CHANNEL GEOMORPHOLOGY AND RESTORATION GUIDELINES FOR SPRINGFIELD PLATEAU STREAMS, SOUTH DRY SAC WATERSHED, SOUTHWEST MISSOURI

A Thesis

Presented to

the Graduate College of

Southwest Missouri State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science in Resource Planning

By

John M. Horton

May 2003

CHANNEL GEOMORPHOLOGY AND RESTORATION GUIDELINES FOR SPRINGFIELD PLATEAU STREAMS, SOUTH DRY SAC WATERSHED, SOUTHWEST MISSOURI

Department of Geography, Geology, and Planning

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ABSTRACT

Land-use change, both historical and present, has been a source of channel degradation within Ozark streams. This study examines the influence of land use on channel morphology within the South Dry Sac Watershed which drains 78.5 km^2. The main objectives of this study are to: (1) perform a geomorphic assessment of stream channel and sediment characteristics; (2) evaluate the effects of watershed factors on channel morphology and dynamics; (3) quantify the geomorphic relationships for use in stream restoration projects in the Springfield Plateau area. Thirty-six reaches were surveyed and evaluated in the field for channel cross-sectional geometry, longitudinal profile, and planform in both urban and rural areas of the South Dry Sac Watershed. Geospatial technologies were used to assess watershed land-use, channel planform and riparian buffers. Urban channels were found to have approximately 10% greater bankfull widths, 5-9% greater mean depths and 15-20% greater cross-sectional areas than rural channels. Additionally, urban channels were found to have about 32-47% lower maximum residual pool depths and about 40% lower meander amplitudes. While overall trends are in agreement, differences between urban and rural channel size are not as obvious in the Ozark streams studied when compared to similar studies in Pennsylvania and North Carolina. This result may be due to low channel migration rates and presence of cohesive banks that limit geomorphic response. In addition, rural channel form in the South Dry Sac Watershed may still reflect disturbance by historical land clearing and row crop agriculture. Regression equations that predict channel morphology based on drainage area and land use are developed for use in channel restoration projects.

This abstract is approved as to form and content

Chairperson, Robert T. Pavlowsky
Southwest Missouri State University

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CHAPTER 1

INTRODUCTION

Understanding the contribution of human activities to degradation of watershed functions is a topic of interest within the environmental management field. Several studies have shown that land clearing, poor agricultural practices, and urbanization can change watershed hydrology and disrupt the physical behavior of channel systems (Graf 1977; Knox 1977; Booth and Jackson 1997; Booth 1990; Hammer 1972). These disturbances often increase discharge, flooding and sediment loads to a point that forces the stream to function outside its normal equilibrium (Yorke and Herb 1978; Jacobson 1995). Some of these channel effects include increases in width, decreased pool depth, lower sinuosity and higher bank erosion rates (Pizzuto et al. 2000). Additionally, increased peak discharges can lead to greater sediment loads, loss of critical riparian areas, and disruption of the stream ecosystem (Jacobson 1995).

The South Dry Sac Watershed is located to the north of Springfield, Missouri and drains portions of the Springfield Plateau of the Ozark physiographic region. This watershed has several characteristics that differentiate it from other streams described in the literature. These include the transportation of both fine-grained and gravelly sediment, bedrock-controlled beds with relatively cohesive banks, and karst drainage features. Approximately one-third of the basin is urbanized with the remaining area used primarily for cattle and hay production. However, urbanization is encroaching further into the rural portions of the watershed.

The purpose of this study is to examine the influence of land use changes on channel morphology within the South Dry Sac Watershed. Land use research has been conducted on other larger Ozark rivers including the Gasconade, Eleven Point, Current and Buffalo River (Jacobson 1995; Panfil and Jacobson 2001). These studies document the effects of changing land use on channel morphology at the basin-scale. In the Buffalo River Basin, it was reported that shallower channels and eroding banks were more common in reaches where forest had been cleared (Panfil and Jacobson 2001). In the Current River Basin, Panfil and Jacobson present a theory of geomorphic lag related to gravel bar distribution being linked to historical land clearing, rather than present land use (2001). Similar trends may be occurring within the South Dry Sac Watershed, however, no data is presently available to address this question.

There are 3 main objectives of this thesis research:

1. Perform a geomorphic assessment of stream channel and sediment conditions in the South Dry Sac Watershed.

Currently, no data exists on the channel morphology or sediment characteristics in the South Dry Sac Watershed. Data collected from this study can be used to further enhance scientific understanding of the fluvial processes in the Springfield Plateau.

2. Evaluate the effects of watershed land use on channel morphology (width, depth, channel slope, riffle-pool spacing, pool depths, and planform) and dynamics (flow capacity, roughness, and sediment size).

There are three important aspects of this objective. First, drainage area relationships are established to understand and predict spatial variation in geomorphic variables. Second, differences between urban and rural stream characteristics are quantified to aid in understanding the influence of land-use on channel morphology. Finally, the effect of riparian vegetation conditions on channel morphology and stability is discussed.

3. Quantify the geomorphic relationships present in the South Dry Sac to plan and design stream restoration projects in the Springfield Plateau area.

Restoration efforts for urban and degraded channels within the Springfield Plateau are currently being discussed. Data sets that describe channel dimension, planform configuration, and sediment characteristics will be developed. Regression analysis is used to develop descriptive equations that can be used to predict channel morphology.

HYPOTHESES

The following hypotheses will be tested:

1. Geomorphic characteristics systematically change downstream as a function of drainage area (Leopold et al 1964; Klein 1981; Rosgen 1996).
2. Urban channels are wider, and have larger cross-sectional areas than rural channels (Hammer 1972; Pizzuto et al. 2000; Doll et al. 2002).

3. Streams with forested buffers are wider and shallower than grass buffered streams (Clary and Webster 1990).

BENEFITS OF RESEARCH

This study will provide three main benefits. First, it describes a geomorphic understanding of channel processes of present-day Ozark streams, particularly in areas of recent urbanization. Next, the data set generated can be compared with other watersheds to understand broader implications of this research to the science of fluvial geomorphology. Finally, this research project will assist local resource planners in understanding watershed processes for which there is little previous knowledge. In addition, it will provide local watershed managers with a data set on which to base stream restoration efforts, habitat improvements and wise land-use planning strategies.

CHAPTER 2

LITERATURE REVIEW

This chapter provides a foundation for the South Dry Sac Watershed channel morphology study. The four salient aspects of this watershed study are addressed. First, basic fluvial geomorphology vocabulary and concepts are discussed. Next, the influence of land-use on the dynamics of channels is presented. Thirdly, Ozarks land-use history and stream characteristics are discussed to provide an overview of the study area and other research on Ozark streams. Finally, restoration and management practices are addressed. Although the South Dry Sac is unique in some ways, it shares many of the same characteristics with surrounding Ozarks watersheds. The interconnectedness of these subjects must be understood before an accurate stream channel morphology assessment and restoration project is launched.

CHANNEL GEOMORPHOLOGY

Understanding fluvial processes is imperative when attempting to link land-use change to stream morphology. Fundamentally, channel morphology is dependent on many variables. Geology, soil type, discharge, sediments and riparian conditions are just some of the key determinants of channel morphology (Brush 1961). These factors ultimately control the size and shape, or cross-sectional geometry, of a particular stream channel reach.

The Bankfull Channel

Cross-sectional profile. The pattern, shape and dimensions of alluvial channels are built and maintained by the hydraulic characteristics of the stream (Cooke and Doornkamp 1974). Bankfull discharge is most often regarded as the channel forming flow, or "dominant discharge", with a recurrence interval every 1.5-2 years (Morris 1996). Leopold (1994) states that the greatest rates of erosion, sediment transport, and bar-building occur during bankfull or near-bankfull discharge. However, the exact definition of bankfull discharge and its role in channel forming events has been a topic of debate among geomorphologists (Williams 1978). While the 2-year flood is sometimes used to approximate the dominant discharge, some studies indicate that more frequent flows near or less than 1-year discharge can control channel morphology (Martin 2001). Major flood events with frequency greater than 5 years do move the most sediment. However, the long return frequency of these extreme events limits their channel-forming significance relative to more frequent bankfull events.

Discharge is often deemed the key variable controlling channel width morphology (Miller 1984). However, Rosgen (1996) elaborates that channel width is a function of three main factors: discharge frequency and magnitude, transported sediment size and type, and bed and bank material composition. The key variable to explaining channel depth morphology is sediment regime and present streamflow (Miller 1984; Rosgen 1996). Additional factors controlling mean depth include valley morphology, basin relief, and bed and bank materials. The relationship of width to depth is expressed as an index value, which describes the shape of the channel. Channel cross-sections with high width:depth ratios are wide compared to their mean depths, and vice versa.

Geology also plays a role in channel morphology. Channels constrained by rock outcrops are referred to as bedrock-controlled (Cooke and Doornkamp 1974). Bedrock channels tend to be wider as a response to the resistant bed preventing the channel from deepening (Leopold 1994). The influence of karst topography on channels is also noteworthy. Sinking creeks, or losing streams, can divert runoff into subsurface areas via swallow holes and underground cave systems. This can leave segments of stream reaches dry during periods of base flow (Thornbury 1969). Further, it may be possible for karst drainage to reduce the magnitude of the dominant discharge relative to the drainage area of the watershed (Martin 2001).

Longitudinal profile. The longitudinal profile is perpendicular to the channel cross-section as one looks up and down stream. Stream bed elevations of a stream from source to mouth tend to reveal a concave upward profile (Cooke and Doornkamp 1974). This trend is a product of discharge, sediment load, size of debris, flow resistance, velocity, width, depth, and slope (Leopold et al. 1964). At the reach scale, bedform features along the longitudinal profile usually occur as pools, riffles and point bars. Pools are defined as areas of low topography within the channel usually with smaller bed material relative to the rest of the channel. Pools generally occur adjacent to point bars along the cutbank at bends in the channel (Keller and Melhorn 1981). Point bars are formed by the deposition of coarse material adjacent to pools on the inside of meander bends.

The cross-section at this segment of the stream appears asymmetrical. Riffles are defined as topographically high segments within the channel that are composed of coarse-grained material. The channel cross-section is typically symmetrical at riffles (Keller and Melhorn 1981). Pool-riffle sequences are found in both alluvial and bedrock channels. However, pools form more readily in streams with coarse bed material. Gravel sizes greater than 2 mm and smaller than boulders seem to be the most conducive for pool-riffle formation (Folk 1968). Some studies have indicated that riffle-riffle spacing occurs at intervals of about five-to-seven times the channel width (Leopold et al. 1964; Keller and Melhorn 1978).

Riparian Conditions

Riparian vegetation conditions are another important component when assessing watershed channel conditions. One study in north central Missouri looked at riparian vegetation and its influence on stream channel migration. Burckhardt and Todd (1998) concluded that banks cleared of forests eroded three times greater than forested banks. Differences in soils and geology can also affect how channels respond to riparian conditions (Ikeda and Izumi 1990). Riparian soils with high clay content are more resistant to erosion, therefore providing a more stable bank.

Riparian corridor width and vegetation type at each site may be indicative of some channel characteristics at that particular reach (Haberstock et al. 2000). Vegetation types, be it grass or trees, can also influence the geometry of streams. Ikeda and Izumi (1990) develop a mathematical model to describe vegetation influence on channel morphology. This study concluded that channels having stiff vegetated banks have greater depths and smaller widths than non-vegetated channel banks (Ikeda and Izumi 1990). However, the authors remind readers that factors such as bed material, gradation and discharge must also be taken into account when assessing width and depth of channels (1990). Other studies compare the qualities of grassed riparian areas to that of forested areas. Trimble (1997) found that grassed stream reaches were narrower and had smaller cross-sectional areas when compared to forested reaches. Grassed riparian areas tend to trap and store more sediment, therefore bank stability is maintained and cross-sectional area reduced (Trimble 1997).

HUMAN IMPACTS ON CHANNELS

Human-induced land-use changes can have a significant effect on a stream's morphology. Deforestation, urbanization, agricultural practices and wetland conversion can all contribute to stream channel degradation (Hammer 1972; Knox 1977; Hooke 1994). Impervious surfaces are one of the many human fabrications that disrupt hydrological processes. Impervious surfaces are simply substances that halt the penetration of water into the soil. The result of this barrier is increased runoff, higher stream channel velocities and greater flooding (Arnold and Gibbons 1996; Wolman 1967). Catchments with 10-20 percent imperviousness can have increases in peak flows up to two-to-three times the normal discharge (Booth 1990). However, watershed-specific variables such as bed and bank material, riparian condition, ultimately play a role in the severity of imperviousness (Bledsoe and Watson 2001). Banks with cleared riparian corridors will degrade faster than those with vegetation left intact. Likewise riparian soils with high clay contents will be more resistant to erosion than soils with high sand and silt content (Smerdon and Beasley 1959).

Hydrological changes in form of increased runoff and erosion occur when lands are converted from forest or prairie into agricultural usage (Krug 1996). Increased runoff is often a product of vegetation removal and improper grazing methods since vegetation plays an important role in slowing runoff and in the absorption of rainfall. Further detrimental effects such as erosion and habitat destruction occur when livestock are allowed unrestricted access to riparian buffers (Magilligan and McDowell 1997). Knox's (1977) Platte River, Wisconsin study examined the impacts of human settlement and historical agricultural practices on stream morphology. It showed that post-settlement headwater and tributary channels were significantly wider and shallower than pre-settlement channels due to increased rates of lateral erosion. The main stem reaches of the Platte River were found to be deeper and narrower than pre-settlement channels due to increased sedimentation and alluviation. Increases in runoff, sediment transport and flood frequency and magnitude were the main causes of these changes (Knox 1977).

Urbanization can also have a significant effect on channel characteristics within a watershed. The hydrology is vastly altered when vegetation is replaced with impervious surfaces like pavement and rooftops. Hammer's (1972) study in Philadelphia examined the affect of impervious surfaces on stream channels and concluded that as little as 10% watershed impervious area can degrade channels. Increases in channel cross-sectional areas were greatest in areas draining large impervious coverage such parking lots and sewered streets where flood frequency increased the most (Krug and Goddard 1986). Using a paired watershed approach, Pizzuto et al. (2000) compared the geomorphic properties between urban and rural channels in gravel-bed streams in southeastern Pennsylvania. This involved selecting reaches within an urban area and then finding wooded, non-urban reaches of equivalent drainage area to compare geomorphic characteristics. Results of the study indicate that impervious surfaces in urban watersheds caused increases in channel width (26%) and decreases in stream sinuosity (8%). Additionally, increased runoff caused urban streams to have lower pool depths and higher channel velocities (Pizzuto et al. 2000).

