Pavlowsky

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Urban Impacts on Stream Morphology in the Ozark Plateaus Region

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ABSTRACT

Urbanization typically increases runoff and sediment loads in streams which can cause geomorphic changes in channel size and planform. It is important to understand and predict these channel changes since they are often associated with flooding, sedimentation, water quality, and habitat management problems. This study examines the influence of urbanization on channel geomorphology in watersheds that drain metropolitan Springfield, Missouri, the third largest city in the state located in southwestern Missouri on the Springfield Plateau of the Ozarks Plateaus Region. Regression analysis is used to describe the spatial variations in channel morphology using drainage area, land use, and riparian vegetation variables. Interestingly, channel cross-section dimensions for a given drainage area did not differ between rural and urban streams. But compared to rural streams, urban streams have shorter riffle spacing, shallower pools and larger bed materials. The magnitude of urban influence on channel form in this study is generally within 20% of the rural reference streams, however, studies in other regions often report changes of 200% or more. The limited response of these Ozark streams to urban disturbance can be explained by pre-conditioning of watershed hydrology by historical land disturbances, presence of cohesive banks with natural gravel armoring near the bed, and karst bedrock-control.

KEYWORDS. Channel morphology, urban impacts, Ozark streams

INTRODUCTION

Urbanization can destabilize streams and influence channel form and sediment transport at the watershed-scale by accelerating the hydrologic response through the addition of impervious areas, expansion of the drainage network, and reduction of channel roughness. Channel beds and banks can become unstable in urban watersheds because the channel-forming discharge (i.e. 1- to 2-year flood) typically increases by >3 times predevelopment levels (Dunne and Leopold, 1978). More information on how urban developments impact stream channel form is needed for regions where field data is presently lacking. This paper examines the influence of urbanization on channel morphology in South Dry Sac Watershed located on the Ozark Plateau in southwest Missouri. The watershed drains the northern part of Springfield, the third largest city in the state. Urban growth rates in the area rank as some of the highest in the country. Information on channel geomorphology and the role of human activities in causing stream erosion and/or sedimentation problems in the Ozarks is timely since recent environmental initiatives in storm water control, water quality protection, and channel restoration need to consider the physical behavior of the channel system in order to be effective.

Channel changes associated with a shift from rural (or forested) conditions to urban land use within a watershed has been an important topic of study in geomorphology for almost 40 years (Wolman, 1967; Booth, 1990; Pizzutto et al., 2000). It is well understood that urban hydrology can cause adjustments in channel slope, width and depth, and sediment caliber and that these parameters are commonly used to characterize channel form within a watershed (Rosgen, 1996).

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It is thought that the threshold for geomorphic response may be exceeded when urban area reaches 10 to 20 percent of the watershed (Hammer, 1972; Doll et al., 2002).

STUDY AREA

The South Dry Sac watershed (79 km^2) is located in Greene County, Missouri and its main stem flows from east to west into the Little Sac River, then into the Osage River system which flows into the Missouri River. Its drainage area contains 25% urban, 18% forest, and 57% grassland areas. The rural areas are now largely used for beef cattle production and low density residential developments. However, agricultural settlement and land clearing in the watershed began in the 1830s and row-cropping was common up until the 1960s. Urban areas are concentrated in the southwest portion of the watershed where urban settlement began in the 1880s. The river drains relatively uniform, horizontally bedded limestones into which a well-developed karst terrain has formed. Upland soils generally consist of several meters of cherty "red-clay" limestone residuum overlain by one meter or less of silty Pleistocene loess. Alluvial soils typically consist of cohesive silt/clay upper banks and clast-supported, cherty gravel lower banks. Channel bed elevations are at or near bedrock in most of the 2nd order and larger streams in the region. The watershed receives about 100 cm of rainfall annually and produces a mean annual discharge at its mouth of approximately 0.9 m^3/s. The watershed is a primary recharge area for the karstic Fulbright Spring which provides about 20% of Springfield's drinking water supply.

