Influence of bank vegetation on channel morphology in rural and urban watersheds

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ABSTRACT

Stream-bank vegetation significantly influences the morphology of streams in the Piedmont region of the United States. We surveyed the morphology of 26 paired stream reaches in southeastern Pennsylvania, northern Maryland, and Delaware. One member of each pair has a forested riparian zone, whereas the other has a riparian zone composed primarily of grass. The paired reaches are nearly contiguous, so all significant channel-forming variables except riparian vegetation are held constant. The extent of urban development of the watersheds upstream of the paired reaches also varies considerably, allowing us to determine the combined influence of riparian vegetation and urbanization on channel morphology. Statistical analyses indicate that (1) channels with forested riparian zones are wider than channels with nonforested riparian zones, (2) channels in urbanized watersheds are wider than channels in nonurbanized watersheds, and (3) the effect of riparian vegetation is independent of the level of urbanization.

Keywords: streams, geomorphology, forests, urbanization, watersheds, fluvial.

INTRODUCTION

Restoration of riparian forests has become a major focus of watershed initiatives throughout the United States (Palone and Todd, 1997). There is a growing interest in restoring streams in urban or urbanizing areas because of the increased impacts caused by rapid growth and urban sprawl (Riley, 1998). Reforestation could play a pivotal role in restoring urban streams, but the scientific understanding needed to guide restoration practices does not currently exist (Booth and Jackson, 1997).

Although the effects of urbanization on watershed hydrology and river-channel morphology have been studied for decades (Wolman, 1967; Booth and Jackson, 1997), previous studies focused on a limited number of morphologic variables and ignored the complicating influence of varying riparian vegetation. For stream-restoration designs to be effective, the combined influence of watershed disturbance (e.g., urbanization) and riparian condition on fluvial morphology must be more fully understood (Goodwin et al., 1997).

Numerous studies link riparian vegetation and geomorphic forms and processes (see Gregory and Gurnell, 1988). Data from several geographic locations indicate that forested reaches of small streams are wider than contiguous nonforested, grass-bordered reaches of the same streams (Sweeney, 1992; Davies-Colley, 1997; Trimble, 1997a). However, others suggest that streams flowing through grassland are wider than those flowing through forest (Murgatroyd and Ternan, 1983; Rosgen, 1996). Such disagreement is most likely due to site-specific differences such as the type and density of vegetation, soil conditions, flow regime, stream size, slopes, geologic setting, disturbance history, and watershed characteristics (Montgomery, 1997).

When a watershed is developed or urbanized, the supply of water and sediment to stream channels changes dramatically (Wolman, 1967). Peak discharges and runoff volumes increase as water quickly runs off of paved surfaces (Schueler, 1995). Increased storm discharges promote channel erosion (Trimble, 1997b), which results in increased channel size (Pizzuto et al., 2000).

Here we present measurements of channel characteristics of paired stream reaches with and without riparian forests in Pennsylvania, Maryland, and Delaware. Our study was designed to answer three questions concerning channel morphology: (1) Does forested riparian cover affect stream-channel morphology? (2) Does the level of urban development in contributing watersheds affect stream-channel morphology? (3) If riparian forests do influence stream-channel morphology, is the influence of riparian forest observed regardless of the level of urbanization in the watershed?

STUDY AREA AND SAMPLING

The study includes 26 paired stream reaches with drainage basins of 0.39–50 km² in southeastern Pennsylvania, northern Maryland, and Delaware (Fig. 1). This region is characterized by a gradient of land cover ranging from mixed agricultural uses with a fragmented, mixed-hardwood deciduous forest in more rural areas, to suburban and highly urbanized...
land uses in and around Philadelphia. The study area is within the Piedmont Uplands, formed mainly on schist, and the Piedmont Lowlands, formed on sandstone and shale. The study reaches are self-formed alluvial channels with gravelly beds and cohesive banks composed of sandy silt. Precipitation is evenly distributed throughout the year; the annual average is 1170 mm.

The sampling design is based on direct comparisons of morphologic attributes in forested and nonforested sections of 26 streams (Table 1). Each of these sites is composed of nearly contiguous (upstream-downstream), forested and nonforested stream reaches with different amounts of urban development within their watersheds. The paired reaches were selected based on several additional criteria: (1) no major tributaries could enter within or between reaches, (2) no major disturbances were ongoing, such as livestock access or grazing, and (3) they could not directly abut each other to ensure that the downstream movement of large woody debris from upstream forested reaches does not affect the nonforested reaches. The forested reach is upstream of the nonforested reach in 17 of the 26 pairs.

The paired-reach design represents a major strength of our analysis because watershed characteristics are virtually identical for the two riparian types within each stream. For any channel characteristic, the difference between paired reaches can be used to test for riparian effects and interactions of riparian effects with other factors. Simple riparian effects can be tested by using paired tests (e.g., Wilcoxon Signed Ranks test), while more complicated effects can be tested using analysis of covariance (ANCOVA).