Human-induced changes also contribute to bed sediment disturbance. Agriculture, urbanization, and timber operations can cause large amounts of sediment to be delivered into fluvial systems (Hooke 1994). Excessive rates of gravel deposition and events related to transport or “gravel waves”, are one notable result of this disturbance. Channels often become sediment storage places of gravel between high discharge events. Rather than being deposited on overbank locations, sediment moves in episodic events and disrupts channel form in the new location of deposition (Jacobson 1999).

OZARK STREAMS

Considerable research has been dedicated to the fluvial processes of Ozark Plateau streams (Jacobson 1999; McKenny and Jacobson 1995, 1996; Panfil and Jacobson 2001; Osterkamp 1979). Channels of the Ozarks Plateaus tend to display similar characteristics. Ozark streams are characterized by patterns of stable reaches followed by disturbance reaches (Jacobson 1995). The stable reaches have trapezoidal shaped channels and are typically several kilometers long, on the larger rivers, with low sinuosities near 1.1. Jacobson (1995) describes the disturbance reaches as areas of deposition and erosion with sinuosities near 1.5 over distances of a few hundred meters. Similarly, Ozark channels can form in alluvial materials and then be interrupted by geologic controls such as bedrock and rock outcrops. Karst features, also commonplace in Ozark streams, add complexity to runoff and discharge characteristics (Jacobson 1999).

European settlement within the Ozarks brought about many changes upon the landscape. Land was cleared for agricultural purposes and to provide lumber for building materials and railroads. Along the streams corridors where land was most fertile, trees were cleared for row crops and grazing. Hill slopes and ridges were logged for their valuable timber. Streambeds were also exploited to provide gravel for roads (Jacobson 1995). Jacobson (1995) hypothesized that vegetative clearing led to a reduction in bank strength, which facilitates erosion and transport of fine sediments.

Research conducted on the Buffalo River in Arkansas and on the Jacks Fork in Missouri sought to explain the relationship between woody vegetation and channel morphology (McKenny and Jacobson 1995). In floodplains with forested reaches, bank height occurred at root depth or just below. Young, dense vegetation was found to provide resistance and therefore promote sedimentation. These vegetated bands are governed by hydrology, sedimentation and biologic factors unique to a site. However, the variance in the ages of different vegetated sites and the role they play in the overall geomorphology for these streams is yet to be determined (McKenny and Jacobson 1995).

MANAGEMENT ISSUES

Watersheds, both urban and rural, have been altered purposely and unintentionally. These alterations were accomplished by channelization, poor agricultural practices and urbanization. Increased channel instability, erosion, sedimentation and pollutant runoff from urban and agricultural areas are regular consequences of watershed alterations. These actions often create a legacy of poor water quality and disrupted channel systems. These degraded and polluted streams have motivated government agencies and private organizations alike to develop better management practices and initiate restoration efforts (Rinaldi and Johnson 1997).

Watershed restoration efforts should begin only when the parties involved understand the particular system they are striving to restore. First, one must understand the components of a hydrological setting, which consists of drainage basins, streams, floodplains and wetlands (Black 1997). Many restoration projects have been based on a political and economical guidelines rather than sound hydrologic and geomorphic principles. Planners should work with geomorphologists to incorporate a course of action that will meet their goals. Optional goals for stream restoration include rehabilitation or full restoration; ecological improvement or aesthetic enhancement; and intervention or natural recovery (Brookes and Sear 1996).

Urban channel restoration managers are faced with many options when reshaping a degraded stream into a stable channel. Channel cross-sections should be designed for stability and discharge capacity relevant to particular land use and drainage area (Morris 1996). Data can be gathered from stable portions of the watershed to guide restoration efforts. Planform restoration considerations include reinstating meander amplitudes and wavelengths similar to the natural basin characteristics. As with cross-sectional restoration, stable reference reaches and aerial photos can used to direct planform restoration. Land availability is also an important consideration for planform restoration planning. Meander establishment may require more land than is available for restoration. Additional troubles such as flood conveyance problems with sinuous streams may also deter one from establishing wide natural meanders (Morris 1996).

Brookes and Sear (1996) offer an eight-step approach to river restoration (Table 2.1). The Brookes and Sear approach relies on specific knowledge of the watershed and its geomorphic characteristics. This approach will only succeed if substantial field data is gathered within the restoration and adjacent watersheds.

The Brookes and Sear approach will provide a basic knowledge of fluvial processes within the region to guide restoration work**.**

Table 2.1 An approach to river restoration appraisal and design **(**Brookes and Sear 1996).

1. Establish objectives and aims of project.
2. Use guiding geomorphological principles to determine data requirements.
3. Collect additional geomorphological data pertinent to the site, area or region.
4. Consider hydraulic constraints and wider environmental and land use issues.
5. Analyse hydraulic and geomorphological data.
6. Consider the potential for either natural or enhanced recovery.
7. Evaluate options.
8. Choose final design.

SUMMARY

Initially, an accurate field data collection phase is foremost in this study. Here, four types of key variables are required for a geomorphic assessment of channels within the South Dry Sac Watershed. First, channel geometry variables such as bankfull width mean depth, maximum depth, width:depth ratio, and cross-sectional area will be surveyed. Second, bedform variables needed for this study include slope, riffle-riffle spacing, pool-pool spacing, riffle-pool spacing, and maximum pool depth. Third, the necessary planform variables include sinuosity, meander wavelength and meander amplitude. Finally, bed material data and sediment characteristics must be assessed. These variables will provide the framework for understanding watershed trends.

Key relationships for assessment of land-use influences on channel morphology must be established. First, this will entail delineating and calculating watershed area and sub-basin land-use with geospatial technologies. Furthermore, riparian buffer characteristics such percent forest, grass and artificial structures must be evaluated to assess their influence on channel morphology. Thus GIS data, coupled with field data, will be used to explain spatial trends between urban and rural channels.

Channel restoration in the South Dry Sac and adjacent watersheds will be dependent on several factors. First, goals and realities involving the restoration reach or watershed must be planned. Next, a complete quantification of channel geometry, bedform features, planform and sediment characteristics must be amassed for use as a reference. Finally, sound geomorphic principles must ultimately guide the restoration and be understood by all parties involved.

CHAPTER 3

SOUTH DRY SAC WATERSHED

BASIN DESCRIPTION

The South Dry Sac Watershed is located in east central Greene County on the northern periphery of Springfield, Missouri (Figure 3.1). The South Dry Sac is a fringe basin, draining both urbanized areas of the city and rural farmland to the north. The watershed drains 78.5 km^2 within the larger Little Sac Watershed. Valley Water Mill tributary and Pea Ridge Creek are the main tributaries contributing to the main stem of the South Dry Sac. The majority of the Pea Ridge sub-basin is located within the city limits of Springfield and has a drainage area of approximately 15 km^2. The Valley Water Mill tributary, with a drainage area of 13 km^2, is generally rural; however, it is presently experiencing increased urbanization.

PHYSICAL CHARACTERISTICS

Geology

The South Dry Sac Watershed drains the Springfield Plateau physiographic region of the Ozark Plateau. The Springfield Plateau is generally a rolling plain with slight undulations. The surface geology consists of Mississippian age limestones and with cherty nodules (Adamski 1995). Within the South Dry Sac Watershed, these include the Burlington-Keokuk Limestone, the Elsey formation, the Pierson formation, and the Northview formation (Emmet et al.

1978). The Burlington-Keokuk limestone underlies over 99% of the watershed and lends itself to karst activity; the remaining 1% is Pierson limestone and Northview shale (Figure 3.2). Karst features such as caves, sinkholes, springs and losing streams are widespread throughout the study area (Bullard 1997). The main stem of the South Dry Sac has a swallow hole located several hundred meters downstream from the confluence of the Valley Water Mill tributary.

Soils

Soils found in the South Dry Sac Basin are largely cherty silt loams and silt loams. Nine different soil series are found at the 36 survey reaches (Table 3.1). Soils found on the small upland reaches of streams were the Wilderness cherty silt loam, Peridge silt loam, Goss cherty silt loam, Goss-Gasconade complex, and Pembroke silt loam (Figure 3.3). The prominent soil found along the floodplain of the upper main stem is Waben-Cedargap cherty silt loam. The floodplains along the middle main stem consist of Cedargap cherty silt loam. The middle and lower floodplains of Pea Ridge Creek are composed of the Cedargap silt loam. The Huntington silt loam is found along the floodplain of the lower main stem (Hughes 1982).

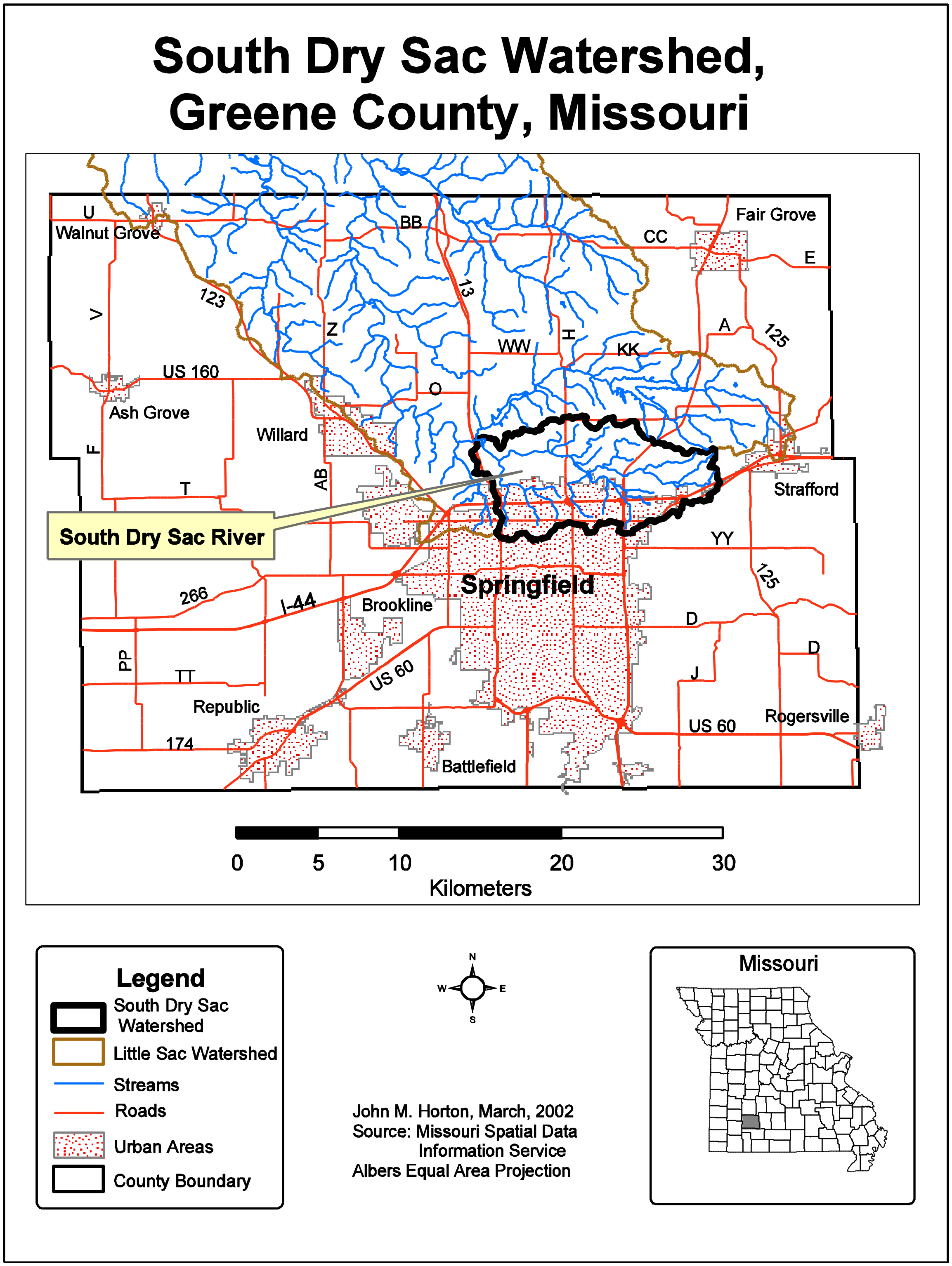


Figure 3.1 South Dry Sac Watershed, Greene County, Missouri.

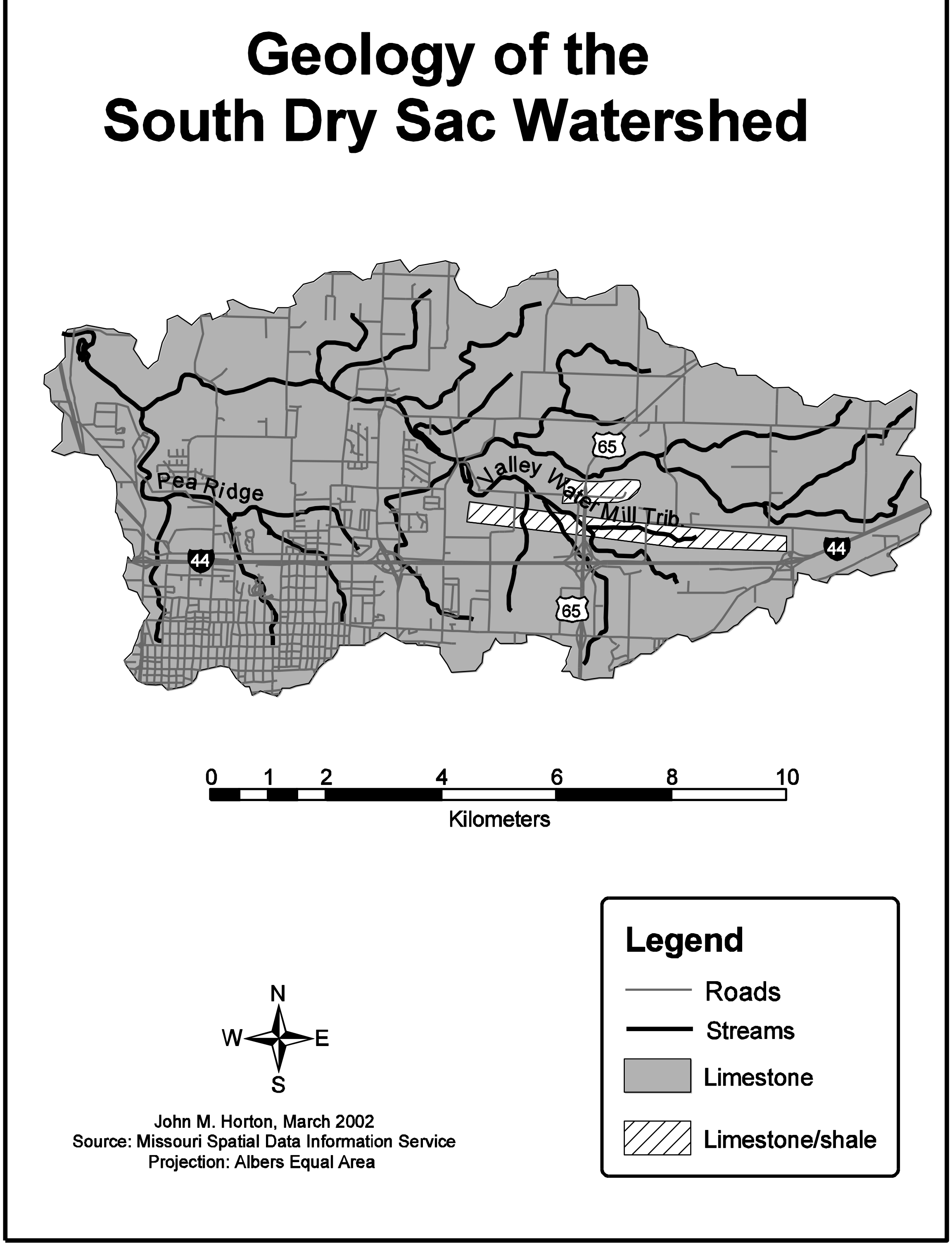


Figure 3.2 Geology of the South Dry Sac Watershed.