METHODS

Auto-level surveys of the channel cross-section and longitudinal profile were collected at 32 reaches representing a wide range of urban influence and riparian buffer characteristics. For this study, a reach is defined as the length of channel extending over three consecutive riffle crests in a representative section of the stream. The study cross-section located across the middle riffle crest. Width and mean depth measurements were determined for two channel stages in this study. The active (or bankfull) channel stage is identified by the top of lower bench or alternating bar deposits inset within the larger low terrace channel. The width of the active bench or floodplain is generally <5 meters. The active channel banks are typically formed of relatively coarse sediment capped with only a few centimeters of silty material. The low terrace stage is identified as the top of the main channel bank at the point where flood water would be expected to initially spread out onto the much wider valley floor. Slope was measured using a regression line through the three riffle crest elevations on the longitudinal survey. Riffle-spacing and maximum pool depth compared to the downstream riffle is derived from the longitudinal survey. Sinuosity was measured in the field with a 100 meter tape for most streams, with aerial photographs used for larger reaches.

Bed sediment size data were collected in two ways. The size distribution (i.e. D50 and D84) was derived by measuring the intermediate axis of 50 "pebbles" collected from 5 active channel transects with 10 equally spaced "blind touch" samples collected along each transect. The transects were spaced at one active channel width intervals with the middle transect located on the cross-section survey line. The maximum clast size of the reach was determined by the average of the 10 largest bed sediment clasts found in the reach. Hydraulic roughness values (Mannings n) were calculated empirically using the method described in Pizzutto et al. (2000) which requires values for sinuosity, D50, mean pool depth (or max pool depth/2), and mean channel depth. Discharge was calculated for both the active and low terrace channel using the continuity equation. The reoccurrence interval for the flood required to fill each channel to maximum stage was estimated by extrapolation of regional regression equations developed from USGS gage network flood data for Ozark streams in southern Missouri.

The percent urban land use within each sub-watershed above the GPS-referenced sample reaches was determined using Landsat Thematic Mapper and ArcGIS software with spatial data provided by the National Land Cover Dataset from 1987-1993. Subwatersheds containing more than 15% urban area were classified as "urban" and those with less than 15% urban area as "rural."

Riparian buffer composition was calculated as percent of grass or forest buffer along the length of both right and left banks for a distance of 30 active channel widths upstream of the survey transect.

RESULTS

Channel Characteristics

Thirty-two reaches are evaluated in this study for drainage areas ranging from <1 to almost 80 km^2 (Table 1). The sample was evenly divided between rural and urban subwatersheds with 16 in each category. There was a slight tendency to sample more urban first and second order streams due to access limitations and poor channel development in some rural areas. Riparian grassland cover ranged from 20 to 42 percent among the Strahler stream order classes. As expected, reach elevation and slope decrease with watershed size. More significantly, reach sinuosity is relatively low with median values in the 1.05 range with most reaches having values less than 1.10. It is common in this watershed to be able to observe three or more riffle crests from a point standing in the channel. Stream channels in the South Dry Sac watershed are bedrock-controlled and flow relatively straight for a few meander lengths after which they encounter the bluff line and then flow back out across a relatively narrow valley. In some instances, channels flow straight for long distances along the bluff line and appear to be semi-permanently locked in place. Bedrock exposures are common on channel beds in some reaches and gravel deposits are typically <1 meter thick over bedrock in all streams of second or larger order.

Table 1: Sample Reach Characteristics

Stream Order	Ad (km2)	Elevation (ft asl)	Slope (m/m)	Sinuosity (m/m)	Urban Area (%)	Grass Buffer (%)
First (n=7)	0.4	1,251	0.019	1.05	84	30
Second (n=9)	2.0	1,249	0.013	1.05	69	42
Third (n=7)	10.7	1,179	0.012	1.08	16	20
Fourth (n=9)	52.9	1,133	0.004	1.05	9	35

The active channel is significantly smaller than the low terrace channel. The median channel width for the low terrace channel ranges from 2.7 times that of the active channel in first order streams and decreases to 1.6 times in fourth order reaches (Table 2). Median width:depth ratios for the active channel decrease downstream from 27 in the first order streams to 16 in fourth order streams, while no similar trend is shown for the low terrace channel. The capacity of the active channel at it highest stage is usually the 1-year flood or less (Table 2). The capacity of the low terrace channel ranges from the 2- to 5-year flood. These streams appear to reflect moderate fluvial force with low to moderate slopes and stream power values <30 W/m^2 for the active channel and <100 W/m^2 for the low terrace channel.

Given the low sinuosity of these channels in general, evidence of lateral erosion, point bar development, and a distinct "bankfull" or active floodplain is lacking in most reaches. Thirty to 50 year old trees often grow out of the low terrace banks indicating that they have been in a stable position for sometime. Studies of other Ozark streams have shown that both stable reaches and unstable or "disturbance" reaches exist in sequence, but in most cases disturbance reaches remain in place through time and represent only a small portion of total stream length (Jacobson nad Gran, 1999). Disturbance reaches tend to be located where bluff lines interfere with channel flow and in association with sedimentation areas below the confluence of tributaries. Disturbance reaches were not sampled in this study in order to study the more systematic and representative variations in channel morphology related to watershed and riparian buffer factors.

