Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision, 1997
S.S. Y. Wang, E.J. Langendoen and F.D. Shields, Jr. (eds.) ISBN 0-937099-05-X

SEDIMENT PRODUCTION FROM SMALL, UNDISTURBED FORESTED BASINS IN THE UPPER COASTAL PLAIN

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ABSTRACT

Forest lands in the Upper Coastal Plain (UCP) of the American South are widely recognized as producing water with relatively low amounts of sediment. Previous research has established that sediment concentrations from forest basins lacking well-defined channel networks averages 5.3 to 6.2 kg of sediment per hectare per centimeter of runoff (kg/ha-cm) in this physiographic region. Our results indicate that sediment concentrations are much greater in forested basins which have channel networks. Eight catchments in the Holly Springs National Forest (HSNF) of Mississippi with areas between 1.8 and 2.8 ha were monitored from 1982 to 1989. Mean sediment concentration for all basins during this period is 52.4 kg/ha-cm. This value is comparable to the 77.7 kg/ha-cm observed for another UCP basins with channel development. Sediment concentrations in the HSNF basins do not correlate with either stormflow peak discharge or water yield, nor do basin morphometric attributes appear to explain the observed variation in concentrations. The presence of continuous ground cover and cohesive bank materials, and the lack of observed surface erosion in the HSNF catchments all suggest that the source of this sediment is in-channel storage. Moreover, these results indicate that relatively high sediment concentrations can be produced by stable forested basins which have not been disturbed by timber harvesting.

INTRODUCTION

Forested areas are widely recognized as producing less sediment than agricultural and developed areas. Several studies have investigated the sediment production characteristics of forested basins in the Upper Coastal Plain (UCP) of the American South. Ursic (1975, 1986) recommended using sediment yield weighted by runoff yield and expressed as a concentration to compare sediment production from forest lands to regulatory water quality standards. He reports that concentrations thus derived are independent of either individual storm or annual runoff yields, thereby implying that annual or mean stormflow concentration should be representative of a basin's inherent sediment production characteristics and not biased by runoff amounts. Ursic also concludes that since concentrations are less

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variable than sediment yields, their use is more meaningful when making comparisons between different sites and studies.

Past research indicates that a "typical" sediment concentration for small forested basins in the UCP based on past research is 5.3-6.2 kg/ha-cm (Ursic 1986, Marion and Ursic 1993). This standard was determined for basins without well-defined channel networks. This exclusion was by design; most past research focused on sediment production from open slope areas, thus they avoided sites where channel systems were established. Also, this standard was offered without any statistical justification that the mean stormflow concentrations as computed for particular locations were representative of the concentration values observed.

This paper has three objectives. First, it will determine the sediment concentrationcharacteristics of eight, small forested basins in the UCP with well-defined channel systems. Second, it will assess how morphometric differences between basins affect sediment concentrations. Lastly, it will evaluate the relationship of hydrologic factors to sediment production from these basins.

DATA AND SITE DESCRIPTIONS

The UCP consists of sedimentary formations that vary in age from Cretaceous to the Quaternary. Relief is typically less than 90 m, but there are extensive areas of rolling hills with moderately steep slopes. Soils are highly erodible and indurated bedrock exposures are rare. The climate is humid subtropical with annual precipitation ranging between 1200-2000 mm and occurring mostly as intense rainstorms which are distributed fairly evenly throughout the year. Temperatures commonly range between 0-15°C in winter and 20-35°C in summer.

Eight small, forested basins in the Holly Springs National Forest were used for this paper to assess sediment production. These watersheds, hereafter referred to as the Tower basins, are typical of conditions and basin characteristics found throughout the Forest and the UCP. They range in size from 1.8 to 2.8 ha, with slopes between 15 and 40%. No active gullies or roads occur within these basins. Vegetation consists of a healthy SO-60 yr old, mixed pine-hardwood stand which has not been significantly disturbed since its establishment. Soils are well drained with a sandy loam to loamy sand surface horizons and sandy clay loam to sandy loam subsoils. Infiltration rates greatly exceed all but the most extreme precipitation intensities. Each basin has a well-defined channel network. Table 1 lists selected morphometric characteristics of these catchments. Streamflow is ephemeral. occurring for periods of days to weeks after rainfall.

Table 1. Selected morphometric characteristics of Tower basins.

Basin Number	Basin Area (ha)	Basin Length (m)	Basin Relief (m)	Main-stream Length (m)	-Main-stream Relief (m)	Total Stream Length (m)	Drainage Density (m/ha)
1	2.87	247.7	30.5	233.2	22.9	548.7	191.2
2	2.49	213.4	20.1	221.0	13.7	350.8	140.9
3	1.76	216.4	23.2	182.9	16.8	392.6	223.1
4	1.99	266.7	30.5	254.5	21.3	373.3	187.6
5	1.76	192.0	32.3	176.8	25.9	465.0	264.2
6	2.38	271.3	29.3	224.0	13.7	458.6	192.7
8	2.59	198.1	20.1	164.6	13.7	399.0	154.1
9	2.23	175.3	27.4	182.9	25.9	377.3	169.2