Table 3.1 Survey reach soil characteristics (Hughes 1982).

Soil Series	Location	Parent Material	Slope Range
Pembroke silt loam	uplands and stream terraces	residuum or thin loess and alluvium weathered from stone under prairie vegetation	1-5%
Goss cherty silt loam	uplands	loamy and clayey residuum weathered from cherty limestone and dolomite under deciduous forests	2-20%
Goss-Gasconade complex	uplands	clayey residuum weathered from cherty limestone	2-20%
Peridge silt loam	uplands and stream terraces	thin loess or alluvium and residuum weathered from cherty limestone under deciduous forests	2-5%
Wilderness cherty silt loam	uplands	loamy and clayey residuum weathered from cherty limestone under deciduous forests	2-9%
Waben-Cedargap cherty silt loams	terraces, alluvial-colluvial fans, and toe slopes	loamy cherty alluvium and colluvium under deciduous forests	0-5%
Cedargap cherty silt loam	floodplains of small streams	silty and clayey alluvium containing a high percentage chert fragments under prairie and scattered deciduous forests.	0-2%
Cedargap silt loam	floodplains of small streams	silty and clayey alluvium containing a high percentage chert fragments under prairie and scattered deciduous forests.	0-2%
Huntington silt loam	floodplains	alluvium washed from soils formed in residuum weathered from cherty limestone, sandstone,and shale under deciduous forests	0-2%

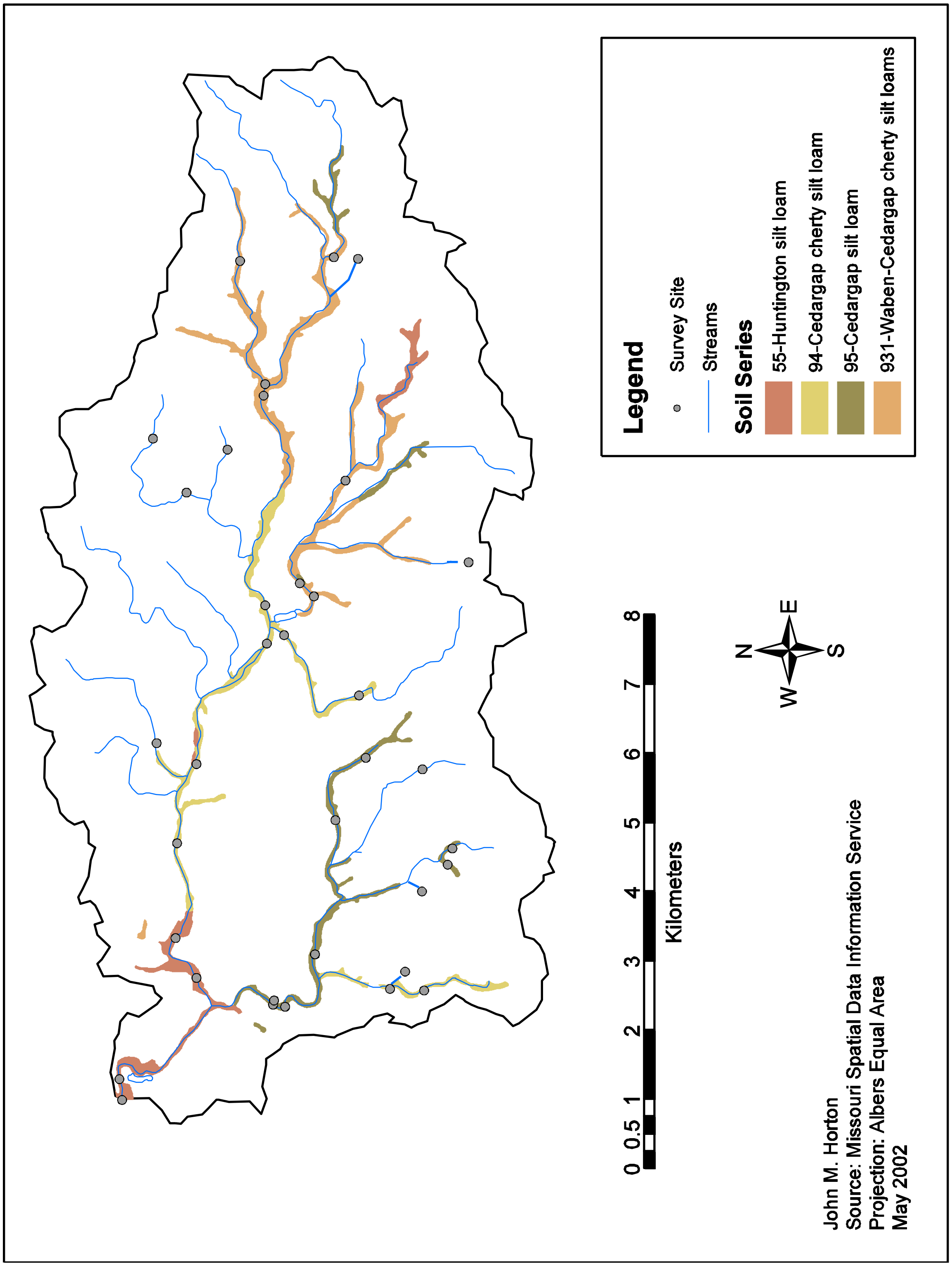


Figure 3.3 Alluvial soil distribution in the SDS Watershed.

Climate

The climate of Springfield is one of hot summers and moderately cool winters. The average temperature in summer is 76 degrees F with the average daily maximum temperature of 87 degrees F. The average temperature in winter is 35 degrees F with an average daily low of 24 degrees (Hughes 1982). Average annual precipitation for the Springfield area is about 40 inches per year. Springfield receives the most rainfall in the months of April through June. Springfield receives the least amount of precipitation in the months of December through February (Adamski 1995).

Discharge

USGS continuous recording flow gage #06918493, SDS, Springfield is located just below the confluence of Valley Water Mill tributary with a drainage area of 40.2 km^2. The annual mean flow from August 1996 through water year 2001 is 0.38 m^3/s. The maximum peak stage was 2.99 meters recorded on July 12, 2000. The gage is located about 200 meters downstream of site 35 and about 100 meters upstream of site 27 used in this study.

Land Use Characteristics

Land cover in the South Dry Sac Watershed is 21.0% urban, 18.7% forest and 58.6% grassland according to National Land Cover Dataset Landsat images from 1987-93 (Figure 3.4). The remaining 1.8% is classified as open water, bare rock and quarries. The urban land uses within the basin are in the form of low and high density residential and industrial/transportation developments. The land use in the rural portion of the basin is principally in the form of dairy and cattle operations. These farms are generally small with most of their acreage committed to pasture and hay production. Deciduous, evergreen and shrubland forest cover exists as small woodlots, riparian corridors and on areas with slopes too steep for farming or development. The majority of the urbanization is located in the southwest and west central portion of the watershed (Figure 3.5).

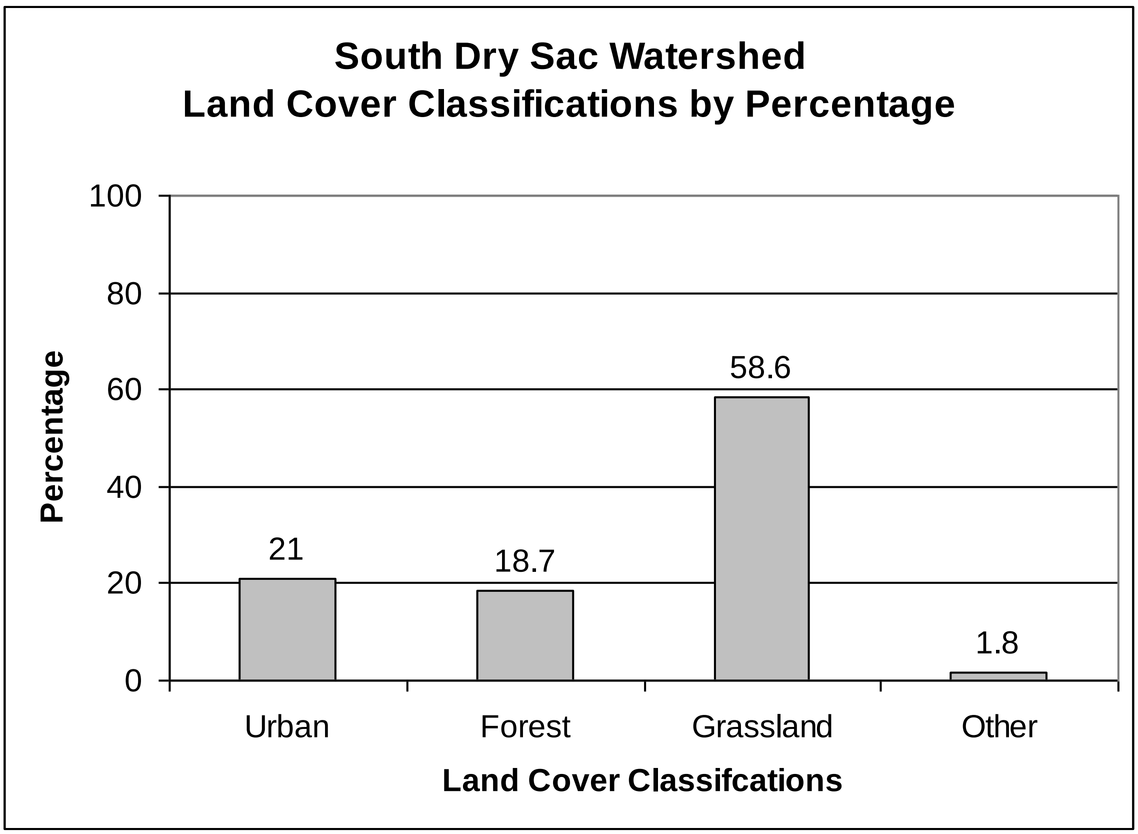


Figure 3.4 South Dry Sac Watershed land cover percentages by class.

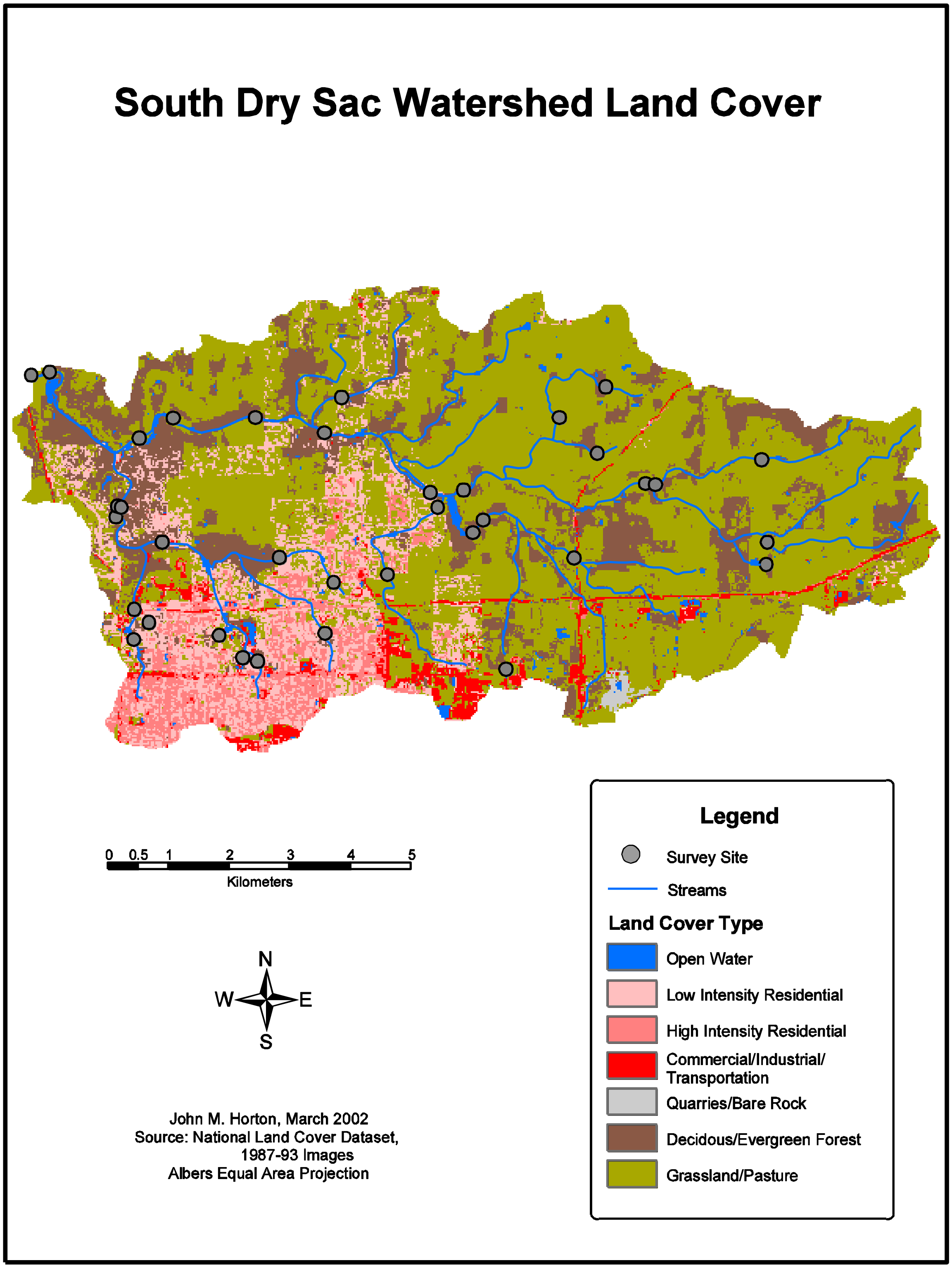


Figure 3.5 Map of South Dry Sac Watershed land cover.

