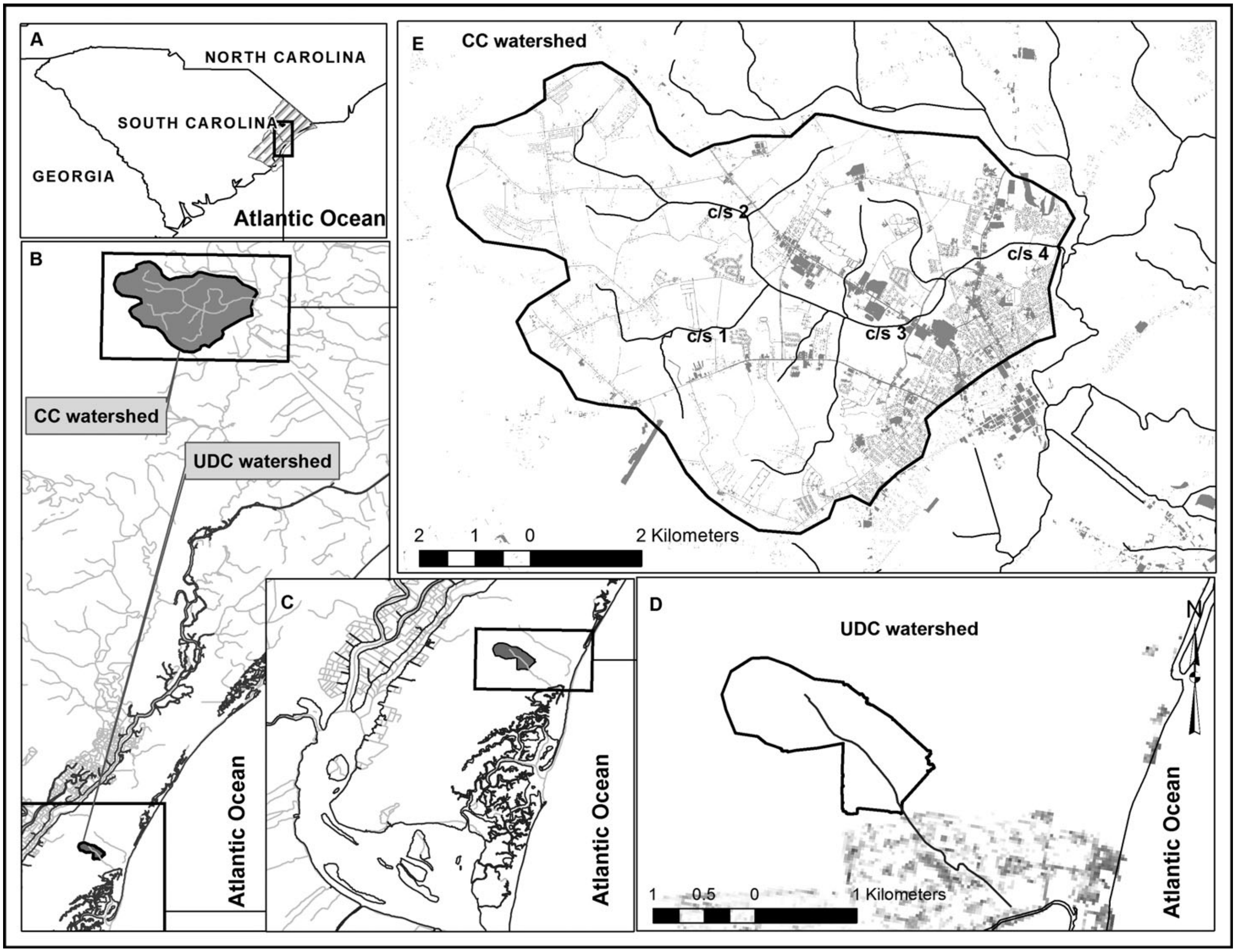

FIGURE 1. Location Map for Crabtree Canal (CC) and Upper Debidue Creek (UDC) Watersheds. (A) The two coastal counties in South Carolina that encompass the study watersheds. (B) The location of the two watersheds with respect to each other. (C) The location of UDC on the coast-parallel Waccamaw Neck peninsula. (D) The UDC watershed. (E) The CC watershed with the locations of four channel cross-section (c/s) surveys shown in Figure 2. Gray areas in (D) and (E) denote impervious surfaces.

wetland complex that is characterized by a stable well-connected floodplain system.

On the other end of the development spectrum, UDC is a first-order stream located on a coast-parallel peninsula known as the Waccamaw Neck. UDC lies in the Southern Coastal Plain Ecoregion (Level III) and drains a 1.57-km^2 watershed that comprises primarily loblolly pine stands and bottomland hardwood species in the riparian zone. Soils in UDC are mostly hydric Leon sands whereas riparian margins comprise poorly draining Lynn Haven sands; both soils are hydrologic class A/D (drained/undrained). Beyond the watershed outlet, UDC flows into a series of impoundments and tidal gates, then into the North Inlet tidal estuary and eventually to the Atlantic Ocean.

Channel Morphology

We surveyed both channels to characterize stream profile, dimension, and pattern by methods prescribed by Harrelson *et al.* (1994). The drainage network for CC comprises several tributary ditches that are essentially channelized first-order streams. This ditch network has augmented the natural stream mileage by a factor of seven. Until recently, sediment deposits from the channel bottom were periodically dredged to ensure flow conveyance and maintain ditch esthetics. By design, most flows are wholly contained within the ditch channel with all connection to the legacy floodplain eliminated. Evidence of bank instability and mass wasting has been widely observed in the CC system. There are also several indicators of

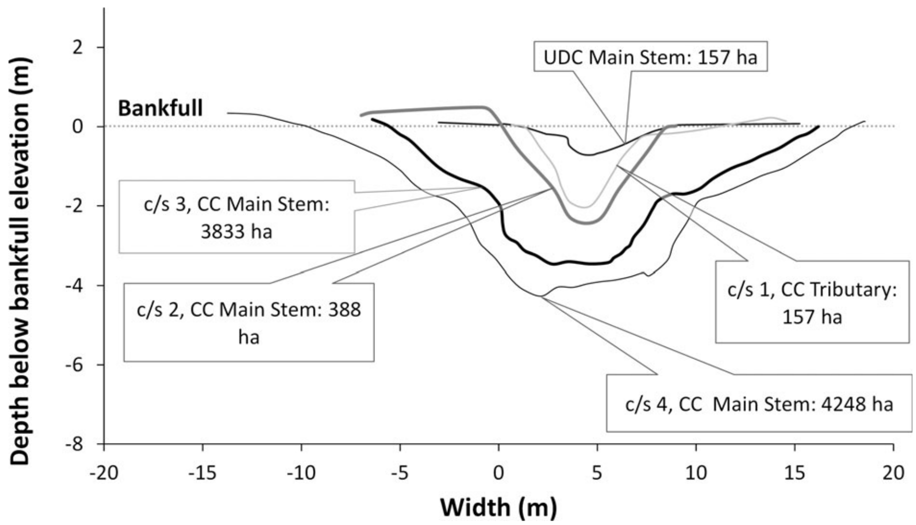

FIGURE 2. Scaled Reference Bankfull Channel Cross Sections (c/s) at Various Drainage Locations in Crabtree Canal (CC) and Upper Debidue Creek (UDC). The smallest channel cross section shown (innermost) is the UDC stream at its outlet. Locations of four cross sections (c/s 1 to c/s 4) within the CC watershed are shown in Figure 1e.

stream channel incision, as evidenced by the exposure of box culvert foundations and bridge pilings at several locations on the main stem of CC.

Upper Debidue Creek has well-defined banks, a sandy bed, and a well-connected floodplain. A network of shallow ditches that were constructed when the watershed was an active plantation feeds the main channel, however, the main stem remains unmodified for the entire lower half of its hydraulic length. Mean depth at bankfull elevation ranges from 0.2 to 0.4 m (average of 0.3 m), and mean bankfull width between 3.2 and 4.5 m (average of 3.8 m). Typical width to depth ratio is 12.0, average channel bed slope is approximately 0.18%, and average channel sinuosity is 1.6. At a comparable drainage area (1.57 km^2) in the CC watershed, average channel width and depth from bankfull elevation was 6 and 2 m, respectively (Figure 2). Stream slope is 0.11 and 0.20% at a watershed area of 1.57 km^2 at UDC and CC, respectively. Characteristics of the CC and UDC stream and watersheds are summarized in Table 1.