**METHODS AND MEASUREMENTS**

We measured the morphologic characteristics of all study reaches during base-flow periods between 1997 and 1999 (Table 1). The thalweg of each sample reach is −100−200 m long. Longitudinal profiles were surveyed at important features (top of riffle, top of pool, deep point in pool), as were five to six detailed cross sections orthogonal to flow. The reach-averaged grain-size distribution was determined by using a modification of the Wolman (1954) method (Pizzuto et al., 2000). We sampled bed material from the middle of the channel, longitudinally, to include all channel features with a minimum sample size of 200 gravel-sized clasts (Rice and Church, 1996). Sinuosity was obtained by dividing the length of the channel thalweg by the length of the valley. The extent of each reach was sampled using a differential global positioning system (GPS) and imported into our geographic information system (GIS) to determine contributing watershed characteristics.

The amount of impervious cover within each watershed was calculated by using two consistent and comparable methods (Table 1). Impervious cover percentages for the 12 watersheds covered by the Delaware Valley Regional Planning Commission (DVRPC) were calculated by using DVRPC land cover layers based on aerial photography flown in 1995 (DVRPC, 1998). The impervious cover percentages of the remaining 14 watersheds were computed by using land cover data derived from Landsat thematic mapper satellite imagery (Vogelman et al., 1998). The impervious cover percentage in each contributing water-
ness found in the study watersheds between defined based on a natural gap in impervious
ban and nonurban (Table 1). The classes were streams were partitioned into two classes, ur-
average forested reach measurement, and
C
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and nonforested channel characteristics,
most of the data were not normally distributed
coxon Signed Ranks test (\(p < 0.05\), because
Percent differences were used rather than simple subtraction to control for the effect of drainage area:

\[ D = \frac{C_F - C_N}{C_F}, \]  

(1)

where \( D \) = percent difference between forested and nonforested channel characteristics, \( C_F \) = average forested reach measurement, and \( C_N \) = average nonforested reach measurement.

To investigate the effect of urbanization, the streams were partitioned into two classes, urban and nonurban (Table 1). The classes were defined based on a natural gap in imperviousness found in the study watersheds between ~12% and 30%. This grouping is supported by studies that identified 10% imperviousness as a threshold above which there is demonstrable degradation of aquatic ecosystems (Schueler, 1995; Booth and Jackson, 1997), and Prisloe et al. (2001), who identified 25% imperviousness as the level above which restoration is largely ineffective.

ANCOVA was used to test for urbanization effects alone. We used average characteristic values for each forested and nonforested pair as the dependent variable to avoid complications with correlations between individual reaches within each pair. We then normalized the data by using a lognormal transformation of the average widths, depths, and cross-sectional areas. In addition, because the size of the contributing watershed greatly influences channel size characteristics, we included lognormal transformation of drainage area as an interaction term. The lognormal transformation of drainage area is a covariant, urbanization class is the treatment effect, and an interaction term tests for differences in the slope of the drainage-area effect between urban and nonurban sites.

To test the combined effect of riparian vegetation and urbanization, we utilized linear regression and ANCOVA. Separating the streams into urban and nonurban categories, we fit linear regressions of the logarithms of width versus drainage area for forested and nonforested stream reaches. ANCOVA was performed with the \( D \) of widths as the dependent variable, urban category as a treatment effect, lognormal transformation of drainage area as a covariant, and an urban-drainage-area interaction term. ANCOVA reveals pure riparian effects as a mean difference (intercept) significantly different from zero, and effects of urbanization are detected when (1) the coefficients of the urbanization treatment term are significantly different from zero or (2) the coefficients of the urban-drainage-area interaction term are significantly different from zero.

RESULTS

Influence of Riparian Vegetation

There are significant differences in the stream characteristics of the paired forested and nonforested reaches (Table 1). Bankfull channels in forested streams are wider and have greater cross-sectional areas. These results are consistent with the findings of Trimble (1997a) and Davies-Colley (1997). No significant differences between forested and nonforested bankfull depth, sinuosity, slope, or median bed particle size (\(d_{50}\)) were found.

Influence of Urbanization

Channel width and cross-sectional area are larger in urban watersheds, which is consistent with the findings of Trimble (1997b) and Pizuto et al. (2000). By using average stream characteristics per each forested and nonforested pair, we documented a significant \((p < 0.001)\) urban effect and significant urban-drainage-area interactions for channel widths and cross-sectional areas, but not depths. Urban effects are not significant without an interaction term, meaning that variations due to drainage area must be accounted for in order to detect significant differences in urbanization. The regression lines relating morphologic characteristics to drainage area for urban and nonurban watersheds have significantly different slopes and intercepts.