CHAPTER 4

METHODS

SURVEY REACHES

Survey sites in the South Dry Sac Watershed were selected so that a broad range of land use and drainage areas could be represented in the study. Attempts were made to sample a balanced selection of grassland/agriculture, wooded and urbanized sub-watershed reaches for evaluation. The site number and survey reach location can be referenced in Figure 4.1. Additionally, survey sites were chosen to represent the different stream orders (Strahler method, orders1-4) within the basin (Table 4.1). However, gaining access to all of these optimum sites was not possible. Most of the land within the watershed is privately owned. Gaining access to this land requires permission from landowners not always readily available. Most people were cordial and willing to grant access to their land. Very few of the landowners approached during the data collection phase were unwilling to grant access. Moreover, finding the owners of rural woodlots and pastures to gain access is particularly difficult.

Field research for this study consisted of measuring channel cross-sections, longitudinal profiles, riparian buffers and channel/floodplain slopes at 36 relatively straight reaches at riffles. Triplicate cross-section surveys were conducted at five of the reaches to assess data collection variability within a reach. Field data processing and GIS analysis were accomplished using

Microsoft Excel, ArcView 3.2 and ArcGIS software. Geospatial data was obtained from the online sources and land cover data sets were obtained from CD-ROM.

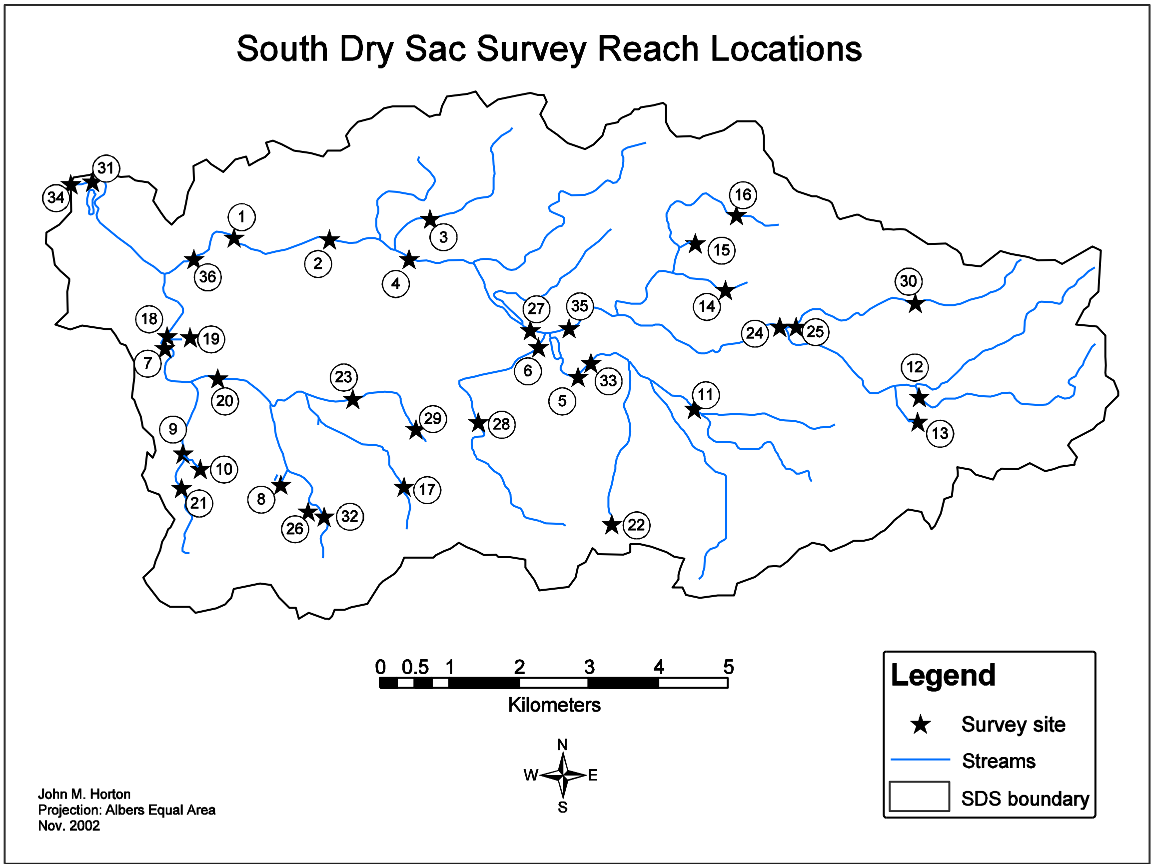


Figure 4.1 Survey reach locations.

Table 4.1 Survey reach and sub-basin size and land use reference.

Sub-Basin and Reach Size				Sub-Basin Land Use		
Site #	**Ad (km^2)**	**Stream Order (Strahler)**	**Elevation (ft)**	**PDA or urban (%)**	**Grass (%)**	**Forest (%)**
22	0.04	1	1342	33.3	57.8	6.7
13	0.19	1	1358	1	81.5	18.5
19	0.22	1	1137	44.4	52.3	3.3
8	0.27	1	1245	83.9	10.7	5.4
14	0.36	1	1306	4.5	91.5	4
15	0.42	1	1267	1	85.2	14.1
10	0.43	1	1225	93.9	2.1	2.9
17	0.56	1	1296	89.1	7	3.2
26	0.67	1	1251	89.2	3.6	4.9
16	0.95	2	1317	3.8	80.8	14.3
30	1.12	2	1352	1	73.5	25.7
29	1.20	2	1260	82.4	15.8	1.1
21	1.75	2	1219	88.5	8	2.8
32	2.03	2	1249	92.5	3.8	2.5
9	2.45	2	1198	86.4	7.8	4.7
23	2.65	2	1220	69.2	28	2.1
28	2.90	2	1261	43	51.8	3.2
12	3.85	2	1335	8	73.8	16.8
6	4.77	2	1200	44.8	49.8	3.8
3	1.92	3	1179	14	65.5	20.4
25	4.32	3	1274	1	74	25.7
11	4.51	3	1267	5	79.6	13.8
20	10.65	3	1156	66.7	21.6	10
33	11.29	3	1213	6.7	71.6	18
5	12.42	3	1208	7.8	71.1	17.8
7	15.32	3	1127	66.7	20.2	11.6
18	15.35	3	1123	66.7	20.2	11.7
24	13.45	4	1265	2.6	75	21.6
35	22.49	4	1189	2	78.4	18.8
27	40.18	4	1181	8.9	72.4	16.8
4	46.70	4	1149	9.3	72.2	16.7
2	52.87	4	1133	9.6	71.4	17.4
1	54.67	4	1115	9.6	71	17.7
36	57.43	4	1105	9.2	71	18.2
31	77.15	4	1078	21	58.8	18.5
34	78.52	4	1073	21	58.6	18.7

FIELD METHODS

Channel Geometry and Geomorphology

Cross-section surveys. Channel cross-sections were surveyed at riffles located in relatively straight and stable reaches representative of the location. Equipment for surveying channel cross-sections included an auto-level/tripod, stadia rod and 100-meter measuring tapes. The cross-section included all topographic breaks in slope from right to left floodplain, as one looks downstream (Figure 4.2). Probable bankfull discharge levels were noted in the field using indicators explained by Rosgen (1996). In SDS channels, bankfull indicators were most readily found at elevations relative to the tops of the highest depositional features such as point bars and mid channel bars where textural changes occur from gravel to fines. Additionally other bankfull indicators were located at exposed roots below an intact soil layer signifying contact with erosive flow. Total channel indicators were usually found at the top of the low terrace or at the valley floor elevation.

Longitudinal profiles. Longitudinal profiles were surveyed at each cross-section survey reach to provide reach slope and riffle/pool data. Pool-riffle sequences were surveyed along each reach using 100-meter measuring tapes, auto level and stadia rod. The tape was positioned in the thalweg at a length to include at least three riffles and two pools if possible. Next, riffle-riffle, pool-riffle, pool-pool sequence depths and spacing were recorded (Figure 4.3). The few reaches with no pool-riffle sequences were noted. Riffle heads, tails, and parts of the pools with greatest depths were noted.

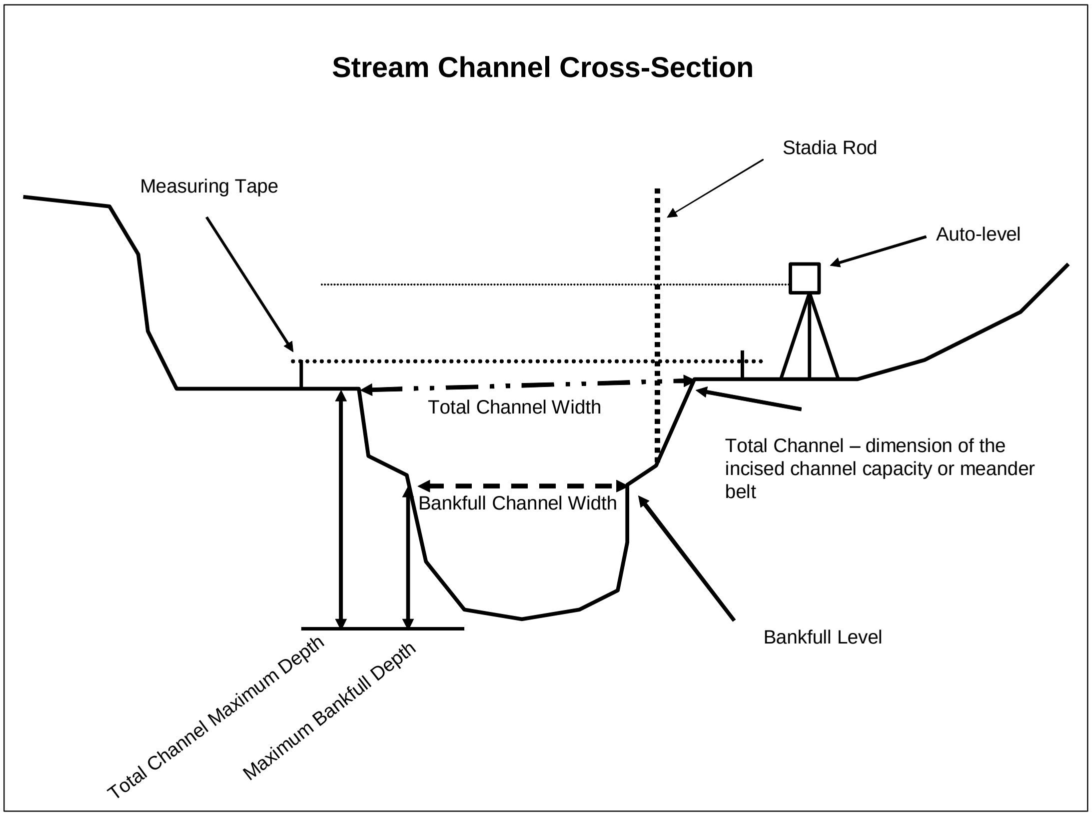


Figure 4.2 Channel cross-section measurements.

Channel and valley slope. Channel slope was determined along the tops of 3-5 riffles using rise and run calculations (*m/m*). Additionally, riffle elevations were plotted in Excel and a regression line was used to determine slope. Valley slopes were calculated using U.S. Geological Survey DLGs (Digital Line Graphs) in ArcView 3.2 GIS software. Valley slopes were calculated by dividing the vertical elevation (rise) change by the horizontal distance (run), expressed in the equation *slope = rise/run*.

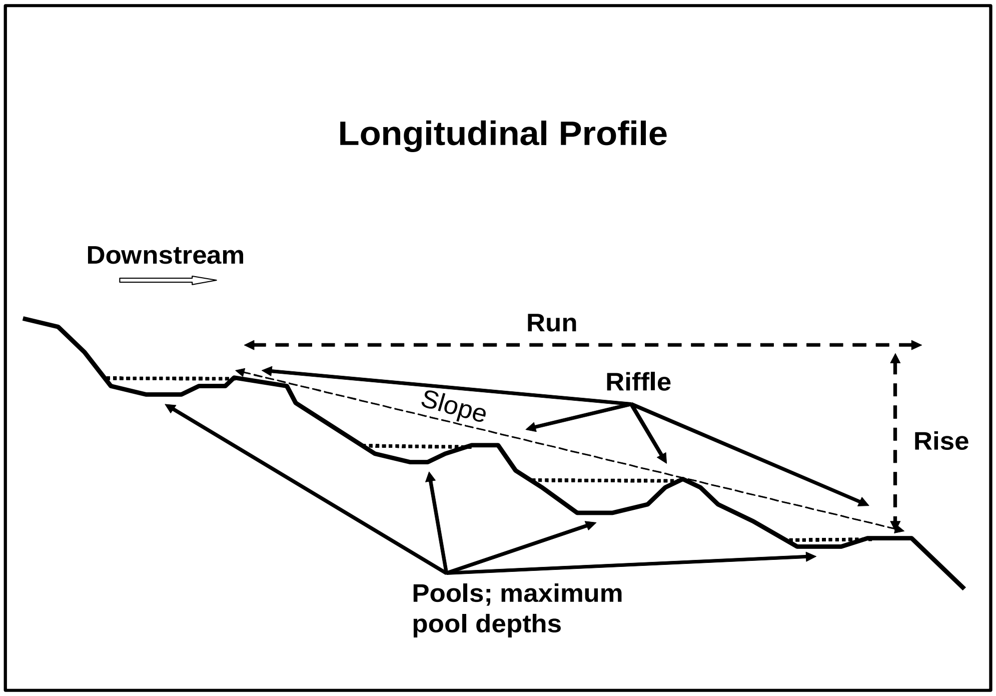


Figure 4.3 Longitudinal profile.