TABLE 1. Channel Characteristics at the Outlets of Both Study Watersheds Are Summarized Below. In addition, details of a subwatershed in the Crabtree Canal (CC) watershed with equivalent drainage area to Upper Debidue Creek (UDC) are also shown for comparison.

	CC at Outlet	**CC Tributary**	**UDC at Outlet**
Level III Ecoregion	**Middle Atlantic Coastal Plain**		**Southern Coastal Plain**
Drainage area (km^2)	46.10	1.57	1.57
Stream order	2	1	1
Bankfull depth (m)	3.2	2.0	0.3
Bankfull width (m)	23.2	6.0	3.8
Width to depth ratio	7.3	3.0	12.7
Slope (%)	0.07	0.20	0.11
Sinuosity	1	1	1.6
Urban and Agriculture (%)	40	35	0

Flow Measurement and Flashiness

Continuous data from CC were collected by a USGS real-time gaging station (USGS 02110701) at the watershed outlet. Daily averages of stream stage, flow velocity, rainfall, and turbidity were used in this study (http://waterdata.usgs.gov/nwis/). Discharge estimates published by the USGS were corrected for tidal and backwater effects (Ruhl and Simpson, 2005). At UDC, a modified 2-ft Parshall flume was installed to measure stream stage on a 10-min basis; stage data were converted into flow rates using a calibrated flow-rating curve. Ten-minute flow data were then averaged to obtain daily average flows. Water table elevations in UDC were collected adjacent to the flume using a vented pressure transducer (Infinities USA Inc., Port Orange, Florida). The pressure transducer was suspended at a depth of 1.5 m within a fully screened 10-cm-diameter well and logged data at hourly intervals. Flow data at both sites were converted to depth of runoff per unit watershed area to enable runoff comparisons between watersheds.

To quantify the variability in stream flashiness at both sites, a modified flashiness index (mFI) was calculated for daily flow values at both sites. The mFI is a modification in the RBFI (Baker *et al.*, 2004) where RBFI is expressed as follows:

$$\mathrm{RBFI} = \frac{\sum_{i=1}^{n} |Q_i - Q_{i-1}|}{\frac{\sum_{i=1}^{n} Q_i}{n}} \tag{1}$$

where n is the number of daily average flow values in the period of interest (n = 365 for annual RBFI, n = 30 for monthly RBFI), and Q_i is the set of daily flow values in the period of interest. The RBFI is typically used to calculate an index value for an entire flow record of daily means, or for seasonal subsets of the flow record (e.g., Henshaw and Booth, 2007). For this study, we modified the RBFI (mFI) to calculate a flashiness value for every day in the flow record day based on a five-day moving flow window. If RBFI is considered a measure of the overall average flashiness in the flow record, then mFI could be analogous to a moving average flashiness based on a five-day window. Our mFI is expressed as follows:

$$\mathrm{mFI}_t = \frac{\sum_{i=t-4}^{t} |Q_i - Q_{i-1}|}{\frac{\sum_{i=t-4}^{t} Q_i}{5}} \tag{2}$$

where mFI_t is an index of flashiness calculated for day t in the flow record and based on a five-day window. Q_t is the mean daily flow for day t in the flow record. $Q_{t-1,}$ to Q_{t-4} are the mean daily flows for day t and the four prior days.

Estimating Suspended Sediment Loading Rates

We estimated suspended sediment fluxes by converting continuous turbidity measurements to suspended sediment concentrations ($\mathrm{SSC_{est}}$) values using site-specific linear regression relationships constructed from storm-based SSC measurements and concurrent turbidity measurements. We chose to use storm-based data to capture the full range of sediment and turbidity loadings that occur in the two watersheds. USGS measures turbidity at CC at 15-min intervals using a YSI 6136 turbidity probe mounted to a YSI 6600 EDS sonde (Yellow Springs Instruments, Yellow Springs, Ohio). At UDC, a DTS-12 turbidity sensor (Forest Technology Systems, Victoria, British Columbia, Canada) was utilized. At CC, turbidity data were available from October 2005 to December 2012, whereas at UDC, a turbidity sensor was deployed between February 2010 and April 2011. A combination of the lack of streamflow and sensor malfunction resulted in 282 days (out of 341 days) of usable turbidity data at UDC. A time line of watershed-specific sampling activities including the range of dates when storm sampling, turbidity sampling, groundwater, and flow measurements were conducted is presented in Table 2.

We deployed programmable autosamplers (ISCO® 6712, Teledyne-ISCO, Lincoln, Nebraska) at both watershed outlets to collect streamflow samples during storm events. Each autosampler obtained time-paced, composited stream samples triggered by incident rainfall above a predefined intensity threshold of 0.1 mm/h. Four 250 ml aliquots were composited per sample bottle every 30 min, with 1 sample bottle representing two hours of streamflow and 24 sample bottles capturing the entire sedigraph over a 48-h period. The sampler intake was positioned at an elevation of 0.3 m above the streambed at both sites. The method developed by Anderson (2005) was used to correct for bias associated with using a single SSC sample to represent a cross-sectional average. This method required collecting a cross-sectionally averaged sample per sampled storm

TABLE 2. Time Line of Sampling Activities in the Two Study Watersheds.

Crabtree Canal			
Flow	October 2005	December 2012	2,638 days
Turbidity	October 2005	December 2012	2,638 days
Storm events	May 2008	July 2008	5 storms
Upper Debidue Creek			
Groundwater	February 2006	April 2010	1,510 days
Flow	July 2008	September 2012	1,415 days
Turbidity	February 2010	April 2011	282 days
Storm events	March 2010	January 2011	6 storms

event by compositing subsamples collected at uniform intervals across the stream cross section with a US DH-48 suspended sediment sampler. All streamflow samples were analyzed for SSC (Guy, 1969) and for the organic fraction by loss on ignition per Standard Methods 2540 E (APHA, AWWA, WEF, 2005).

Statistical Analysis

Rainfall and flow data from both watersheds were compared by creating probability exceedence plots to assess similarity in climatic conditions and runoff response. Flow and rainfall data were grouped by water year (WYR) to compare mean values by paired *t*-test. Flow data were also grouped by season (growing season, May to October; and dormant season, November to April) to determine seasonal effects on streamflow in the two watersheds (e.g., Boggs and Sun, 2011). We developed watershed-specific linear regressions between bias-corrected measures of SSC and concomitant turbidity values for five storms at CC (between May and July 2009), and six storms at UDC (between March 2010 and January 2011). SSC values estimated from turbidity measurements (SSC_{est}) were multiplied with flow to obtain instantaneous loading rates. We estimated total suspended sediment yield by integrating instantaneous loads over the period of record using the partial balance method (Probst, 1986). In the CC watershed, the estimated sediment yield included positive loads (sediment export) and negative loads (sediment import) associated with backwater events.

Pearson correlations (Harrell, 2012) were calculated between SSC estimates (SSC_{est}) and other variables that were hypothesized to influence SSC; independent variables included were flow (Q), modified flashiness (mFI), and daily rain accumulation (P). Partial least squares regression (PLSR) was also used to estimate the factors that most influence SSC at the two sites. PLSR was chosen because it is a useful tool for the analysis of strongly correlated data (Wold *et al.*, 2001). PLSR is typically used to infer relationships between predictor and response variables by examining coefficients and loading weights on the most explanatory component axes (Onderka *et al.*, 2012). For PLSR, data were centered and scaled to improve component analysis (Bro and Smilde, 2003); data were centered to a mean value of zero and scaled by variance to a standard deviation of one. PLSR performance was assessed by performing leave-one-out cross-validated predictions (Lachenbruch and Mickey, 1968). Analysis of covariance (ANCOVA) was employed to determine site-related influences on the relationship between turbidity and SSC.

Local polynomial regression (LOESS) fitting techniques (Cleveland and Grosse, 1991) were used with bivariate data to create smoothed trend lines that helped to discern the deterministic component of variation in the data. Specifically, LOESS was used to calculate sediment yield estimates in UDC for the entire period of flow measurement (n = 1,410 days) extending beyond limited turbidity record of only 282 days (Table 2). Where well developed, the SSC-Q relationship may be used to predict SSC (SSC_{pred}) in the absence of measured SSC (Loughran, 1976). The LOESS technique does not presume the nature of the relationship; instead, the technique is governed solely by the distribution of the data in bivariate space. The degree to which smoothing takes place is controlled by a "bandwidth" parameter that defines the neighborhood of data points used to fit a polynomial function. The greater the bandwidth, the smoother the fitted LOESS regression. For this study, LOESS bandwidth was chosen using a generalized cross-validation method proposed by Wahba (1985). Upper and lower bounds for sediment yield predictions generated by the LOESS model were calculated by bootstrap analysis (Efron and Tibshirani, 1993).