Combined Influence of Riparian Vegetation and Urbanization

Forest sites, whether urban or nonurban, have larger widths than nonforested sites (Fig. 2). The differences in width between forested and nonforested sites persist despite the effects of urbanization. Four regression lines for channel width are presented in Figure 2. Forested urban streams are wider than nonforested, urban streams (Table 2). Similarly, forested nonurban streams are wider than nonforested nonurban streams. Furthermore, the separation between the two classes of forested and nonforested streams (see vertical arrows in Fig. 2) appears to be equal for urban and nonurban

![Figure 2. Bankfull width as function of drainage basin area. Separation between forested and nonforested regression lines, as illustrated by vertical arrows, indicates effect of riparian vegetation on bankfull width in urban and nonurban categories.](image)

### TABLE 2. REGRESSION EQUATIONS FOR WIDTH VS. DRAINAGE AREA

<table>
<thead>
<tr>
<th>Data set</th>
<th>Regression equation*</th>
<th>Coefficient of determination ((R^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forested urban</td>
<td>(w = 5.83A^{0.12})</td>
<td>0.45</td>
</tr>
<tr>
<td>Nonforested urban</td>
<td>(w = 3.86A^{0.12})</td>
<td>0.24</td>
</tr>
<tr>
<td>Forested nonurban</td>
<td>(w = 4.15A^{0.20})</td>
<td>0.82</td>
</tr>
<tr>
<td>Nonforested nonurban</td>
<td>(w = 1.97A^{0.46})</td>
<td>0.91</td>
</tr>
</tbody>
</table>

*Variables: \(w\) = bankfull channel (m); \(A\) = drainage area (\(km^2\)).
streams, suggesting that the influence of riparian vegetation is similar regardless of the extent of urbanization. Finally, urbanization influences stream width regardless of riparian vegetation (Fig. 2); the regression lines for urban sites have higher intercepts and lower slopes than the regression lines for nonurban sites (Table 2). This analysis was performed only for widths because depths were not found to be significantly different previously, and cross-sectional areas were, therefore, primarily a reflection of changes in width.

The combined interaction between riparian vegetation and urbanization is difficult to decipher in Figure 2. Therefore, additional analyses (ANCOVA) were used to test whether the riparian effect varies with watershed urbanization. The results show that the percent differences in widths do not vary as a function of urban development. Thus, our analysis supports the conclusion that riparian vegetation exerts a strong influence on channel width regardless of the level of urbanization in the watershed.

DISCUSSION AND CONCLUSIONS

This is the first demonstration that both riparian vegetation type and watershed-level land use are equal influences on the downstream hydraulic geometry of alluvial rivers. Forested channels are wider than nonforested channels, and the magnitude of this difference is not influenced by the degree of urbanization within the contributing watersheds.

We do not know the specific erosional and depositional processes that cause these changes. However, Allmendinger et al. (1999) measured erosion rates at the outsides of bends and deposition rates on vegetated surfaces at the insides of bends. Their data indicate that narrow nonforested channels exhibit rapid channel migration and high floodplain accretion rates. Wider forested channels migrate slowly and have low floodplain accretion rates. Allmendinger et al. (1999) concluded that the differences in width between forested and nonforested paired reaches were best explained by differences in the extent of grassy vegetation and resulting floodplain accumulation rates on the insides of migrating bends.

The observations summarized herein provide a basis for explaining how riparian vegetation is able to exert such a strong control on channel size regardless of the level of urbanization. Apparently, the ability of grass to trap and accumulate sediment is not diminished by urbanization. Thus, the peak flows generated by urbanization in our study area are not sufficient to erode grassy vegetation, and enough sediment remains available to be trapped on accumulating floodplain surfaces to influence the width of forested and nonforested reaches.

These results have important implications for river restoration design practice around the country. Many restoration designs rely on regression curves that relate bankfull stream dimensions to drainage area for various regions (Dunne and Leopold, 1978; Rosgen, 1996). Dunne and Leopold (1978) developed and presented these curves to summarize generalized trends in stream morphology, and Rosgen (1996) presented them as a tool for natural channel design and river restoration. These curves do not separate streams based on riparian vegetation type or level of watershed urbanization, and they are presented without acknowledgment of local controls (such as bedrock) or local variability. Kondolf et al. (2001) argued that regional curves should be used for restoration design with caution. Our study suggests that local conditions (both upstream and within the riparian zone), fluvial processes, and the nature of the disturbance should be taken into consideration. In addition, more localized regional curves should be developed that take into account riparian condition, watershed land use, and natural variability.

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REFERENCES CITED

Allmendinger, N.L., Pizzuto, J.E., Johnson, T.E., and Hession, W.C., 1999, Why channels with “grassy” riparian vegetation are narrower than channels with forested riparian vegetation: Eos (Transactions, American Geophysical Union), v. 80, fall meeting supplement, abstract H32D-10.


Trimble, S.W., 1997a, Stream channel erosion and change resulting from riparian forests: Geology, v. 25, p. 467–469.


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The original idea that riparian vegetation affects stream channel morphology and has implications for the structure and function of stream ecosystems in this region originated at the Stroud Water Research Center (Sweeney, 1992; 1993) and the test of that idea on 16 streams (Sweeney et al., 1999) provides the non-urban data base for this study. Research for the non-urban study sites was supported by a grant from National Science Foundation grant DEB-96-1388. We thank scientists at the Stroud Water Research Center for the conceptual basis for the study, selection of non-urban study sites, and help with geomorphic stream measurements—especially, B. W. Sweeney, J.D. Newbold, T.L. Bott, J.K. Jackson, L.A. Kaplan, L.J. Standley, D.S. Montgomery and D.H. Funk.