Bed Sediment Analysis

Bed sediment was measured at five places along the each survey reach. The Wolman “uniform” pebble count technique, as described in the Panfil and Jacobson (2001) study and by Rosgen (1996) was modified for this study. First, the bankfull channel width was established at the cross-section survey point. Then two upstream and two downstream survey traverses were established at intervals equal to the bankfull width (Figure 4.4). Next, 10 equidistant, blind touches were made along the measuring tape at all five traverses. The B-axis of the bed sediment was then recorded. A total of 50 observations were recorded at each survey reach.

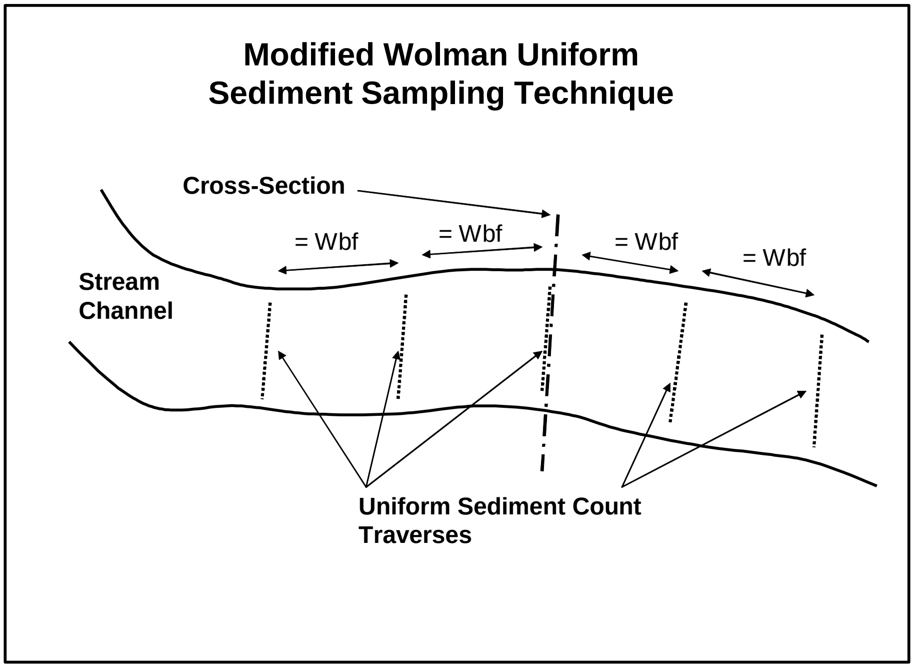


Figure 4.4 Uniform pebble count sampling.

FIELD DATA PROCESSING AND GIS

Cross-Section Analysis

Data from the cross-section surveys were transformed to a set of horizontal distances and elevations relative to a set point (Parsons 1985). This was accomplished by using an Excel spread sheet to graph the cross-section profile. Bankfull width, mean depth, total channel capacity width, and total channel capacity mean depths were calculated from these graphs. Width/Depth ratios were calculated by dividing bankfull width by mean bankfull depth. Cross-sectional areas were calculated by multiplying bankfull width by mean bankfull depth. Table 4.2 provides a complete list of variables and indices obtained from field data computation.

Longitudinal Profile

Longitudinal profiles were graphed in Excel the same way the cross-sections were processed. Once graphed, riffle-riffle, riffle-pool and pool-pool spacing were calculated. Maximum residual pool depths were also derived from the longitudinal profile graphs.

Planform

Stream channel sinuosity was acquired using GIS software. This method involved measuring stream channel reach lengths from digital orthophotos. Next, the straight or valley length was measured (Figure 4.5). Then, channel length was divided by valley length. Meander wavelengths were as also measured from the orthophotos. This was accomplished by measuring the distance between outside meander bends at the deepest point of the bend. Distances along this axis were then analyzed to assess the frequency of meandering. Similarly, meander amplitude was derived from the digital orthophotos.

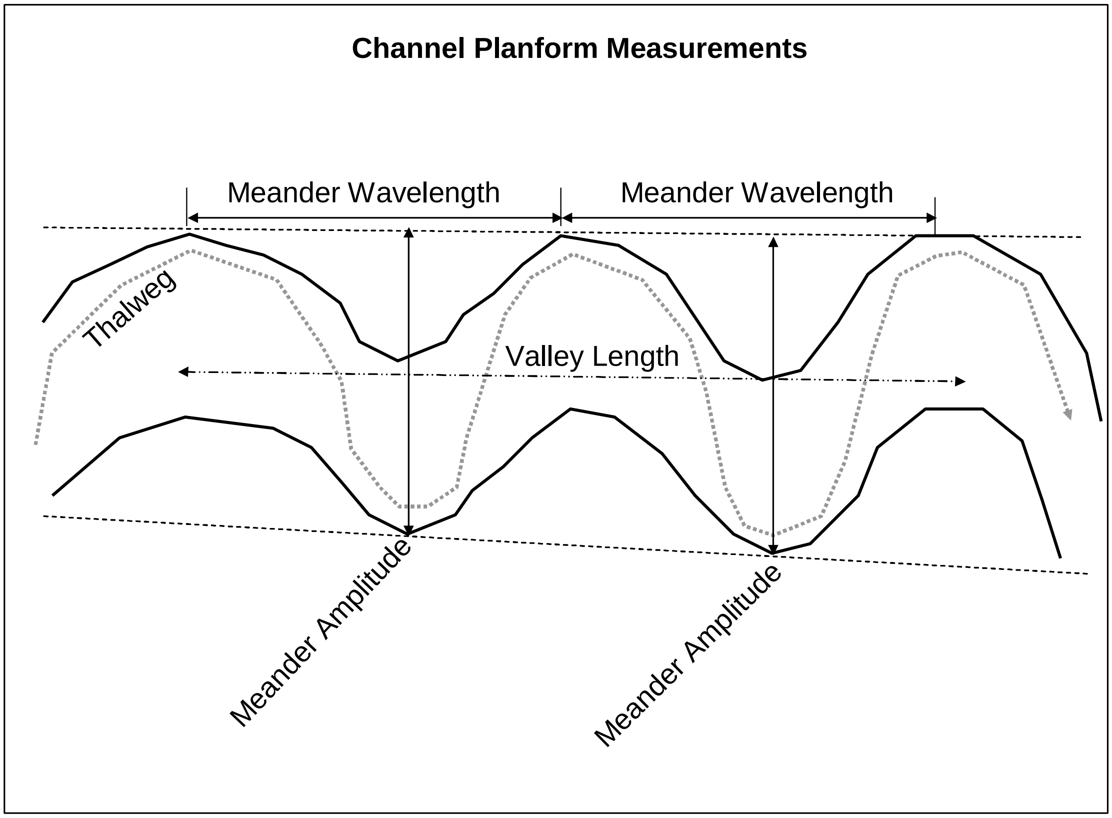


Figure 4.5 Channel planform measurements.

Table 4.2 Variables and indices calculated for channel morphology assessment.

Variable or Indices	Method of calculation and/or notes, units
Cross-Section	
Width	bankfull and total channel, (m)
Mean Depth	bankfull and total channel, (m)
Cross-Sectional Area	width x mean depth; bankfull and total channel, (m^2)
Maximum Depth	bankfull and total channel, (m)
Entrenchment Ratio	2x max bankfull depth / bankfull width
Width:Depth Ratio	width / mean depth; bankfull and total channel
Longitudinal Profile	
Slope (riffle)	Excel, regression of riffle heights
Slope (topographic map)	vertical elevation change / horizontal distance (rise/run); calculated from DLG in a GIS (m)
Slope (75% basin)	vertical elevation change / horizontal distance (rise/run); measured from 10% upstream of survey site to 15% downstream of the divide, (m)
Riffle-Riffle Spacing	distance between riffle heads averaged, (m)
Pool-Pool Spacing	distance between greatest pool depth averaged, (m)
Riffle-Pool Spacing	distance between riffle head to greatest pool depth averaged, (m)
Maximum Residual Pool Depth	maximum pool depths for reach averaged, (m)
Planform	
Sinuosity	channel length / valley length
Meander Amplitude	width between outside bend of channel and opposite side meander belt axis averaged, (m)
Meander Wavelength	distance between meander amplitudes averaged, (m)
Sediment	
D10	10th percentile, (cm)
D50	median sediment size (cm)
D84	84 percentile, (cm)
Maximum Clasts	10 largests clasts within reach averaged, (cm)

Watershed Assessment

Drainage area calculation. Drainage areas above survey site were calculated using GIS software. This entailed downloading an U. S. Geological Survey DEM (Digital Elevation Model) of the South Dry Sac study area to create a watershed base map. Channel survey sites were plotted on the map from GPS coordinates (Schilling and Wolter 2000). Drainage areas upstream of survey sites were then determined using ArcView 3.2 software equipped with Watershed Delineator extension.

Land cover assessment. Land cover for the study was determined using images from the National Land Cover Dataset. The images used were 30-meter Landsat Thematic Mapper obtained from 1987 through 1993. These images were loaded into ArcGIS software and then the South Dry Sac Watershed was clipped from the land cover images. The same process was repeated for each sub-basin above each survey reach. Land cover classification percentages above each study site sub-basin were then calculated using ArcGIS software. Percent Developed Area (PDA) of each sub-basin was determined by combining residential, commercial and industrial land uses (Southard 1986). Grasslands/pasture, forest and open water were deemed undeveloped. Percent impervious area, needed to estimate urban discharge, was calculated using an approach also explained by Southard (1996) expressed in the regression equation:

$$I=2.03\ (PDA)^{0.618}\ .$$

In this study, rural channels are defined as stream reaches where less than 15 percent of the area upstream of the survey site is developed (<15% PDA). Conversely, urban channels are defined as stream reaches where greater than 15 percent of the area upstream of the survey site is developed (>15% PDA). These designations were derived from various studies that found as little as 10-20% developed area can have an affect on channel morphology (Doll et al. 2000; Hammer 1972; Hollis 1975). Developed area is simply residential, business, industrial and transportation land use combined into one class. This design also allowed for a near equal amount of sites to be represented in each grouping.

Riparian vegetation assessment. Riparian vegetation was measured and recorded to determine the types of vegetation and land-use at each survey site. Riparian buffer widths were also assessed using digital orthophotos loaded into ArcGIS software. Using ArcGIS measuring tools, riparian conditions and vegetation types were measured and quantified along the survey reach the length of 30 bankfull widths upstream of the actual cross-section survey site.

ROSGEN LEVEL II CLASSIFICATION

Fluvial geomorphologists continue to strive to create a system of stream classification in order to make science and management more proficient (Downs 1995). The Rosgen Level II Classification is a morphological description of the channel and valley in which it forms. Five variables are needed to complete this classification. They are as follows: (1) entrenchment ratio, (2) width:depth ratio,

(3) sinuosity, (4) slope and (5) channel material. All of these variables, except entrenchment ratio, were discussed earlier in this chapter. The degree of entrenchment is the vertical containment of the channel. It is calculated by the following equation:

Entrenchment ratio = flood-prone width / bankfull width.

where:
flood-prone width = width measured at elevation relative to 2 x bankfull maximum depth.

Rosgen (1996) emphasizes that an accurate field assessment of bankfull stage is completed before classification work begins. The same process described earlier for determining bankfull stage was used here.

The classification process was accomplished using the key to the Rosgen Classification of Natural Rivers (Figure 4.6). Classification begins by routing channel morphology data through the classification flow chart. First, entrenchment ratio is considered. Entrenchment ratio is given an allowance of +/- 0.2 units if it is evident the classification process will be impeded by this variable. Next, width:depth ratio is considered. Width:depth ratio is also given a classification flexibility of +/- 2.0 units. The third physical variable is sinuosity with a unit allowance of +/- 0.2. Fourthly, reach slope is factored in the classification scheme. Finally, channel material ranging from bedrock to silt/clay determines the final stream classification type.

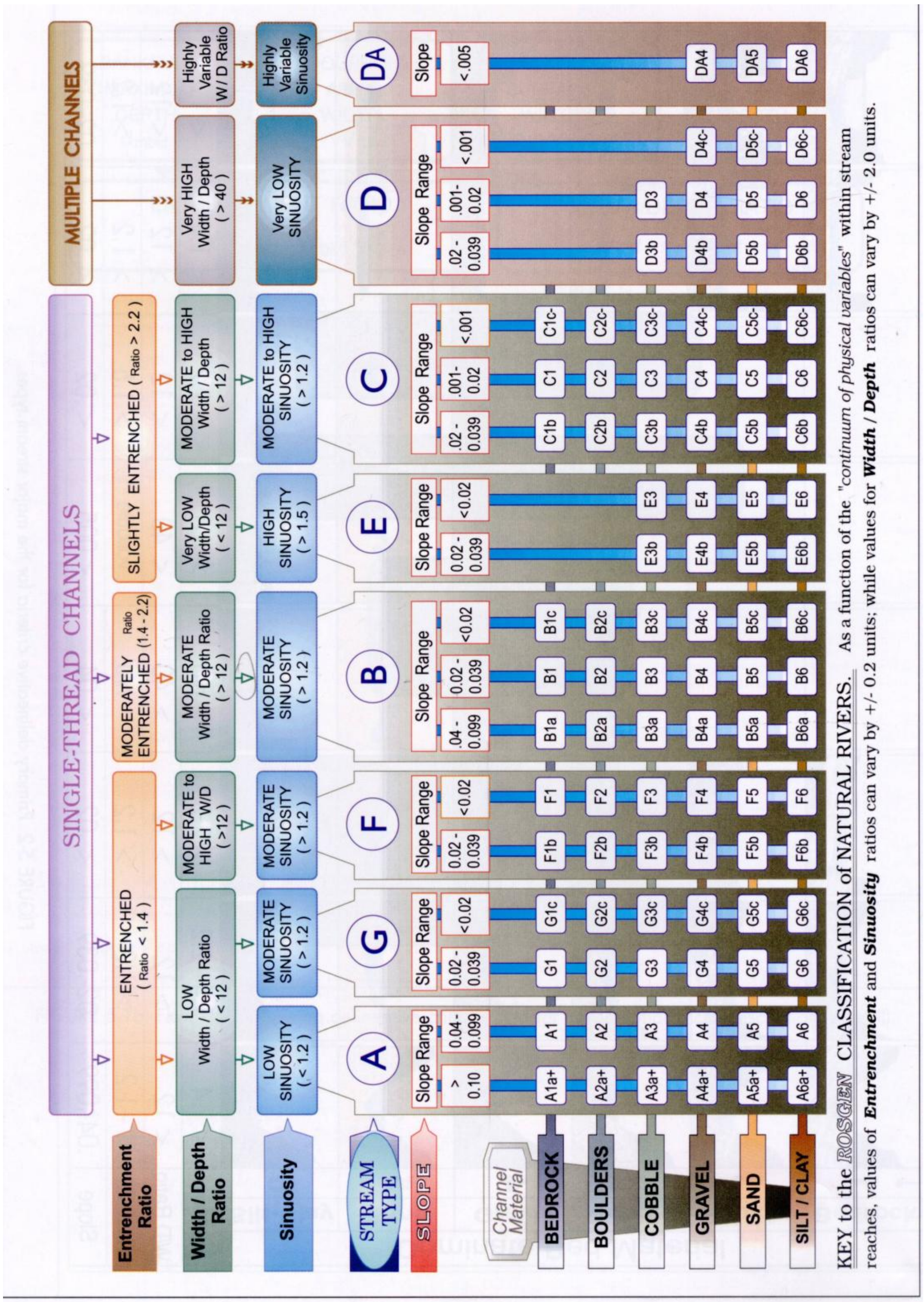


Figure 4.6 Key to the Rosgen classification of natural rivers (Rosgen 1996).