Bootstrap analysis was used to estimate upper and lower bounds for sediment yields by generating 5,000 LOESS regression models using resampled Q-SSC_{est} pairs (with replacement). Each model was then used to predict an SSC_{pred} value for every Q in the flow record (July 2008 to September 2012, n = 1,410 days). With 5,000 SSC_{pred} values calculated for every Q, we estimated a lower bound, a median, and an upper bound based upon the 2.5th, 50th, and 97.5th percentiles of the SSC_{pred} distribution. Therefore, for each of the 1,410 days in the flow record, we calculated a median SSC_{pred} with upper and lower bounds. We used these SSC_{pred} values to estimate suspended sediment yield from UDC for the entire period of measured flow (Table 2). We carried out all statistical analyses using the R statistical software (version 2.15.2) (R Core Team, 2012).

RESULTS

Streamflow and Flashiness

The two watersheds experienced similar rainfall events over the period of study as evidenced by the similarity of rainfall *vs.* exceedence probabilities plotted in Figure 3. In addition, paired *t*-tests on rainfall and flow (unit area basis) data grouped by Water Year (WYR) showed that mean annual rainfall

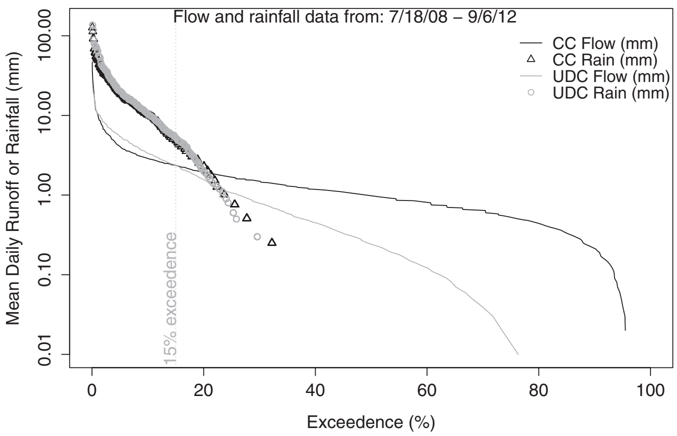

FIGURE 3. Percent Exceedence of Rainfall and Flow for Crabtree Canal (CC) and Upper Debidue Creek (UDC). Flows begin to diverge beyond the 15% exceedence mark. Only data from periods when daily flow and rainfall measurements were available at both sites were used. Concurrent flow measurements from both sites were made between 7/18/08 and 9/6/12. Dates are mm/dd/yy notation.

between the two watersheds during WYR2008 and WYR2012 were not significantly different ($t = -0.73$, df = 4, p-one tail = 0.25), but runoff for that period was ($t = 2.29$, df = 4, p-one tail = 0.04). Flow duration curves show that CC and UDC behaved similarly for only the least frequent (upper 15%) of flows, with considerable divergence at the more frequently occurring flow events (Figure 3). Flow duration curves grouped by season (Figure 4A) show that flow events in CC did not vary appreciably by season, whereas in UDC flows grouped by season reflected dissimilar flow characteristics between growing and dormant seasons. Flows in UDC occurred for only 55% of the time during the growing season (proportion of the total number of growing season days that exhibit no flow), while occurring almost year round during the dormant season. Flow in UDC was consistently lower than CC for any given exceedence condition during the growing season. During the dormant season, flow in UDC was higher than CC for events that occurred less than 20% of the time, and lower than CC for the more frequent flows that occurred over 20% of the time. UDC produced lower runoff depths than the urban stream for every growing season except for the summer of 2008 (Figure 4B) when the forest stream (139 mm) had more runoff than the urban stream (90 mm). The growing season of 2008 was the only period when flows in UDC exceeded CC. We believe this anomaly was due to a large rainfall event that occurred on October 24, 2008 with 137 mm of rainfall at UDC, and only 54 mm at CC — that event generated 60 mm and only 15 mm of runoff from UDC and CC, respectively. In addition, since flow

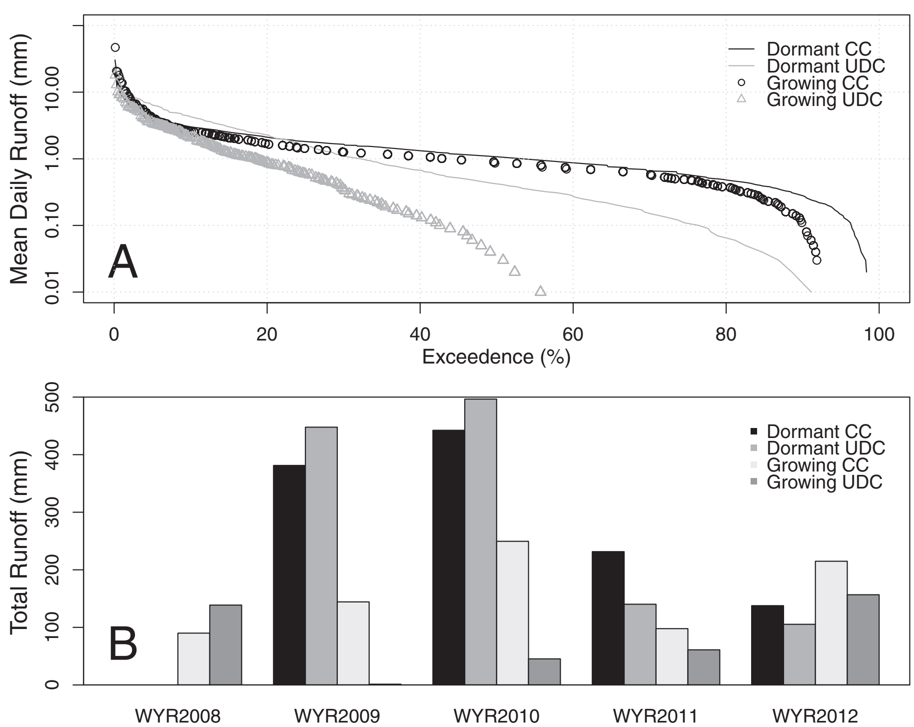

FIGURE 4. (A) Flow Duration Curves from Crabtree Canal (CC) and Upper Debidue Creek (UDC) Grouped by Season. Only data from periods when daily flow measurements were available at both sites were used to create this figure. (B) Total runoff summed by water year (WYR) (October-September) and grouped by season for all concurrent flow measurements. Concurrent flow measurements from both sites were made between July 18, 2008, and September 6, 2012.

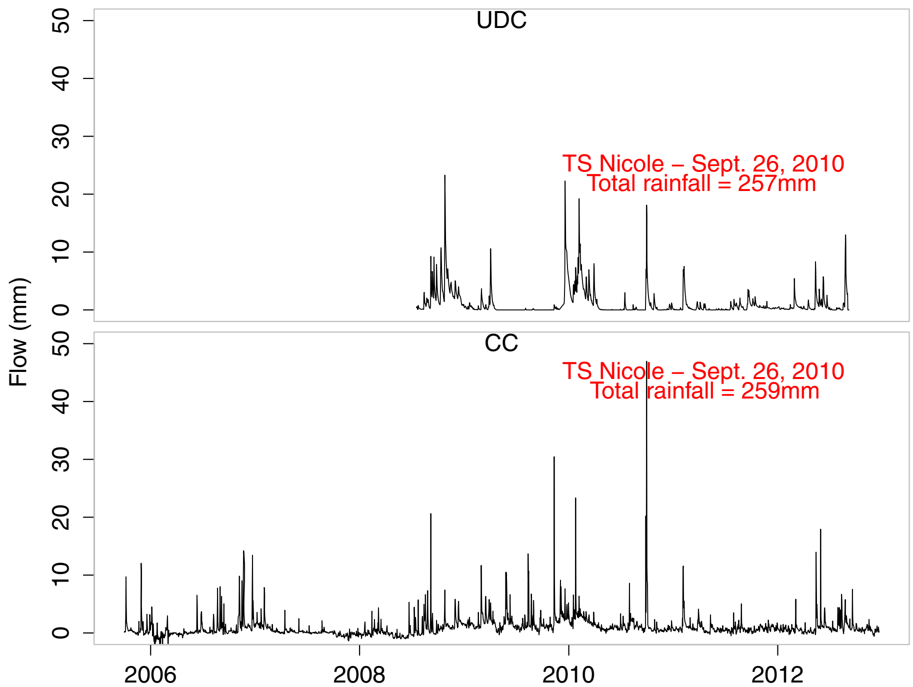

FIGURE 5. Streamflow in Upper Debidue Creek (UDC) and Crabtree Canal (CC) over the Period of Study.