Table 2: Active and Low Terrace Channel Properties (median values)

Stream Order	Width (km2)	W:D (m/m)	Roughness (Mannings n)	Velocity (m/s)	Stream Power (W/m2)	RI (years)
<u>Active Channel</u>						
First	2.4	13.2	0.039	0.98	24.3	0.9
Second	3.4	16.4	0.041	0.93	18.6	0.8
Third	5.9	25.9	0.045	0.81	21.3	0.8
Fourth	13.3	26.7	0.043	0.79	11.3	0.8
<u>Low Terrace Channel</u>						
First	6.4	26.7	0.038	1.16	31.8	4
Second	8.0	17.6	0.037	1.64	59.1	2.2
Third	11.4	20.7	0.040	1.80	70.5	4
Fourth	21.2	16.1	0.039	1.64	28.0	3

Although the streams studied here consist mainly of straight reaches, relatively sinuous channels appear to be clustered in the first, second, and third order streams located in the eastern, upper portions of the basin most distant from the mouth (Figure 1). This area is generally the most intensely farmed in the watershed and stream courses tend to flow through relatively wider valleys with more alluvial fill. Thus the influence of bedrock control on channel form may be reduced in these locations and thus allow a more meandering planform to develop. It is also possible that bank disturbances by riparian forest clearing and grazing may have initiated lateral channel erosion and meandering, but no proof for this process is presented here.

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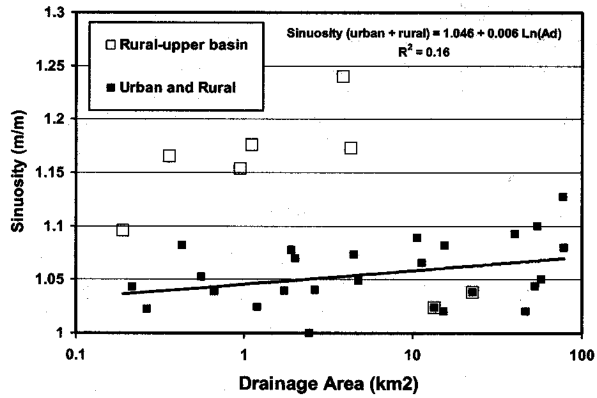

Figure 1: Sinuosity Trends. **Double square symbols mark the two 4th order reaches sampled from the upper basin that have low sinuosity values like the rest of the reaches sampled.**

Lack of Urban Effect on Channel Width and Depth

Relatively good correlations between drainage area and active channel dimensions are found in this study (Figure 2). However, width and depth relationships did not vary between urban and rural streams in this study. The specific causes of the lack of response of active channel width and depth to urban influence are not tested here, however, several explanations can be offered at this time. First, while the rural subwatersheds in this study may not be affected by urban factors, they have been subjected to land disturbances associated with agriculture since the 1830s. It is common to find 0.5 meters or more of post-settlement alluvium at the top of low terrace deposits. Thus, the "rural" streams studied here are not in a pristine "reference" state and probably reflect a transitional form between disturbed and fully-recovered rather than those streams that are more pristine in nature.

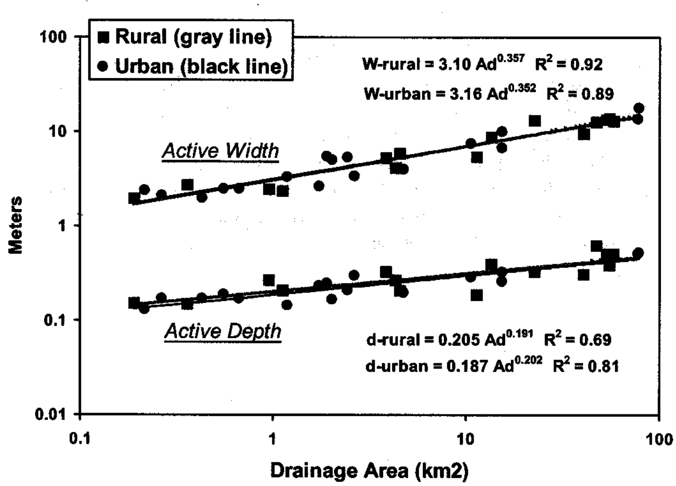

Figure 2: Active Channel Cross-section Trends.