DISCHARGE CALCULATION

Bankfull Discharge Estimate

Bankfull discharges were calculated by multiplying bankfull cross-sectional area by mean velocity expressed as $Qbf = A * V$. Velocity was derived from the Manning Equation as follows:

$$V = (C * R^{0.66} * S^{0.5}) / n.$$

where:

C = units conversion coefficient, 1.49 for *foot* units or 1.0 for *meter* units
R = hydraulic radius, (W*D)/(2D+W)
S = channel slope, calculated as rise/run.
n = Manning roughness coefficient (gets larger as roughness increases).

The “n”, or Manning roughness coefficient, was derived from field observations based on the Chow (1959) method. Two additional methods for obtaining “n” were used to assess variability of “n” estimates. The Rosgen (1996) method for calculating “n” utilizes the D84 sediment and relative roughness. The Pizzuto et al. (2000) method for calculating “n” is based on the equation

$$\text{“n”} = Fp(n_{grain} + n_{bed}) + n_{grain} + n_{bed}.$$

where:

Fp = planform sinuosity factor, 0.6(K-1).
where: K = sinuosity of reach, Fp should not exceed 0.3.
n_{grain} = bed material resistance, $0.0395(d50)^{1/6}$.
where: d50 = median bed sediment size (cm).
n_{bed} = bedform roughness, $0.02(P_D/D)$.
where: P_D = mean pool depth (m).
D = mean bankfull depth (m).
n_{bed} values > 0.02 are reduced to 0.02.

This equation utilizes D50 bed sediment and bed form roughness. The field and Pizzuto derived “n” plotted closer to a one-for-one relationship. The Rosgen “n’’ plotted lower than both the Pizzuto and Chow derived “n” (Figure 4.7). The field method by Chow (1959) was used to estimate discharge in this study. Hydraulic radius was calculated from the bankfull channel geometry. Riffle slopes (Figure 4.8) were used for calculating bankfull discharge because they best represent the particular characteristics of the reach.

Field velocity checks were also conducted on selected reaches. Table 4.3 displays empirical and field derived velocity and calculated discharge for five survey reaches. This table is provided to illustrate how field measurements compare to empirically-derived data used in this study. The field derived velocities were recorded at selected SDS reaches during a bankfull discharge event on May 17, 2002 (Figure 4.9). In addition, a USGS gage-recorded discharge is offered to compare with calculated discharge for the same site (Site 27). The discharge at the gage on May 17, 2002 was estimated to be about 15% higher (several cm) than bankfull stage. In general, the analysis indicates a good agreement between field and empirical values. However, error is highest in very small streams (site 15) and those with hydraulically smooth bedrock beds (site1).

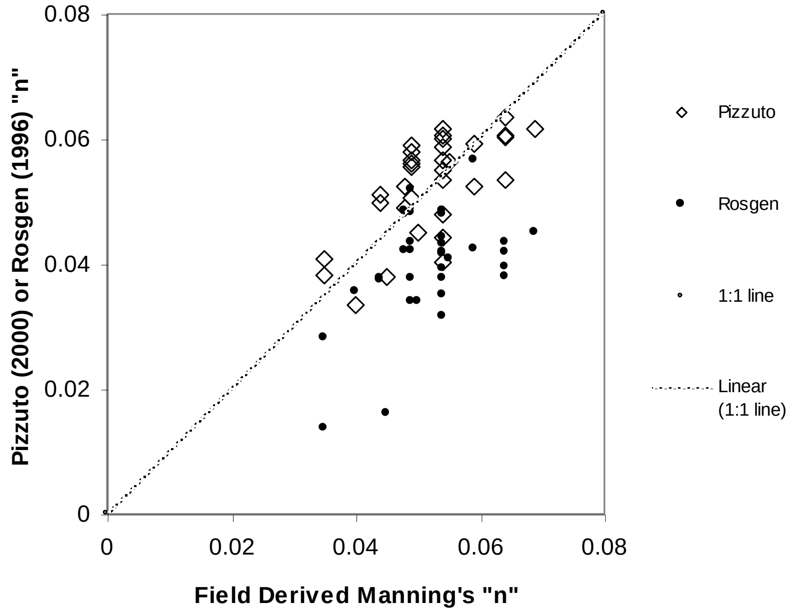


Figure 4.7 Rosgen and Pizzuto derived “n” vs. field derived “n”.

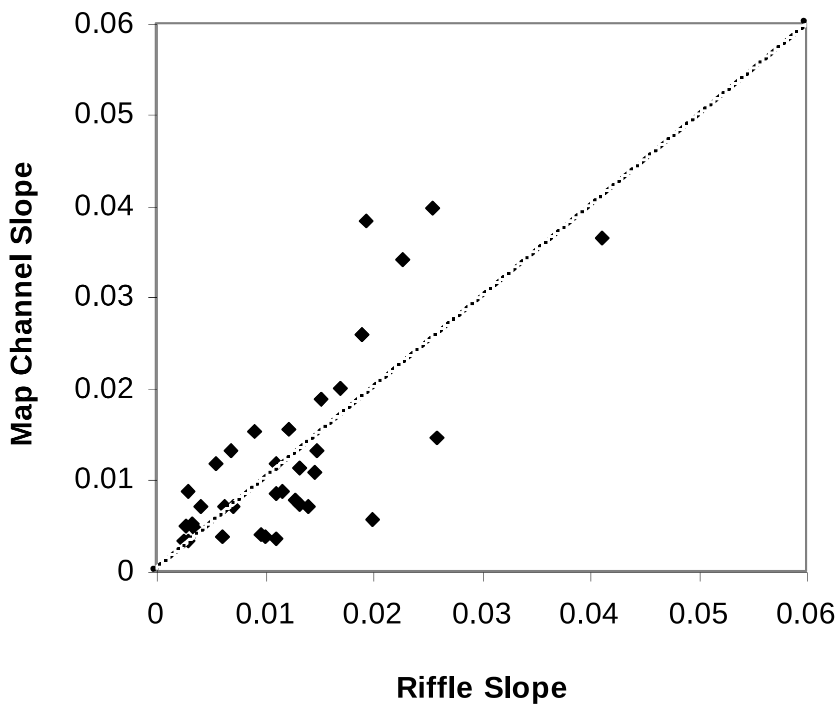


Figure 4.8 Map channel slope compared to riffle slope along 1:1 line.

Table 4.3 Comparison of field and empirically derived velocity and discharge at selected SDS survey reaches.

Site #	Ad (km^2)	Velocity, Calculated (m/s)	Field Velocity Measurement (m/s)	Qbf (m^3/s)	USGS Gage Qbf (m^3/s)
15	0.4	0.3	0.52 (meter)		
16	1.0	1.2	1.2 (meter)		
33	11.3	1.7	1.6 (meter)		
27	40.2			12.42	15.1
1	54.7	2.6	1.75 (surface float)		

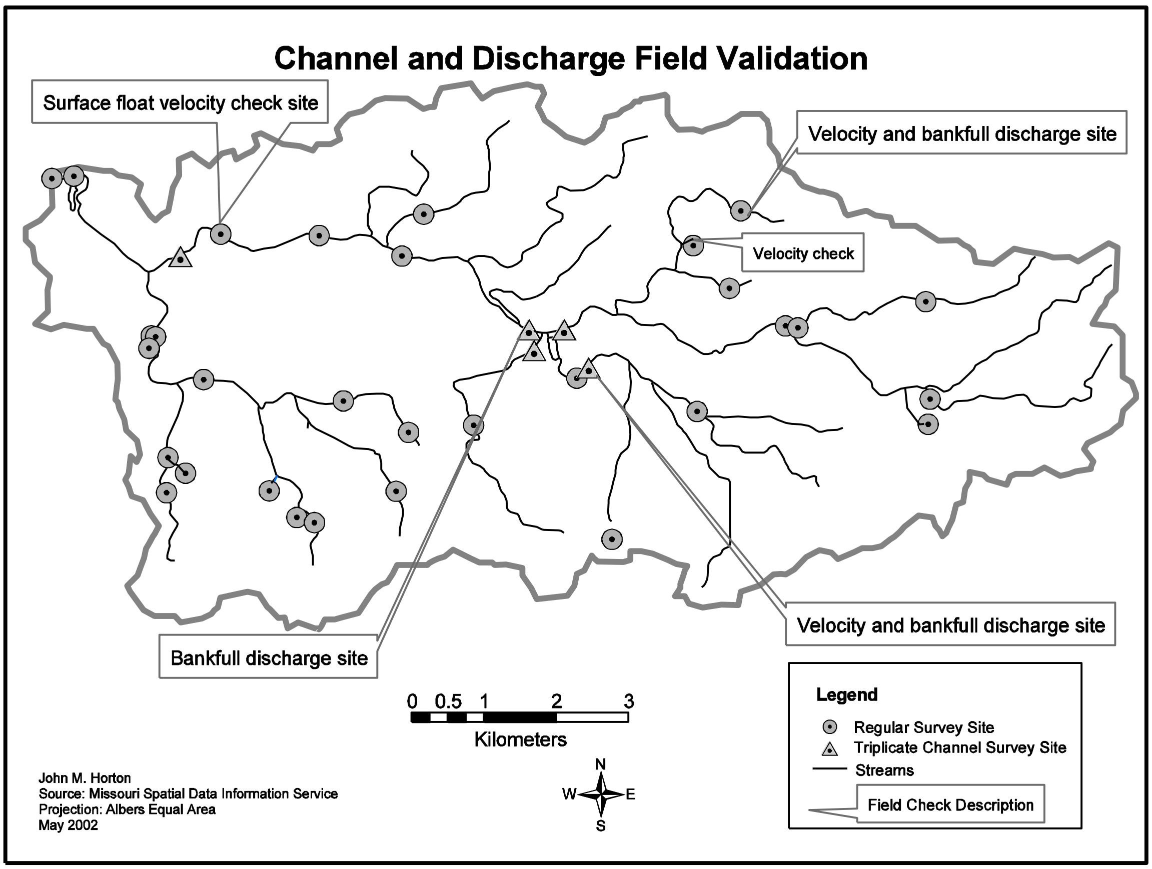


Figure 4.9 Channel and discharge field validation.

Discharge Estimate Equations

Two regression equations were used to estimate discharge for urban and rural Missouri streams. The first equation, calibrated for urban watersheds, considers all of Missouri as one hydrologic unit (Jennings et al. 1994). These regression equations are used for estimating urban Q2-100 discharges (Table 4.4). The standard errors of estimates in these regression equations can range from 26 to 33 percent.

The second equation, Region II Rural O2-100 is more specifically calibrated for the Ozark Plateaus region of Missouri. The Region II Rural equation considers such Ozark characteristics as steeper gradients, dendritic drainage patterns and karst. This equation is a generalized least-squares regression technique for estimating rural Q2-100 discharges. The standard errors of estimate for the Region II Rural equation range from 30 to 42 percent (Alexander and Wilson 1995).

Table 4.4 Discharge estimate equations.

Recurrence Interval and Equation	
Urban Q2-100	**Region II Rural Q2-100**
$Q2 = 224A^{0.793}I^{0.175}$	$Q2 = 77.9A^{0.733}S^{0.265}$
$Q5 = 424A^{0.784}I^{0.131}$	$Q5 = 99.6A^{0.763}S^{0.355}$
$Q10 = 560A^{0.791}I^{0.124}$	$Q10 = 117A^{0.774}S^{0.395}$
$Q25 = 729A^{0.800}I^{0.131}$	$Q25 = 140A^{0.784}S^{0.432}$
$Q50 = 855A^{0.810}I^{0.137}$	$Q50 = 155A^{0.789}S^{0.453}$
$Q100 = 986A^{0.821}I^{0.144}$	$Q100 = 170A^{0.794}S^{0.471}$

Urban Q2-100 equation: A = drainage area, mi^2, and I = impervious area, percentage (Jennings et al. 1994). Region II Rural Q2-100 equation: A = Area, mi^2 and S = slope, ft/mile (Alexander and Wilson 1995).

CHAPTER 5

RESULTS

ROSGEN STREAM CLASSIFICATION

Many watershed management and stream restoration project managers may find it valuable to begin with a recognized classification system on which to base their efforts. The purpose of this chapter is to categorize SDS stream reaches using the Rosgen Level II Classification System (Rosgen 1996). The Level II classification is a detailed morphological description of stream types based on geomorphic field data. Furthermore, it provides a framework for channel and watershed management strategies as described by Rosgen (1996).

REACH CLASSIFICATION

Classes by Site

The predominant Rosgen stream type in the SDS watershed is the C4 type (Table 5.1). The C4 stream type is defined as a “slightly entrenched, meandering, gravel-dominated, riffle-pool channel with a well developed floodplain” (Rosgen 1996). Class C4b streams are simply channels with slopes between 0.02-0.039. Typical cross-sections and longitudinal profiles graphs for three C4 channels (1^{st}, 2^{nd}, and 4^{th} order) are provided in Figure 5.1. The C4 cross-sectional profiles have a trapezoidal shape and longitudinal profiles generally display a systematic riffle-pool sequence. The 1^{st} and 4^{th} order channels are rural reaches; the 2^{nd} order is an urban reach.

Other SDS stream types falling into the C classification include the C6 and C1 (Figure 5.2). The C1 types are defined as “slightly entrenched, meandering, alluvial channels with bedrock controlled beds, and occur on gentle gradients in broad valleys” (Rosgen 1996). The C6 is characterized by Rosgen as “a slightly entrenched, meandering, silt-clay dominated, riffle-pool channel with a well-developed floodplain” (1996).