Sediment yield and runoff data were collected from water years 1982-1989. Streamflow was measured using 3-ft H-flumes and stage recorders installed at the outlet of each basin. Sediment production was measured using a combination of two sampling methods. Sediment which passed over each flume was sampled using a Coshocton wheel proportional sampler installed immediately below the flume invert. The amount of sediment transported over the flume for a given sampling period was calculated from the sediment concentration measured for that period and the corresponding runoff yield. Sediment which settled out in the flume approach and not sampled by the Coshocton wheel was weighed each time the Coshocton sample was collected and converted to dry weight based on a subsample. The combined sediment concentration was computed by adding the transported and deposited sediment yields together and dividing by the runoff yield for the sampling period. Thus, if 80 kg/ha were transported, 20 kg/ha deposited, and runoff yield was 1.0 cm, then sediment concentration was 100 kg/ha-cm. Whenever possible, sediment yield was measured after each runoff event, however, there were many occasions when two or more runoff events occurred during a single sampling period. Also, the data record is not continuous due to equipment malfunctions and operator mistakes. It contains 23 to 34 samples for each watershed with a total of 232 events sampled.

Three different data sets were used to address our objectives. A “Composite” data set was used to assess typical sediment production behavior from the sample basins. It is composed of data from all valid sample periods from WY 1982-1989. As such it contains runoff and sediment data for all types of runoff events. Mean annual sediment yields could not be directly computed for the Tower basins because of missing data. We assume that the mean derived from a random, unbiased sample of runoff events is equivalent to the mean annual sediment concentration. We consider the Composite data set to be such a sample. No bias was used in selecting samples other than rejecting any data which was suspect due to aspects of the way in which they were collected. No judgements were based solely on the measured values. We assume this approximates a random sample. A “Common event” data set was used to assess whether there are differences in sediment concentration between basins. It is comprised of data for only those events in which all eight basins responded to the same storm. It is thus constrained so as to control for rainfall event magnitude and antecedent conditions. A “Single” data set was used to analyze the relationships between sediment production and hydrologic factors. It contains data for only those events in which runoff produced a single-peak hydrograph and the corresponding sediment sample represents only sediment transported during that single runoff event. We reason that any relationship between runoff and sediment variables will be most evident using these data.

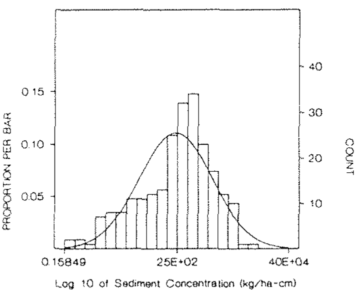

Figure 1. Sediment concentration distribution for all Tower events. Log-normal distribution shown by curve.

RESULTS AND DISCUSSION

The distribution of sediment concentrations from the Composite data set is highly skewed. It is best approximated by the log-normal distribution (see Fig. 1). Normal, exponential, and gamma distributions all offer poorer fits to the observed data than does the iog-normal. There is a larger than expected number of relatively high concentration values even when log-transformed, Concentrations range from 0.16 to almost 699.00 kg/ha-cm for non-zero values, or over four orders of magnitude. The interquartile range is approximately 9 to 69 kg/ha-cm.

Mean values are generally used as the location statistic to describe typical sediment production. Given the skewed distribution of the Tower data, the mean does not represent the most frequently occurring values It is 61.2 kg/ha-cm for the raw data, although 50% of the observed values were less than or equal to 3 1.15 kg/ha-cm. The mean of 52.36 kg/ha-cm for the log-normal distribution is a much better estimate of central tendency.

Fig. 2 shows annual or mean annual sediment concentrations from various UCP studies and the Tower basins. It is adapted from Marion and Ursic (1993) which contains the details on the data sources and site locations. All values plotted are for relatively undisturbed forested basins that are comparable in size to the Tower catchments. All are for basins without well developed channel networks except site CPU-19 and the Tower basins. All except site CPU-19 are less than half the magnitude of the Tower basins. Indeed, the range of "typical" sediment concentrations for undisturbed forested basins reported by Marion and Ursic (1993) of 5.3-6.2 kg/ha-cm is one-tenth that measured for the Tower basins. Only site CPU-19 (Ursic 1975), which also possessed a well-developed channel network, shows sediment production comparable to the Tower sites.

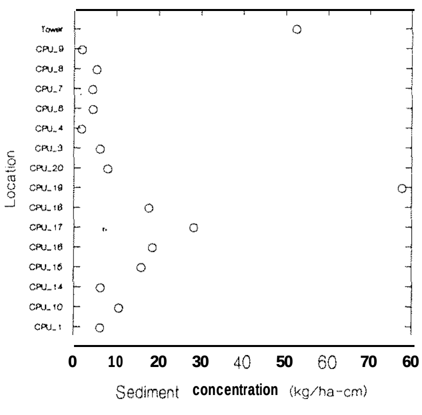

Figure 2. Mean annual or mean stormflow sediment concentrations from small, undisturbed basins in the Upper Coastal Plain.