TABLE 3. Rainfall and Runoff Measurements from the Two Watersheds Made between July 18, 2008, and September 6, 2012.

Event	Parameter	CC	UDC
Averages by water year [mean ± SE]	Rainfall (mm)	957 ± 61	1,008 ± 84
	Runoff (mm)	398 ± 45	319 ± 34
	Runoff/ rainfall ratio	0.42	0.32
Tropical Storm Nicole[1]	Rainfall (mm)	259	257
	Runoff (mm)	122	69
	Runoff/ rainfall ratio	0.47	0.27

Notes: CC, Crabtree Canal; UDC, Upper Debidue Creek.
[1]Rainfall associated with Tropical Storm Nicole integrated at both sites from September 26 to 30, 2010, and runoff from September 26 to October 8, 2010.

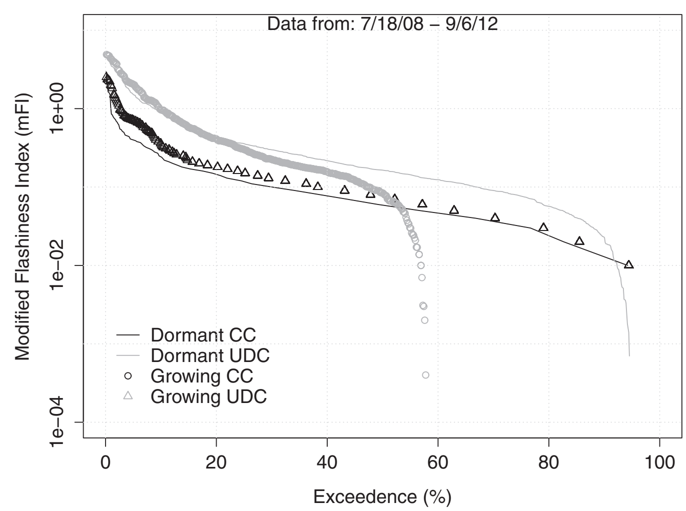

FIGURE 6. Modified Flashiness Index (mFI) Grouped by Season from Upper Debidue Creek (UDC) and Crabtree Canal (CC) over the Period of Study. Concurrent flow measurements from both sites were made between 7/18/08 and 9/6/12. Dates are mm/dd/yy notation.

measurement at UDC only began in the late summer of 2008, only 73 days of data were used from both sites to accumulate growing season runoff totals for 2008. We speculate that the truncated dataset does not fully reflect climatic conditions for the 2008 growing season.

Over the period when concurrent flow measurements were made at both sites, the ratio of total runoff (as equivalent runoff depth) to rainfall was 0.32 and 0.42 for UDC and CC, respectively. However, for a single tropical storm (Tropical Storm [TS] Nicole — September 26, 2010) that produced similar amounts of rainfall at both sites (Figure 5), the ratio of runoff-to-rainfall was 0.27 and 0.47 for UDC and CC, respectively. Other aspects of runoff production are summarized in Table 3. Flashiness measured as RBFI for the entire flow record was 0.35 at UDC and 0.16 at CC. A temporal index of flashiness based on a five-day "prior" window (mFI) showed that the median value of mFI was 0.14 at UDC and 0.06 at CC. A comparison of mFI grouped by season shows that mFI is always higher in UDC when compared with

CC (Figure 6) except when there is no flow in UDC. Important characteristics of streamflow in the two watersheds are summarized in Table 4.

Relating SSC to Turbidity — Urban and Rural Sites

SSC and turbidity were measured during five storm events at CC and during six events at UDC (Figure 7). Linear regressions relating the variation in measured SSC with measured turbidity were statistically significant for both sites (α = 0.95). A linear regression model explained about 90% of the variation in SSC with variation in turbidity at UDC, whereas at CC a linear regression model explained 80% of the variability in SSC with turbidity. Linear

TABLE 4. Comparison of Streamflow Characteristics between Stream Sites Derived from the Entire Data Record at Both Sites.

Parameter	CC	UDC
Average daily flow (Q) (m^3/s)		
Range	-1.61^1 to 25.12	0.00-0.42
Median	0.321	0.004
IQR	0.0712-0.6950	0.0002-0.0191
RBFI for entire flow record	0.16	0.35
mFI		
Median	0.06	0.14
IQR	0.03-0.13	0.03-0.34

Notes: CC, Crabtree Canal; UDC, Upper Debidue Creek; IQR, interquartile range; RBFI, Richards-Baker Flashiness Index; mFI, modified flashiness index.

[1]Negative values representing 16.8% of all flows measured at CC indicate backwater from the Waccamaw River.

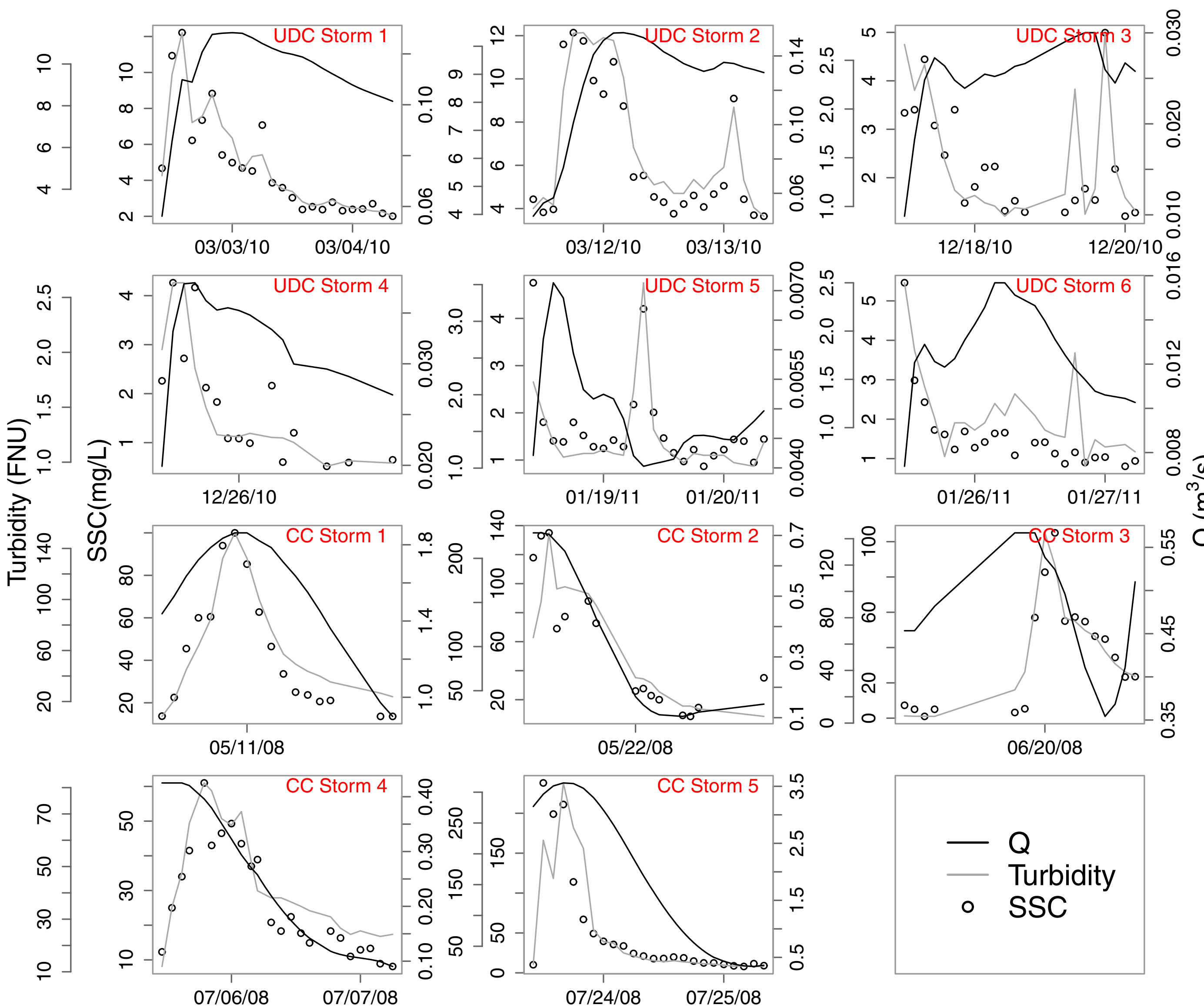

FIGURE 7. Storm Events Measured in Upper Debidue Creek (UDC) and Crabtree Canal (CC). Q, flow; SSC, suspended sediment concentration. Dates are mm/dd/yy notation.