Table 5.1 Rosgen Level II Classification for SDS channels with geomorphic variables needed for classification.

Site	Ad, km^2	Stream Order	Entrench-ment Ratio	W:D Ratio	Sinuosity	Riffle Slope
22	0.04	1	1.23	13.93	1.00	0.0597
13	0.19	1	3.72	13.16	1.10	0.0123
19	0.22	1	9.10	8.57	1.04	0.0412
8	0.27	1	5.14	12.07	1.02	0.0227
14	0.36	1	10.86	12.96	1.17	0.0194
15	0.42	1	19.33	107.14	1.05	0.0092
10	0.43	1	6.90	15.26	1.08	0.0256
17	0.56	1	5.52	27.62	1.05	0.0094
26	0.67	1	8.33	15.65	1.04	0.017
16	0.95	2	54.00	9.26	1.15	0.026
30	1.12	2	9.82	28.50	1.18	0.0191
29	1.20	2	18.00	27.78	1.02	0.0111
21	1.75	2	7.32	12.81	1.04	0.0149
3	1.92	3	2.45	22.27	1.08	0.0147
32	2.03	2	8.97	18.57	1.07	0.0069
9	2.45	2	5.92	19.00	1.00	0.0063
23	2.65	2	10.47	8.11	1.04	0.0055
28	2.90	2	7.08	12.00	1.06	0.0132
12	3.85	2	1.38	12.34	1.24	0.0133
25	4.32	3	3.61	8.13	1.17	0.0111
11	4.51	3	1.93	26.51	1.07	0.0117
6	4.77	2	3.97	10.33	1.05	0.0129
20	10.65	3	4.76	15.44	1.09	0.003
33	11.29	3	14.00	12.75	1.07	0.0026
5	12.42	3	9.78	23.00	1.20	0.0044
24	13.45	4	1.48	14.18	1.02	0.0042
7	15.32	3	6.72	16.49	1.02	0.0071
18	15.35	3	4.34	32.55	1.08	0.0231
35	22.49	4	4.90	18.43	1.04	0.0034
27	40.18	4	4.44	14.36	1.09	0.0036
4	46.70	4	4.14	15.59	1.18	0.0061
2	52.87	4	4.25	18.60	1.04	0.001
1	54.67	4	6.88	15.69	1.10	0.0097
36	57.43	4	10.77	25.00	1.05	0.0037
31	77.15	4	1.20	17.66	1.13	0.0025
34	78.52	4	1.09	70.00	1.08	0.0012

Table 5.1 Continued

Site	D50 sediment (cm)	Sediment Class	Rosgen Classific-ation	Parameters Not fitting the Classification Scheme
22	0.1	Bedrock	A1	W:D ratio fits +/- 2.0 units
13	1.25	Gravel	C4	sin. fits +/-0.2 units
19	0.1	Bedrock	C1b	sin. fits +/-0.2 units
8	2	Gravel	C4b	sin. fits +/-0.2 units
14	1.9	Gravel	C4	sin. fits +/-0.2 units
15	0.2	Silt/Clay	C6	sin. fits +/-0.2 units
10	1	Gravel	C4b	sin. fits +/-0.2 units
17	2.65	Gravel	C4	sin. fits +/-0.2 units
26	6.6	Gravel	C4	sin. fits +/-0.2 units
16	2.7	Gravel	C4b	sin. fits +/-0.2 units
30	2.5	Gravel	C4	sin. fits +/-0.2 units
29	0.2	Silt/Clay	C6	sin. fits +/-0.2 units
21	2	Gravel	C4	sin. fits +/-0.2 units
3	5.6	Gravel	C4	sin. fits +/-0.2 units
32	1.15	Gravel	C4	sin. fits +/-0.2 units
9	4	Gravel	C4	sin. fits +/-0.2 units
23	5.1	Gravel	C4	none
28	4.71	Gravel	C4	sin. fits +/-0.2 units
12	3.75	Gravel	F4	none
25	4.6	Gravel	C4	sin. fits +/-0.2 units
11	0.6	Gravel	B4c	sin. fits +/-0.2 units
6	3	Gravel	C4	sin. fits +/-0.2 units
20	2.3	Gravel	C4	sin. fits +/-0.2 units
33	2.5	Gravel	C4	sin. fits +/-0.2 units
5	2.6	Gravel	C4	none
24	0.1	Bedrock	B1c	sin. fits +/-0.2 units
7	4.5	Gravel	C4	sin. fits +/-0.2 units
18	6.6	Gravel	C4b	sin. fits +/-0.2 units
35	3	Gravel	C4	sin. fits +/-0.2 units
27	2.5	Gravel	C4	sin. fits +/-0.2 units
4	5	Gravel	C4	sin. fits +/-0.2 units
2	8.75	Gravel	C4	sin. fits +/-0.2 units
1	0.1	Bedrock	C1	sin. fits +/-0.2 units
36	2.5	Gravel	C4	sin. fits +/-0.2 units
31	4.65	Gravel	F4	none
34	2	Gravel	F4	none

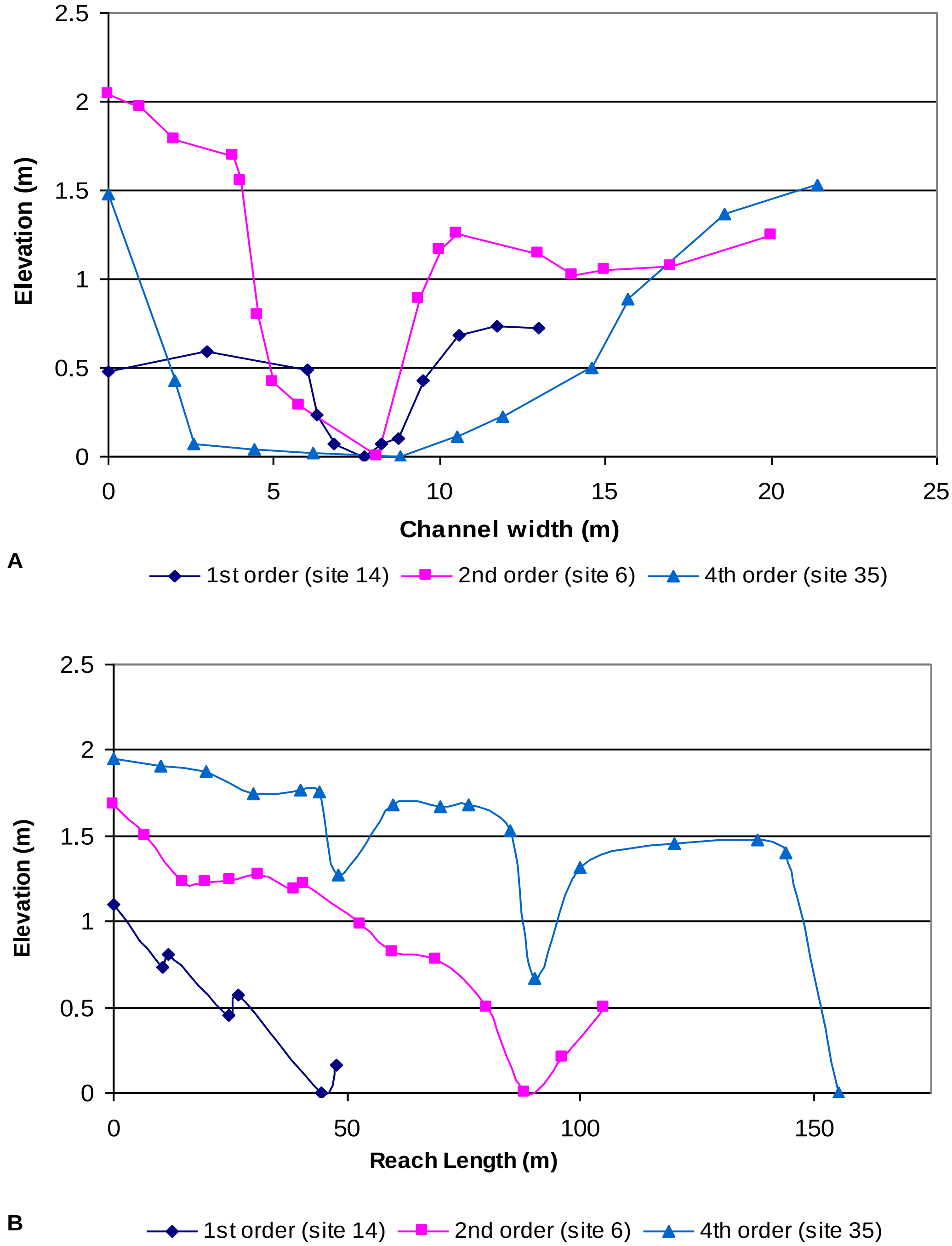


Figure 5.1 Typical C4 channel characteristics. (A) 1st, 2nd, and 4th order cross-sections and (B) 1st, 2nd, and 4th order longitudinal profiles.

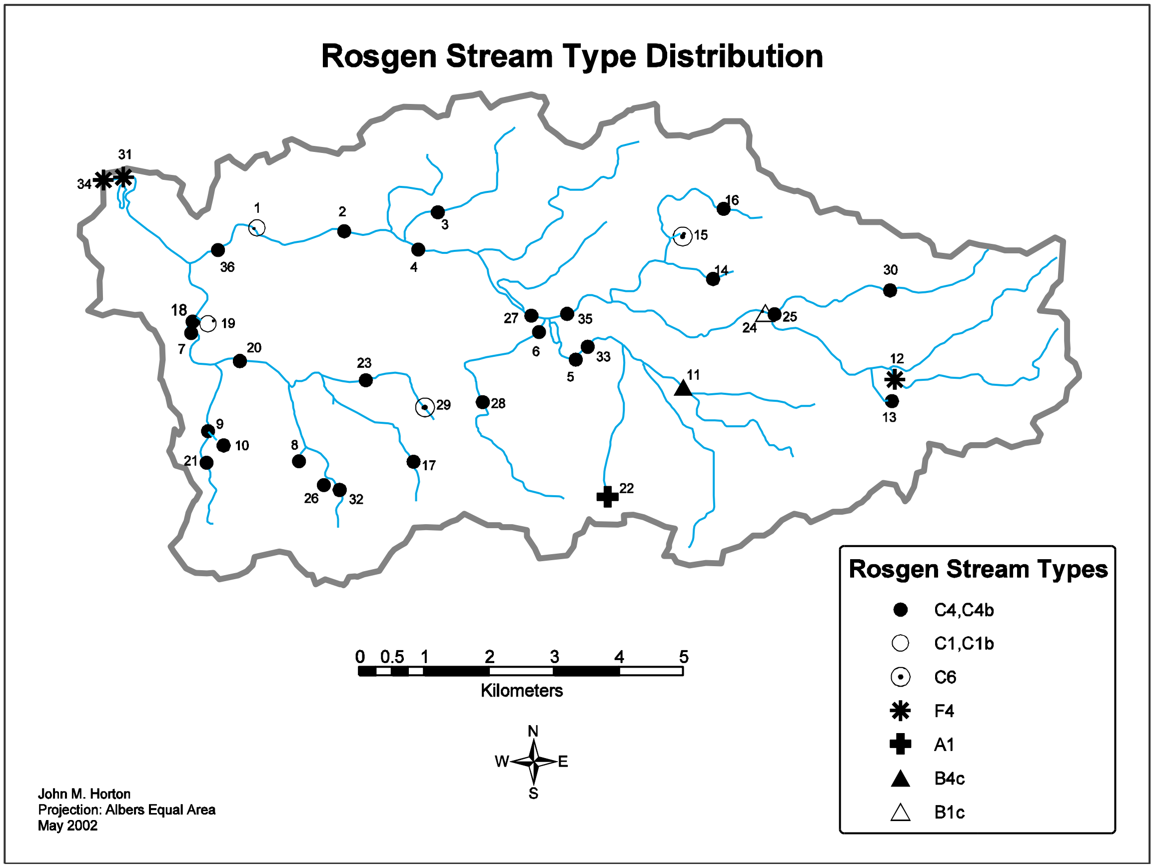


Figure 5.2 Rosgen stream type distribution.

Two SDS streams are grouped as moderately entrenched or B type streams. Site 24 is a B1c type and is associated with bedrock reaches and slopes of <.02. Site 11 is classified as a B4c type, which is defined as a "moderately entrenched system on gradients of 2-4%. According to Rosgen (1996), "B4 types normally develop in stable alluvial fans, colluvial deposits, and structurally controlled drainage ways".

Three stream reaches in the SDS fell under the classification of F4. This stream type is defined as "a gravel dominated, entrenched, meandering channel, deeply incised in gentle terrain" (Rosgen 1996). Sites 34, 31, and 12 are all located wide alluvial valleys. Sites 31 and 12 are both "pinned" against a bluff and a resistant high terrace respectively. Site 34 was omitted from the Chapter 6 channel geometry analysis because of its extremely high width:depth ratio and numerous mid-channel bars that prohibit an accurate assessment of bankfull height.

Site #22, is also an entrenched channel, but classified as an A1 type. A1 type streams are defined as "a steep, entrenched and confined channel in bedrock, that is associated with faults, folds, joints and other structurally controlled drainage ways" (Rosgen 1996). This site, due to its anomalous geometry in relation to its drainage area and bedrock scour pools, was also omitted from the Chapter 6 channel geometry analysis.

Problems and Corrections or Assumptions

The Rosgen Level II Classification is not a rigid method of classifying streams. The problem arises when one must choose a classification that does not fit the "continuum of physical variables". Flexibility is built into the classification key to account for variances in channel morphology that will inevitably occur. The physical variables of entrenchment ratio and sinuosity allow for +/- 0.2 units variance. Width/depth ratio allows for variances from +/- 2.0 units. Only four reaches in this study were routed through the Rosgen classification key without using the allowance for variables.

Sinuosity caused the greatest number of problems while classifying SDS channels. Most channels in the SDS have entrenchment ratios >2.2, and have sinuosities < 1.2. The Rosgen Key allows for a units variance of +/- 0.2 for sinuosity. Ultimately, the decision was made to use the allowance for sinuosity; thus guiding the majority of channels to the C type classification. This decision was supported by the C descriptions offered by Rosgen (1996). The channels within the SDS were found to generally agree with the C type classification.