Second, the low sinuosity of these streams indicates that lateral channel adjustments are constrained and hence floodplain development is also hindered. Besides the reduction of lateral adjustment rates, floodplain sedimentation rates are also low. Floods in the 2-5 year range are contained in the low terrace channel and not allowed to spread out upon a wider floodplain and dissipate energy or store sediment. Thus, while lateral erosion is limited and the channel may be considered stable, boundary conditions are still erosional and most fine-grained sediment and even fine gravel is transported through the reach to be stored at disturbance zones or exported from the system. More research is needed to document the sediment transport dynamics of these channels. Nevertheless, there is little opportunity for fine-grained sedimentation and active floodplain formation to occur and so these Ozark streams may generally be slow to recover in a geomorphic sense.

And, finally, low terrace bank materials tend to be resistant to erosion in this watershed. Bank deposits in this watershed are largely composed of resistant cohesive banks with gravel basal units that are not subject to failure very often. Sand content is also very low in these bank sediments as compared with other areas in the Ozarks. In addition, the effect of inundation on bank saturation and failure is also limited. With the exception of the lower reaches and several reaches served by spring flow, these are ephemeral streams subject to flashy stage changes during floods. Thus, potential for bank failure due to hydrostatic forces occurring during wetting and drying cycles and pore dewatering in minimized.

Urban Effect on Longitudinal Profile and Bed Sediment Size

In contrast to the channel cross-section, the longitudinal profiles of these streams differ slightly between rural and urban subwatersheds. Riffle spacing and pool depth both tend to decrease in urban streams as compared to their rural counterpart (Figure 3). Given the lack of opportunity to expend energy with lateral channel adjustments as described previously, it is reasonable to expect vertical adjustments in bed form may occur in response to urban factors. While channel incision of <0.5 m depth into stream beds sometimes occurs in these streams, shallow bedrock generally limits depth adjustments. Thus, sedimentary bedforms such as riffles and pools would be the most sensitive to urban effects since they are free to adjust rapidly. Moreover, sediment size tends to increase downstream and in urban streams (Table 3). While the downstream increase in bed sediment size may be influenced by the availability of larger materials from bluff erosion, the confluences of urbanized tributaries are mostly located along the downstream section of the main stem of the South Dry Sac River. Thus, decreasing riffle spacing and pool depth and increasing sediment size is believed to be the result of fluvial response to urban factors in this watershed.

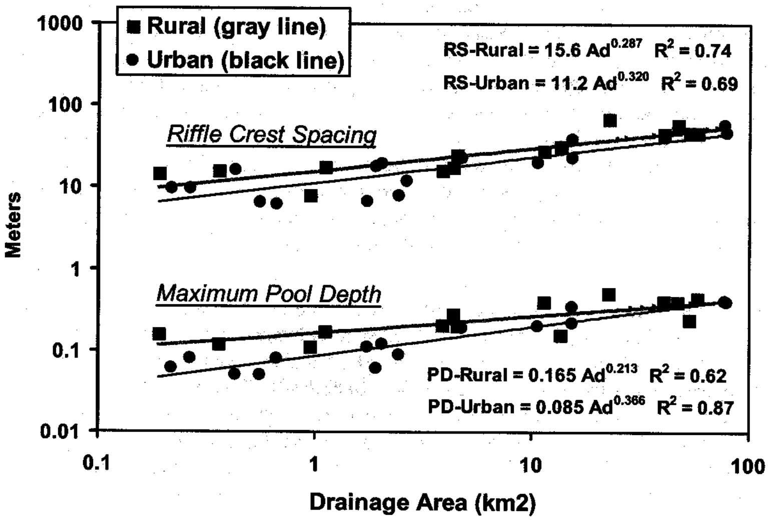

Figure 3: Active Channel Longitudinal Profile Trends

Table 3: Bed Sediment Size by Subwatershed Size and Land Use (median values)

Watershed Type Size	Land Use	n	D50 (cm)	D84 (cm)	Dmax (cm)
<1 km2	Rural	3	1.9	4.2	14.7
	Urban	5	2.0	5.7	20.0
1-10 km2	Rural	4	3.1	6.0	23.1
	Urban	7	3.0	6.0	28.6
>10k km2	Rural	8	2.5	5.0	24.2
	Urban	5	4.5	10.0	24.3