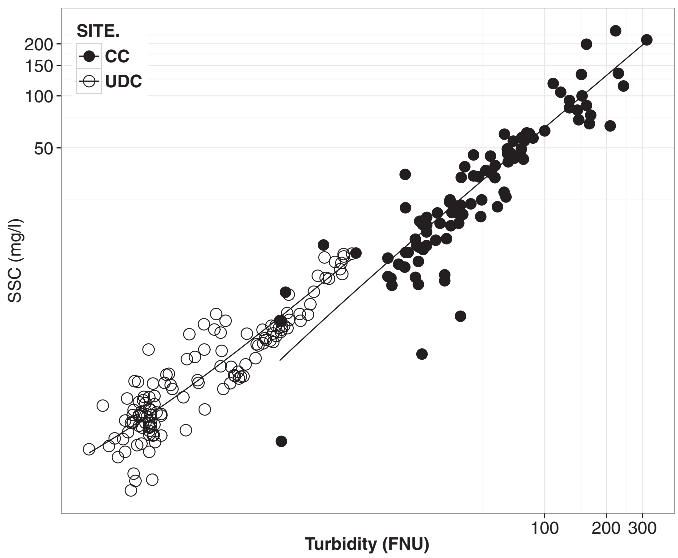

FIGURE 8. Suspended Sediment Concentrations (SSC) *vs.* Turbidity from Storm Sampling Data from the Forested Upper Debidue Creek (UDC) and the Urban Crabtree Canal (CC). Data points and linear regression lines are plotted on log-log axis.

regression models derived from the storm-based data are given below:

$$\text{UDC} : \text{SSC(mg/l)} = 0.97 \times \text{Turbidity(FNU)} + 0.28\ [R^2 = 0.90, p < 0.01] \tag{3}$$

$$\text{CC} : \text{SSC(mg/l)} = 0.66 \times \text{Turbidity(FNU)} - 0.43\ [R^2 = 0.80, p < 0.01] \tag{4}$$

To test if the regression models were statistically distinct (dissimilar slopes and intercepts), ANCOVA was performed with site location (SITE) as a treatment. The ANCOVA (between-subjects factor: SITE [CC, UDC]; covariate: Turbidity) shows that SSC had a significant effect on Turbidity [$F(1, 222) = 1{,}389.4$, $p = 0.00$]; but SITE did not significantly affect SSC [$F(1, 222) = 0.59$, $p = 0.44$], and the interaction term between Turbidity and SITE did not have a significant effect on SSC [$F(1, 222) = 0.53$, $p = 0.47$]. The ANCOVA results therefore suggest that the two regression models have statistically similar slope and intercept terms (Figure 8).

SSC — Organic and Mineral Fraction Partitioning

SSC values measured in streamflow samples from CC ranged from 1 to 238 mg/l, with a median (interquartile range) value of 24.7 mg/l (13.7-54.9 mg/l); SSC at UDC ranged from 0.5 to 12.2 mg/l, with a median value of 2.2 mg/l (1.3-4.3 mg/l). The organic fraction of sediment comprised the larger percentage of SSC at UDC with a median organic fraction of 71% (64-78%), whereas at CC the median organic fraction was 20% (16-25%) of the total SSC measured during storm sampling. Although the organic fraction comprised the major portion of SSC in UDC, samples from CC contained greater concentrations of organic and mineral suspended sediment in terms of absolute values (Figure 9). In UDC, correlation analysis showed that flow during storm sampling was significantly correlated with the organic ($r = 0.70$, $p = 0.00$) and mineral ($r = 0.53$, $p < 0.01$) content (mg/l) of SSC in the water column. However, the fraction of OM (%) in sampled SSC was not correlated ($r = 0.02$, $p = 0.76$) with flow. In CC, flow during storm sampling was also significantly correlated with organic ($r = 0.38$, $p < 0.01$) and mineral ($r = 0.51$, $p < 0.01$) content of SSC. The fraction of OM in sampled SSC was significant and negatively correlated with flow ($r = -0.31$, $p < 0.01$) in CC. The fraction of SSC that comprised organic matter in suspension decreased as SSC increased; this trend was observed at both sites (Figure 10).

Relationship between Flow and Estimated SSC

Site-specific SSC-Turbidity models (Equations 3 and 4) were used to estimate SSC (SSC_{est}) based on measured turbidity data. At both sites, Pearson correlation analysis was carried out with SSC_{est}, mFI, Q, and P. Correlation analysis was only performed on data from days that had both measured turbidity and incident rainfall. There were 704 days in CC and 64 days in UDC that met both criteria of available turbidity measurements and rainfall occurrence. This analysis showed that SSC_{est} was most highly correlated with Q ($r = 0.64$, $p < 0.01$) in UDC. In CC, SSC_{est} was most correlated with mFI ($r = 0.62$, $p < 0.01$). SSC_{est} was also significantly correlated with Q ($r = 0.58$, $p < 0.01$) and P ($r = 0.49$, $p < 0.01$) in CC. Q and P were significantly correlated ($r = 0.46$, $p < 0.01$) in CC, but not in UDC. Scatter plots and associated correlation values from both sites are presented in (Figure 11).

Results of PLSR analysis showed that the root-mean-square error of prediction with a single component was 0.7862 and 0.7614 for UDC and CC, respectively. In UDC, components 1 and 2 explained 32 and 25% of the variance in the data, respectively. Q loaded most heavily on the first component axis and P had the highest loading on the second component axis. mFI had low loading weights on both components reflected by its close proximity to the origin

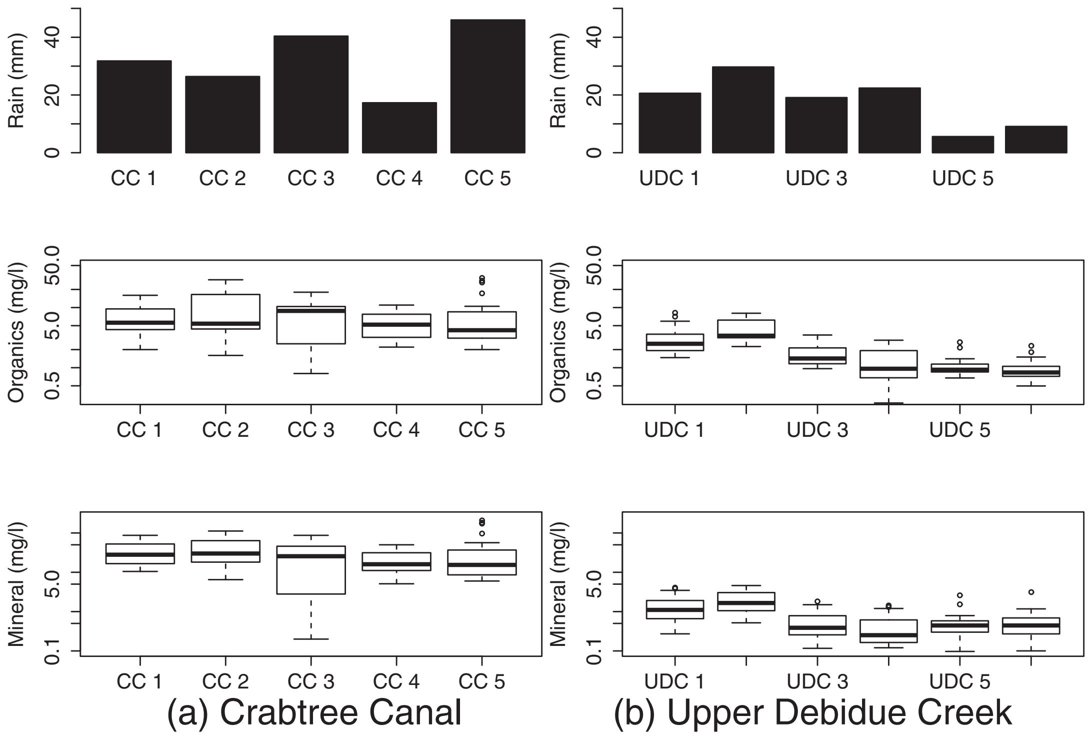

FIGURE 9. Range of Organic and Mineral Content of Suspended Sediment Concentrations from Storm Sampling Data in (a) Crabtree Canal (CC) and (b) Upper Debidue Creek (UDC). Organic and mineral concentrations are plotted on a $\log_{10}$-transformed y-axis.