There appear to be important differences between Tower watersheds in their sediment production behavior. Variation in sediment concentrations between watersheds was evaluated using the Common data set. Overall differences were tested using the Friedman non-parametric test due to the small sample size (8 events) and its large departure from a normal distribution. They are significant at the 0.05 alpha level. Multiple comparison tests (Daniel 1978) suggest that Tower 1, 4, and 5 all have higher than expected sediment export while Tower 6 and 8 have lower than expected export. While the only significant difference (overall alpha = 0.20) is between Tower 5 and 6, the other comparisons are close to the rejection level.

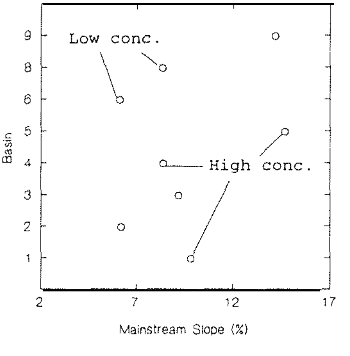

Figure 3. Mainstream slope for all Tower basins. Basins with relatively high and low sediment concentrations are noted.

Basin morphometric variables were used to evaluate whether differences in basin structure might explain these differences in sediment production. Variables assessed were basin relief, basin length, basin width, basin perimeter, mainstream length, mainstream relief, mainstream slope, number of stream segments, number of streams by stream order, total stream lengths by stream order, total channel length, and drainage density. Fig. 3 is typical of the unclear relationship between sediment concentrations and basin morphometry. All variables show a pattern in which the morphometric values for the relatively low and high sediment producing basins are intermixed with each other. Mainstream relief and, to a lesser degree, mainstream slope and drainage density all have higher values for the high sediment producing basins and lower values for the low producers. However, interpretation of the relationship is confounded by the fact that values for the three basins with moderate export behavior don’t plot between the two other groups, rather they span the range between them.

Tower basin sediment concentrations are independent of all runoff measures considered. Their relationship to flow duration, lag-to-peak, runoff yield, and peak discharge were evaluated using rhe Single data set. Fig. 4 is typical of these relationships which are most clearly evident when plotted on log scales. Generally, concentrations increase with increases in any of the flow metrics, however the correlations are extremely low (less than 36%). Their independence from flow variables confirms Ursic’s (I 975, 1986) findings.

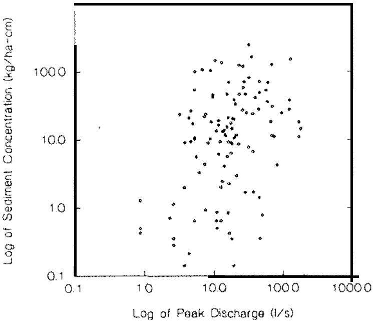

Figure 4. Relationship of sediment concentration to peak discharge for “Single” type events on all Tower basins.

Given that concentrations do not appear to be controlled by either basin structure or runoff characteristics, what other factors might explain either the high sediment production by these basins in general or the differences between them’? Substantial sediment contributions from out-channel sources to channel networks during storms does not seem likely. Ground cover was continuous throughout the record period and was not disturbed by any timber harvesting activities. Physical evidence of overland flow on open slopes has not been observed. The fact that infiltration rates are well above all but the most extreme rainfall intensities further suggests that overland does not occur frequently in these basins.

The contribution of channel banks during storms was not evaluated in this study. Visual observations indicated that channel banks are composed of fairly cohesive material. Tests indicate that the lower soil horizons which make up the channel banks range from sandy loams to sandy clay loams (Morris 1981). It is possible that those basins with higher sediment concentrations may have less cohesive banks than seems the general case for area soils.

Both high overall concentrations and differences between basins may be the result of a slug-type sediment transport mechanism. Slug transport occurs when high density sediment pulses move irregularly downstream. Slug movement rates may be tied to hydraulic thresholds, episodic breakdown of temporary storage structures (e.g., litter wads, coarse woody debris dams), longitudinal variation in bed particle size composition, or combinations of these factors. Slug-type transport occurrence is suggested by the sporadic occurrence of sediment deposits in Tower flume approaches and their lack of correlation to runoff variables.

CONCLUSIONS

Our's and Ursic's (1975) results indicate that sediment concentrations are higher in runoff from forested basins having well developed drainage networks. Individual stormflow sediment concentrations for all Tower basins are log-normally distributed with a mean of 52.4 kg/ha-cm and the middle 50% of values falling between 9 to 69 kg/ha-cm. This mean value is roughly an order of magnitude greater than that for forest basins lacking channel systems. This indicates that relatively high sediment export from forested basins is not unusual even under undisturbed conditions.

Sediment concentration controls are complex. Neither runoff or basin morphometric characteristics explain variations in sediment concentration. Sediment concentration is clearly independent of runoff amount, peak discharge, flow duration, or lag-to-peak time. There are no apparent relationships between the morphometric attributes of individual Tower basins and the sediment concentrations produced by them. In-channel processes or structures may be the primary controls which determine sediment concentrations in these basins. The lack of observed out-channel sediment sources or indications of overland flow processes for delivering sediment to channels indicates that slope processes are not the primary controls over sediment transport dynamics. It remains to be determined why sediment concentrations increase with increasing channel development.

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