Lack of Riparian Vegetation Influence

This study found that riparian vegetation type did not influence channel form. While the low terrace channel generally is 4 to 5 times larger in cross-section area than the active channel, variations in the trend could not be explained by riparian vegetation or urban factors (Figure 4). Similarly, riparian vegetation was not useful for explaining variations in channel size and shape (Figure 5). The lack of riparian vegetation influence on channel morphology probably reflects three factors. First, the threshold of erosion for channel banks is relatively high as previously discussed so vegetation root influence may only exert a secondary effect. Additionally the influence of riparian vegetation influence may be too variable over time or occur at a scale not linked to geomorphic recovery processes. Second, extensive grassland riparian areas were hard to find in this area since most streams are lined by trees. In addition, tree growth often extended down onto the low terrace banks. And, finally, these streams tend to run dry most of the time due to the effect of karst drainage and "losing" stream hydrology. Thus, cattle do not water in the streams and trample the channel banks in most pastured grassland areas in the watershed.

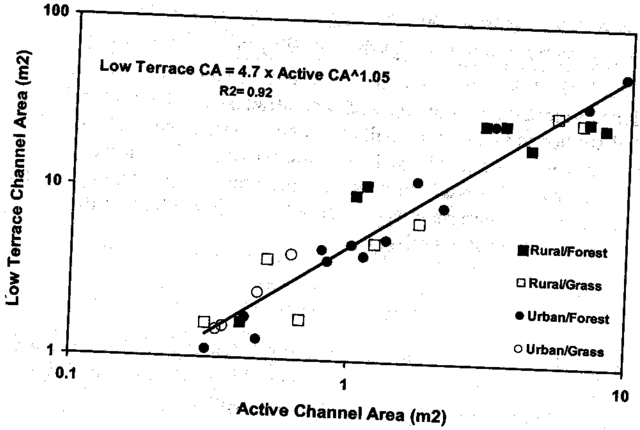

Figure 4: Active and Low Terrace Channel Cross-section Area Trends

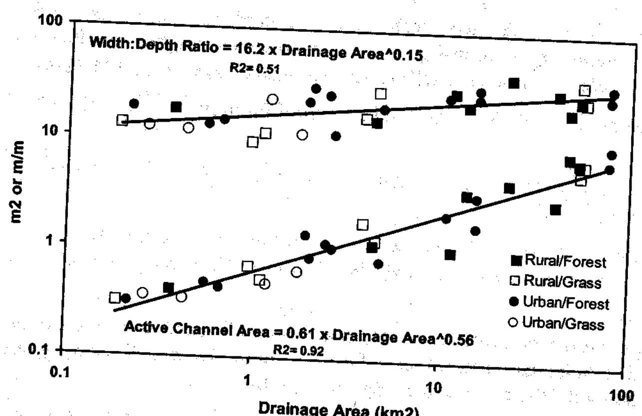

Figure 5: Buffer Influence on Active Channel Size and Shape

CONCLUSIONS

Streams in the South Dry Sac watershed are generally composed of an active or bankfull channel adjusted to the 1-year flood within a larger, low terrace channel which contains the 2- to 5-year flood. The low terrace channel can probably be described as a very narrow meander belt along a relatively straight channel. The low terrace channel tends to be 1.5 to 3 times wider and 4 to 5 times larger in area compared to the active channel. No influence of urbanization on channel width and depth is found in this study. Reasons for this outcome include: (1) lack of an undisturbed "rural" reference for direct comparison, (2) limited potential for lateral fluvial adjustment due to bedrock control and cohesive banks; and (3) slow geomorphic recovery rates of these systems due to low rates of fine-grained sedimentation and floodplain development. However, urban subwatersheds tend to have shorter riffle spacing, shallower pools, and larger bed sediment diameters compared to rural counterparts. Apparently, channel bed form and sediment size properties are more sensitive to urban hydrology and related sediment regime changes than cross-section form in these bedrock-controlled streams draining karst.

While this study emphasizes the lack of detection of a distinct urban influence on channel width and depth, there is clear evidence of stream erosion and sedimentation associated with urban development in the area. Field studies indicate that small drainage-ways and streams not influenced greatly by bedrock-control are subject to bed and bank erosion below urban developments (Martin, 2001). However, this study underscores the importance of understanding the role that geomorphic resistance factors and recovery potential plays in evaluating the physical stability of stream systems at the watershed-scale.

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