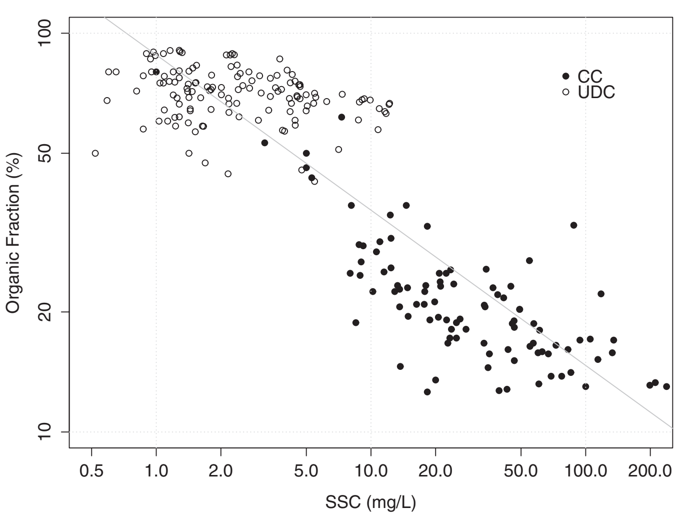

FIGURE 10. Variation in Organic Fraction with Suspended Sediment Concentrations (SSC) from Storm Samples Collected at Both Sites. Data are plotted on $\log_{10}$-transformed axes. A trend line based on data from both sites comprising a power function ($R^2 = 0.78$, $p < 0.05$) illustrates the decrease in organic fraction with increase in SSC.

(Figure 12A). In CC, components 1 and 2 explained 74.8 and 17.9% of the variance in data. All three variables loaded highly on component 1, with mFI having the highest loading, closely followed by Q. P had the highest loading on component 2 (Figure 12B). PLSR provides additional confirmation that SSC is most associated with Q in UDC and with mFI in CC.

Sediment Yield from Upper Debidue Creek

SSC estimates based on the SSC-Turbidity model (Equation 3) alone and for the 282 days of turbidity measurements suggested a sediment yield of 1.15 ± 0.05 tons. This yield on a per unit watershed area is 0.97 ± 0.04 tons/km^2/yr, where upper and lower bounds describe the 95% confidence interval.

To estimate sediment yield for the entire flow record at UDC (July 2008 to September 2012) and to extend SSC_{est} beyond the 282 days of available turbidity data, a LOESS regression model was used to predict SSC_{pred} with Q as an independent variable. Initially, Q and SSC_{est} data pairs obtained during turbidity monitoring (n = 282 days) were used to parameterize the LOESS model. However, the range of Q values (0-0.14 m^3/s) measured during turbidity monitoring represented only 97% of the range of Q values measured over the entire record. The unrepresented 3% of Q were of the upper range of flows measured at UDC and ranged from 0.14 to 0.42 m^3/s. To obviate model extrapolation, and to constrain the model to meaningful pairings of Q

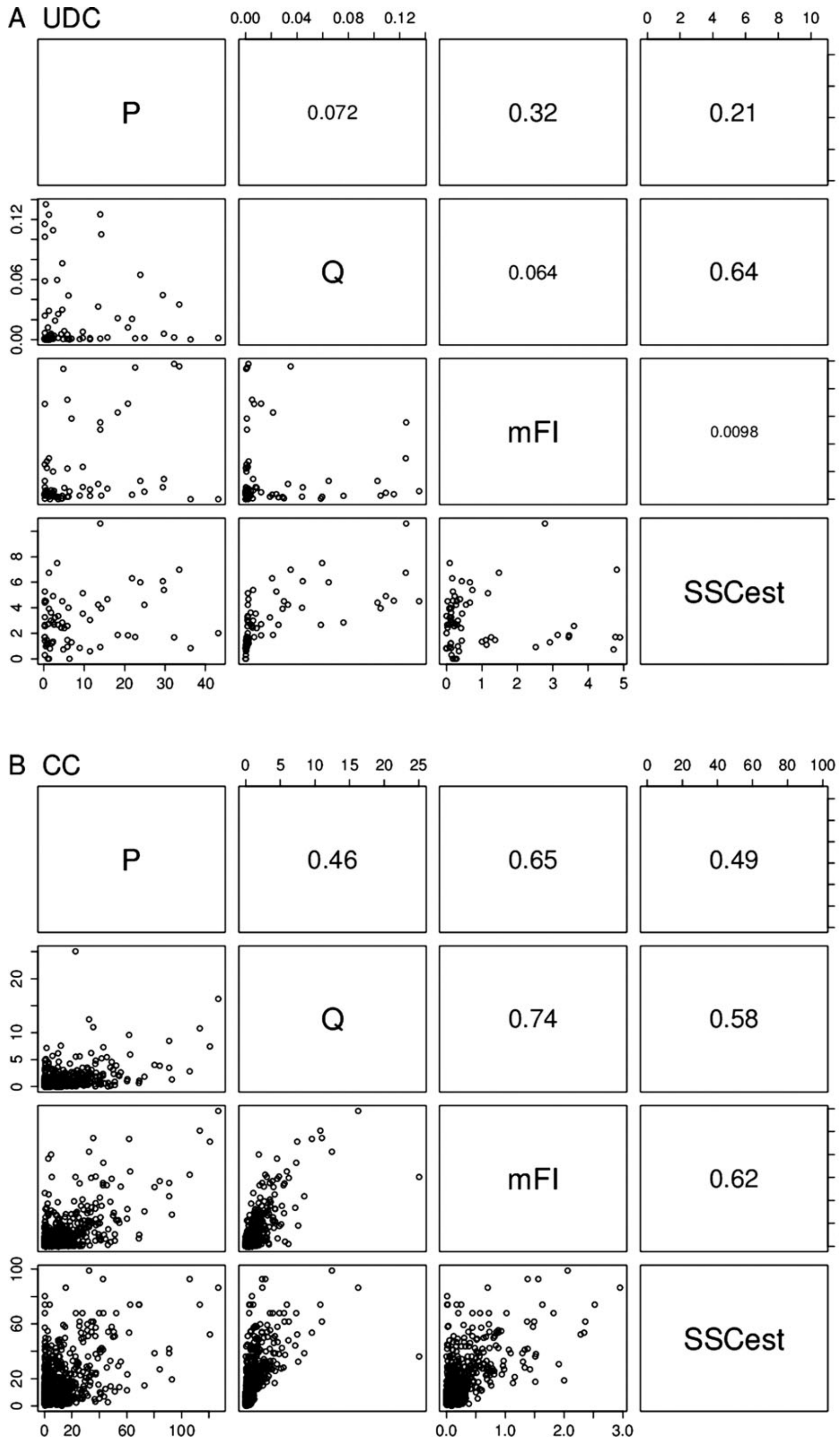

FIGURE 11. Correlation Matrix with Correlation Coefficients Is Shown. Scatter plot of variables tested for correlation in (a) Upper Debidue Creek (UDC) and (b) Crabtree Canal (CC). P, daily rainfall (mm); Q, mean daily flow (m^3/s); mFI, modified flashiness index; SSCest, estimated suspended sediment concentration (mg/l).

and SSC_{est}, Q and SSC_{est} data pairs from the CC dataset were used to fill in the missing upper 3% of the range. The resulting hybridized model development dataset totaled 351 Q-SSC_{est} data pairs, comprising 282 data pairs from UDC and 69 data pairs from CC.

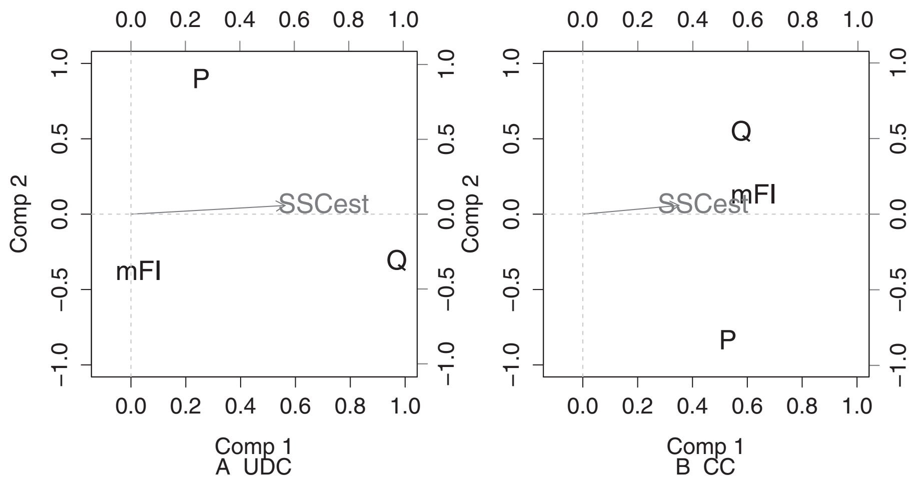

FIGURE 12. Loading Plots from a Partial Least Squares Regression with Estimated Suspended Sediment Concentration (SSC_{est}) as a Dependent Variable, and Rainfall (*P*), Flashiness (mFI), and Flow (*Q*) as Independent Variables. The scores and loadings plot show that SSC_{est} is best associated with flow in Upper Debidue Creek (UDC) and with flashiness in Crabtree Canal (CC). Comp 1, Component axis 1; Comp 2, Component axis 2.

Based on the bootstrapped LOESS regression (bandwidth = 0.32) model, the estimated suspended sediment yield for UDC was 11.93 ± 2.09 tons. When expressed as an annual sediment export rate per unit watershed area, the estimated suspended sediment yield was 1.99 ± 0.35 tons/km^2/yr for this smaller forested watershed. The predicted suspended sediment yield for just the 282 days of turbidity monitoring was 1.02 ± 0.17 tons/km^2/yr, which is similar to the 0.97 ± 0.04 tons/km^2/yr yield estimated by using the Turbidity-SSC linear regression model (Equation 3).

Sediment Yield from Crabtree Canal

We estimated the total annual sediment yield for the CC watershed using SSC_{est} values derived from the Turbidity-SSC model presented in Equation (4). With a continuous turbidity record between October 2005 and December 2012 (n = 2,638 days), daily sediment loads were integrated over time to yield a total of 3,222 ± 598 tons, or 446.15 ± 82.81 tons/yr. When normalized by watershed area, the specific yield was 9.68 ± 1.80 tons/km^2/yr. Sediment yield from CC concurrent with turbidity monitoring in UDC was 514.43 ± 114.43 tons/yr, and the specific sediment yield was 11.16 ± 2.48 tons/km^2/yr, where upper and lower bounds describe a 95% confidence interval. While the sediment yields calculated at the CC outlet represent net sediment exports, there is a possibility that some sediments derived from sources downstream of the gage and transported to the gage during backwater events bias our results. However, given the geomorphic stability of the downstream riparian swamp system, its well-connected floodplain, and the relatively low-flow magnitudes associated with these backwater events, the potential for bias is likely to be insignificant.

Estimating Sediment Yield in Crabtree Canal from Anthropogenic Activities

Nonforest land cover types in the CC watershed include 24.4% wetland, 17.2% agriculture, and 23.0% urbanizing with the balance of 35.3% under forest cover. In the CC watershed, mean annual sediment yield from forest cover (16.25 km^2) alone based upon the estimated specific sediment yield from a forested watershed (UDC: 1.99 tons/km^2/yr) is 32.24 tons/yr. Given that the mean annual sediment yield measured at the CC watershed outlet was 514.43 tons/yr and assuming that wetland regions do not generate sediment, the sediment yield from urbanizing and agricultural land cover in CC is therefore 482.14 tons/yr or 16.15 tons/km^2/yr. This estimate includes sediments generated from all in-channel sources.

DISCUSSION

Streamflow

On the basis of soil drainage classes alone, the urban CC with hydrologic group C soils (drained) should produce less runoff per unit drainage area than the forested UDC with hydrologic group D soils (undrained). However, the mean runoff-to-rainfall ratio was higher in the urban watershed that produced about 10% more runoff per unit rainfall than the forested watershed. Seasonal flow duration curves from UDC and CC were least similar during the growing season and most similar during the dormant season. UDC was characterized by intermittent flow conditions in the growing season whereas flow was perennial in CC. The urban CC watershed with its efficient drainage network and high degree of imperviousness is suited to transform incident precipitation to surface runoff. On the other hand, the forested UDC watershed with its diffused drainage network and high vegetative cover promotes higher evapotranspiration losses and higher storage in organic matter-rich surface-soil layers and depressions (Whelan, 1957; Schüler, 2006; Sun and Lockaby, 2012) — both evapotranspiration and storage are processes that limit runoff production. The disparity in hydrologic character was further exemplified by runoff response to a single extreme rainfall event (TS Nicole) when only 28% of the rainfall occurring during that extreme event appeared as streamflow in UDC compared to 49% in CC (Table 3). The disparity in watershed sizes between UDC and CC hinder our ability to directly compare results from the two watersheds. Rainfall distribution can become increasingly heterogeneous with increases in watershed area, especially in the case of summer thunderstorms with small geographic footprints. However, TS Nicole, a large tropical storm with a broad geographic footprint allowed for some comparison of runoff response between the two watersheds. Our results also agree with other studies that compare runoff from similarly sized watersheds with contrasting land cover (e.g., Lull and Sopper, 1969; Wahl *et al.*, 1997; Boggs and Sun, 2011).

Stream flashiness as quantified by the RBFI (Baker *et al.*, 2004) indicated that UDC experienced flashier flows than the urban CC. While watershed urbanization and stream channelization typically result in increased RBFI measures, RBFI is also inversely related to watershed area (Baker *et al.*, 2004), and directly proportional to unit area groundwater inflows. Groundwater table position has already been shown to be an influential parameter of runoff production in UDC (Epps *et al.*, 2013). We therefore hypothesize that the RBFI value in UDC when compared with CC is attributable to UDC's smaller watershed area and significant groundwater input. Flashiness based on mFI reveals that the flashiest flows tended to occur between December and April when groundwater levels, and therefore the associated baseflow in the stream, are highest (Figure 13).

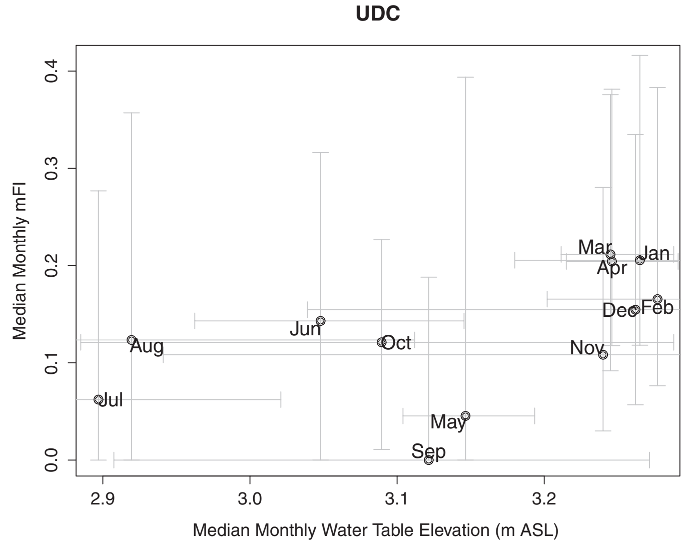

FIGURE 13. Variation in Modified Flashiness Index (mFI) with Groundwater Position in Upper Debidue Creek (UDC) Showing That Months Associated with High Groundwater Elevation (December-April) Are Also the Months When the Flashiest Flows Occur in the Stream. The scatter plot represents monthly median values derived from daily averages. Error bars extend from the monthly median to the 25th and 75th percentiles. m ASL, meters above mean sea level.

Sediment Composition

Turbidity was a good surrogate for SSC in both watersheds as these two parameters were strongly correlated (Equations 3 and 4). An ANCOVA suggested that the linear regression relationships between turbidity and SSC were similar in both watersheds despite disparities in the ranges of estimated SSC and the dissimilar nature of the sediment at the two sites. In UDC, while organic and mineral content both increased with increasing flows, the proportion of SSC comprising organic matter from storm sampling was consistent across the sampled storms and the system. With the quality of SSC consistent across the sampled storms, the data suggest a consistent and abundant source of material available for transport. In addition, given that OM comprised the majority fraction of SSC, it would appear that UDC epitomizes a stable forested first-order stream where floodplain connection and abundant sources of organic input lead to high OM content in the water column (Ward and Stanford, 1995; Hein *et al.*, 2003). On the basis of these results, we hypothesize that the abundance of OM available from a well-connected floodplain was the primary source of material exported from UDC. In contrast to UDC, the mineral fraction dominated SSC across all sampled storms in CC. In addition, the fraction of organic matter decreased with increasing flows in CC suggesting both a variable and flow-dependent sediment source that resulted in greater proportions of mineral matter entrained with increasing flows. The high percentage of mineral matter and its dependency on flow magnitude was likely a reflection of the widespread channel instability in the CC watershed. This instability was driven by anthropocentric activity on the landscape (Hammer, 1972; Arnold *et al.*, 1982; Booth, 1990) and by instream channel maintenance activities (Simon and Hupp, 1986).

SSC and Flashiness

SSC in UDC and CC was significantly correlated with flow (*Q*), a relationship that has been well established in a wide variety of landscapes (e.g., Heidel, 1956; Guy, 1964; Arnborg *et al.*, 1967; Walling, 1977; Williams, 1989). In CC, the highest concentrations of SSC occurred when the change in daily flow relative to the average five-day flow was the greatest, that is, the highest mFI. The Pearson correlation between SSC_{est} and Q in UDC, and SSC_{est} and mFI in CC were confirmed by PLSR analysis. PLSR showed that in UDC, SSC was more associated with Q than with mFI or P. In fact, mFI appeared to have little influence on SSC even though UDC experienced flows that were flashier than flows in CC. In CC, PLSR results suggest that SSC_{est} was more associated with the rate of change in flow as opposed to flow magnitude. With a channel defined by uniform side slopes and no floodplain connectivity, a rapid change in flow is equivalent to a rapid change in stream stage. The rapid rise and fall of stream stage can induce sudden wetting and drawdown in the channel bank material leading to bank instability (Thorne *et al.*, 1998). Work by Simon *et al.* (2000), showed that five major factors contribute to bank failure in incised stream channels: (1) increase in soil bulk unit weight; (2) decrease in matric suction and consequent loss of cohesion; (3) generation of positive pore water pressures; (4) entrainment of failed material; and (5) loss of confining pressure during recession of storm flow. In a stream experiencing rapid changes in flow (or flashiness) as observed in CC, every one of the above five criteria would be satisfied. Bank failure has been a common sight after a storm event in CC, and it is conceivable that sediment production in that drainage network is derived primarily from failed bank material. This could also explain the relatively high mineral content of these sediments as compared with UDC.

Sediment Yield

Annual estimates of sediment yields per unit area of watershed show the urbanizing watershed yielded 5.6 times more suspended sediment compared with the forested watershed. This result is identical to a 5.6 times increase in annual sediment loads reported by Wahl *et al.* (1997) when comparing an urban to a forested watershed near our study sites (period of data collection: 1993-1994). The effect of urbanization on sediment yield produced similar results in these two studies conducted in the same physiographic region, even though they were conducted almost two decades apart. In terms of absolute loads, sediment yield from UDC (1.99 tons/km^2/yr) and CC (11.16 tons/km^2/yr) were 32% less than the yields of 2.92 tons/km^2/yr and 16.33 tons/km^2/yr reported by Wahl *et al.* (1997) for a forested and urban watershed, respectively. We speculate that the dissimilarity in absolute yield comparisons was likely due to dissimilar rainfall patterns during the study periods. Annual rainfall for both watersheds studied by Wahl *et al.* (1997) was 1,370 mm during the 1993-1994 period, whereas for this study, average annual rainfall between 2008 and 2012 was 957 mm and 1,008 mm in UDC and CC, respectively.

In a study by Simon and Klimetz (2008) on suspended sediment export from gaged streams in the Southeast, 24 sites in the Middle Atlantic Coastal Plain and 30 sites in the Southern Coastal Plain with drainage areas that ranged from 0.1 to 100,000 km^2 were analyzed for suspended sediment yields. Each site was categorized as "stable" or "unstable" based on a rapid geomorphic assessment. When compared with the stable streams in the Southern Coastal Plain Ecoregion that Simon and Klimetz (2008) studied, UDC's annual sediment was most comparable to the yield from the 25th percentile (1.58 tons/km^2/yr) of stable sites. The annual sediment yield from CC was closest in value to the yield from the 50th percentile (11.1 tons/km^2/yr) of unstable sites in the Middle Atlantic Coastal Plain Ecoregion.

An estimate of annual sediment yield from forested land cover in CC (based upon yields measured in UDC) suggests that 93.7% of the sediment measured at the CC outlet was produced from instream sources and the 40.2% of the watershed area classified as agriculture or developed. In terms of specific yields from CC, we estimate that instream sources, agricultural, and urbanizing land cover produced about 8.1 times the amount of sediment generated from forested land.

CONCLUSIONS

In an effort to quantify the range of flow and sediment yields produced by anthropogenic activities within coastal watersheds of the South Carolina Lower Coastal Plain, we estimated flow and sediment yields from a small, forested watershed and from a larger urbanizing watershed. Flow, rainfall, turbidity, and SSC data were analyzed by several innovative statistical tests that revealed important information related to sediment and flow production in coastal watersheds. PLSR proved to be a useful tool in the analysis of multicollinear data. Bootstrap analysis of LOESS regression simulations helped to quantify upper and lower bounds for sediment yields.

Our results showed that while flow expressed as equivalent depths of runoff was similar on an annual basis, the smaller forested watershed with a shallow water table experienced flashier flows. An extreme storm event produced a greater runoff response in the urban watershed compared with the forested watershed, a result that illustrates the ability of the forested watershed to assimilate high rainfall storm events. We speculate that the mechanisms that enable this assimilation were higher evapotranspiration losses and floodplain storage.

Channel form and land use were suggested as important factors in determining the quality of sediments in terms of mineral and organic fractions. The urbanizing watershed exported 5.6 times more suspended sediment than the forested watershed on a per unit area basis. The sediment exported from the small headwater forested stream system (UDC) was primarily composed of OM, whereas the larger urbanized and channelized watershed exported sediment composed primarily of mineral matter. By accounting for sediments that likely came from the forested areas, we estimated that agricultural and urbanizing land cover alone generated 8.1 times the sediment from the forest areas. Our research suggested that rapidly changing flows in the urban watershed was the primary driver of SSC in the water column. With widely observed bank instability in the system and the high mineral fraction of suspended sediment, we speculate that most of the exported sediment was derived from the channel banks. The sediment export rate from the urbanizing watershed was consistent with export rates from other similar watersheds in the region. In the stable floodplain-connected channel that drains the forested watershed, sediment production was flow limited with the majority of sediment comprising OM. We hypothesize that the high organic content was an indication of a material sourced from detritus on the floodplain and direct litter input from overhanging canopy. However, this hypothesis warrants further investigation.

In recent years, there has been considerable progress with improved runoff and sediment retention practices on the landscape; however, the management of the drainage networks in the coastal watersheds of South Carolina is still an area of exigent need. Efforts to encourage a return to dynamic stability as predicted by well-established channel evolution models are currently underway. In September 2010, the Horry County Stormwater Management Program revised channel maintenance plans to limit the excavation of accumulated sediments from within channelized streams — a practice that has been shown to exacerbate channel instability. This revised strategy was adopted in eight suburban and exurban watersheds in the County. Based upon studies from other parts of the country, two-stage channels were constructed in two reaches of CC as part of an effort to restore floodplain connectivity. Determining the impacts of these efforts is an area of ongoing work. However, based upon other studies (Jayakaran and Ward, 2007; Smith and Pappas, 2007; Vermonden *et al.*, 2009), we believe that limiting the dredging of accumulated sediments within the channel is a step in the right direction and a model for wider adoption across South Carolina.

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