General Findings

Generally, SDS channels are moderately to slightly entrenched. Specifically, three channels surveyed are entrenched, three are moderately entrenched, and the remaining 30 are slightly entrenched. Similar trends were also found in a study conducted in two sub-basins of the James River Watershed, an adjacent watershed to the SDS (Martin 2001). In this particular study, a rural versus urban paired-watershed design was implemented. Martin (2001) found that in the urbanizing branch, a majority of the streams fit into the C stream type classification. The rural branch in Martin's study was more variable, with D, B and C being the most prevalent respectively. The author also concluded that a fluid classification process was not possible because of the low sinuosity of Ozark streams. Martin (2001) also was required to use the flexibility built into Rosgen's "continuum of physical variables" as is done in this study.

Spatially, the SDS C type streams are distributed evenly throughout the watershed (Figure 5.2) with variable land-use and riparian characteristics (Table 5.2). The C type streams exist across 1^{st}, 2^{nd}, 3^{rd} and 4^{th} order streams. The three F4 streams in the watershed appear in wide, depositional alluvial valleys as suggested by Rosgen (1996). Two of these are 4^{th} order reaches (sites 31, 34) located near the terminus of the watershed; the remaining one (site 12) is situated in a very sinuous portion of the main stem (2nd order at this point) with a wide, alluvial, valley flat. The A1 reach (site 22) is located near the watershed divide and has appears to be severely altered by urbanization. It is a bedrock reach that was possibly a C in its “natural” state before the nearby parking lot runoff provided channel altering discharge. The B types are located in 3rd and 4th order reaches with opposing riparian characteristics. The B1c (site 24) is a main stem, bedrock reach with stable forest and grass riparian corridors. The B4c (site 11), located next to recent land-clearing activity, may have also been a C type stream before the adjacent land clearing introduced gravel into the channel thereby altering the cross-sectional area characteristics.

Sites 12, 11and 25 have comparable drainage areas, but are classified as F4, B4c and C4 respectively. Figure 5.3 A and B shows the differing cross-sectional profiles and longitudinal profiles of these stream classifications. The F4 and C4 streams are located in rural areas and display more uniform riffle-pool sequences. The B4c reach is also classified as a rural channel, but is located next to a golf course development that has undergone recent land clearing. Gravel deposition may be responsible for its shallow channel and poorly defined riffle-pool sequences.

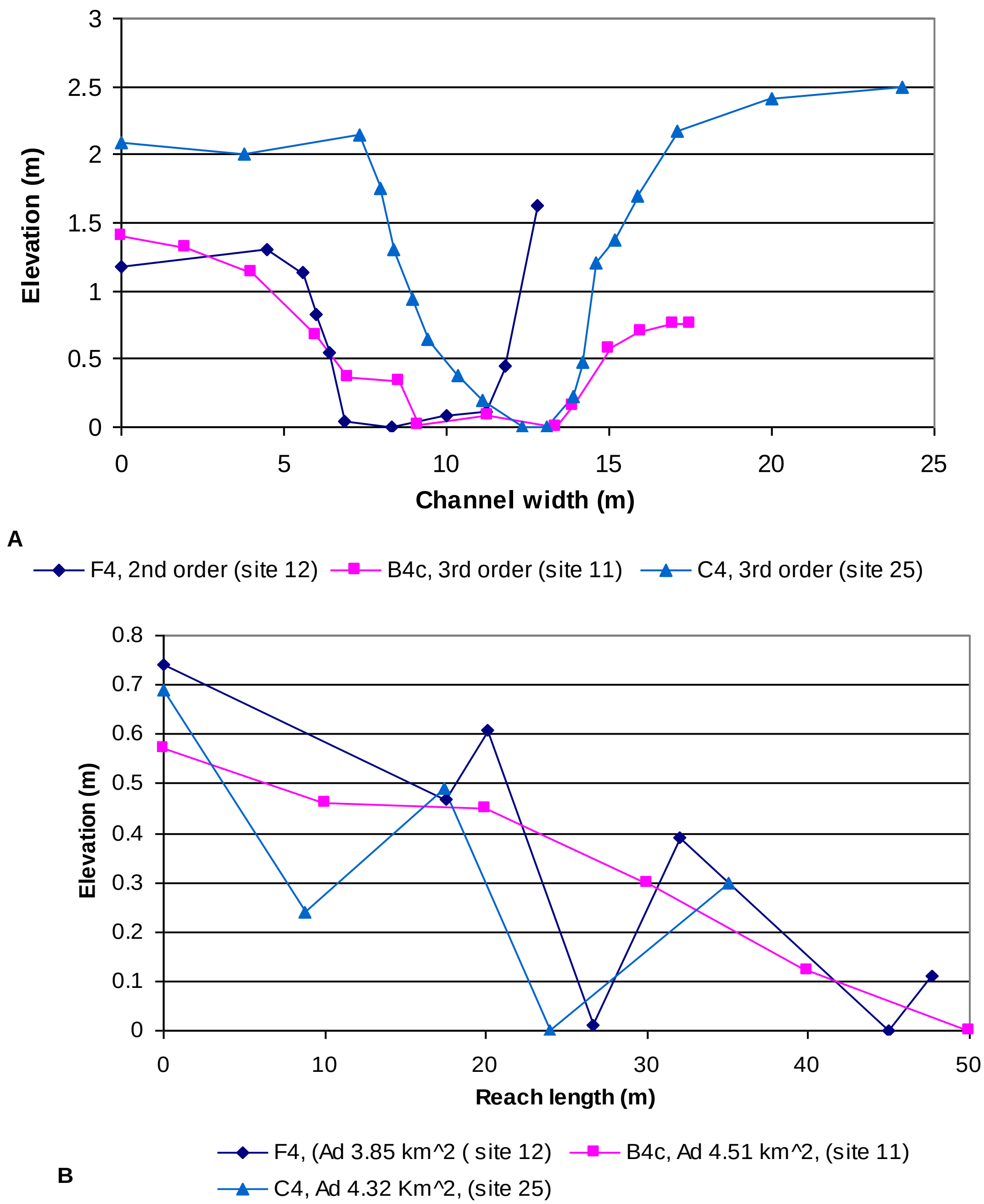


Figure 5.3 Comparison of F4, B4c and C4 channels of similar Ad. (A) Cross-sectional area. (B) Longitudinal profile.

Table 5.2 Land cover, riparian and bed characteristics for SDS survey reaches.

		Sub-Basin Land Use			Riparian Conditions (30 x bankfull width)				
Site #	**Ad (km^2)**	**PDA (%)**	**Grass (%)**	**Forest (%)**	**Grass (%)**	**Mixed (%)**	**Forest (>10%)**	**Forest (<10%)**	**Artificial (%)**
22	0.04	33	58	7		23		23	54
13	0.19	1	82	19	60		40		
19	0.22	44	52	3			100		
8	0.27	84	11	5	100				
14	0.36	5	92	4	25		75		
15	0.42	1	85	14	100				
10	0.43	94	2	3	57	24	19		
17	0.56	89	7	3	30		70		
26	0.67	89	4	5		28	72		
16	0.95	4	81	14	75			25	
30	1.12	1	74	26	90	10			
29	1.20	82	16	1	100				
21	1.75	89	8	3	72		28		
3	1.92	14	66	20			100		
32	2.03	93	4	3			100		
9	2.45	86	8	5		46	22		32
23	2.65	69	28	2				100	
28	2.90	43	52	3	100				
12	3.85	8	74	17	32			68	
25	4.32	1	74	26				100	
11	4.51	5	80	14	16		7		77
6	4.77	45	50	4	22		78		
20	10.65	67	22	10			37	63	
33	11.29	7	72	18			100		
5	12.42	8	71	18			91		9
24	13.45	3	75	22			65	35	
7	15.32	67	20	12	22		56	22	
18	15.35	67	20	12			80	20	
35	22.49	2	78	19	11		79	10	
27	40.18	9	72	17	30		43	27	
4	46.70	9	72	17	25		75		
2	52.87	10	71	17	39		61		
1	54.67	10	71	18	100				
36	57.43	9	71	18	59		41		
31	77.15	21	59	19			88	12	
34	78.52	21	59	19	10	3	72	15	

Table 5.2 Continued

			Dominant Bed Material		
Site #	**Distance to Artificial Structure**	**Valley Floor Soil Series**	**% Bedrock**	**% Gravel**	**% Fines**
22	100	Pembroke SL	50	50	0
13	n/a	Goss CSL	0	40	60
19	290	Goss-Gasconade cplx	100	0	0
8	160	Goss-Gasconade cplx.	0	100	0
14	75	Goss CSL	0	100	0
15	102	Goss CSL	0	0	100
10	30	Goss CSL	0	75	25
17	646	Peridge SL	0	100	0
26	358	Cedargap SL	0	75	25
16	472	Wilderness CSL	0	65	35
30	145	Waben-Cedargap CSL	0	100	0
29	95	Cedargap SL	0	50	50
21	30	Cedargap CSL	33	67	0
3	462	Goss-Gasconade cplx.	0	60	40
32	329	Cedargap SL	0	50	50
9	50	Cedargap CSL	0	85	15
23	595	Cedargap SL	0	100	0
28	128	Cedargap CSL	0	50	50
12	104	Waben-Cedargap CSL	0	90	10
25	145	Waben-Cedargap CSL	0	100	0
11	67	Waben-Cedargap CSL	0	100	0
6	559	Cedargap CSL	0	63	37
20	115	Cedargap SL	0	75	25
33	78	Waben-Cedarge CSL	0	100	0
5	154	Waben-Cedargap CSL	0	94	6
24	482	Waben-Cedargap CSL	100	0	0
7	322	Cedargap SL	33	47	20
18	590	Cedargap SL	0	75	25
35	2482	Cedargap CSL	0	100	0
27	106	Cedargap CSL	0	100	0
4	164	Cedargap CSL	0	67	33
2	146	Cedargap CSL	0	100	0
1	350	Huntington SL	100	0	0
36	1083	Huntington SL	0	100	0
31	2434	Huntington SL	0	90	10
34	184	Huntington SL	0	100	0

Comparison to Ozark Landform

Rosgen (1996) states that C4 streams readily form in U-shaped glacial valleys and valleys flanked by Holocene and glacial terraces. Other typical locations for C4 stream types are in very broad, coarse alluvial valleys associated with the plains areas. Furthermore, C4 "streambanks are generally composed of unconsolidated, heterogeneous, non-cohesive, alluvial materials that are finer than the gravel dominated bed material" (Rosgen 1996). Sediment supply is moderate to high with point bars and depositional features being common. C4 streams are prone to lateral shifts and vertical instability resulting from watershed disturbances such as changes in flow and sediment regimes. Rosgen (1996) lists specific valley types in which the C4 typically forms (Table 5.3). The descriptions exemplify the broad spectrum of valley types in which C4 stream types can form and the processes that formed them.

The SDS, being located on the Springfield Plateau, somewhat matches Rosgen's description of C4 streams by being located in valleys flanked by holocene terraces. Somewhat broad valleys with lateral terraces characterize the lower main stem of the SDS, but most 2nd and 3rd order reaches are confined in relatively narrow valleys. Valley types *IV* and *VI* most closely describe the geomorphological valley setting of C4 streams in the SDS. The low sinuosity typical of SDS channels may be related to the "canyons and gorges" characteristic of type *IV* valleys. However, this counters Rosgen's (1996) description of C4 streams as being "prone to lateral shifts". Furthermore the structural controls (bluff and bedrock outcrops) typical of *VI* valleys may also be responsible for low SDS sinuosities. Sediment supplies for valley types *IV* and *VI* are moderate to high and low respectively (Rosgen 1996). This is somewhat true of numerous SDS reaches experiencing bankcutting that introduces gravel and fines into channels. But resistant clay banks found in other SDS reaches contribute less sediment to channels. Most of the other valley types described in Table 5.3 are found in the American west or plains regions, not the Ozarks. The Rosgen classification procedure does become more difficult once the basic channel geometry data is computed and attempts to link form to process begin.

Table 5.3 Rosgen valley types for C4 streams (Rosgen 1996).

Valley Type	Valley Description	Typical Valley Slope	Soil and/or floodplain origin	Characteristic of SDS
IV	"classic meandering, entrenched or deeply incised, and confined landforms directly observed as canyons and gorges"	often < 2%	highly weathered materials	yes
V	"product of glacial scouring process where the resultant trough is now a wide, "u"-shaped valley"	generally < 4%	moraines, holocene alluvium	no
VI	"fault-line valley, is structurally controlled and dominated by colluvial slope building processes"	often < 4%	colluvium, alluvium	maybe-yes
VIII	"multiple river terraces positioned laterally along broad valleys with gentle, down-valley elevational relief"	gentle	alluvium	no
IX	"observed as glacial outwash plains and/or dunes"	na	glacial, alluvial, and/or eolian	no
X	"very wide, with very gentle elevation relief and mostly constructed of alluvial materials originating from riverine or estuarine depositional processes"	gentle	alluvium	no

Implications for Stability and Management

Resource managers using the Rosgen classification method have a tool with which to base restoration efforts. Planners with little knowledge of watershed management will find Rosgen’s classification scheme and reach descriptions to be generally easy to comprehend. The geomorphic descriptions of channels coupled with field data from the SDS may provide the managers with a viable management tool. Channels that deviate from the C class may represent relatively disturbed channels linked to human disturbances, which can then be scrutinized for restoration and management. Nonetheless, one must remember that no stream classification system available today is all-encompassing (Shields 1996). This is especially true for channels that have suffered from human disturbances. More detailed restoration and management strategies by Rosgen (1996) are offered in Chapter 8.

CHAPTER 6

RESULTS

GEOMORPHIC RELATIONSHIPS

This chapter examines the geomorphic relationships of SDS channels between drainage area and channel morphology, bed topography, planform, and bed sediment size. Separate analysis of rural and urban streams used to evaluate the linkages between land use and channel morphology. Three sites were omitted from analysis because they represent anomalous conditions (discussed in previous chapter; i.e. watershed position and nonconforming channel geometries in respect to drainage area). The sites omitted from all geomorphic analysis in this chapter are 15, 22 and 34. Additionally, sites 10, 11 and 29 were omitted from the longitudinal profile section because of poorly defined pool-riffle sequences. Other sites such as bedrock reaches were omitted from the some sediment analysis plots because of plotting difficulties (very little or no sediment existed at these sites) that affected regression analysis. Omitted sites are noted in figure captions. In all, 33 sites are analyzed in this chapter, 17 rural and 16 urban. A complete statistical analysis to test significance was not conducted; rather, scatterplots were used to examine spatial trends throughout the watershed.

CHANNEL FORM

Bankfull Channel Geometry

Bankfull channel widths for urban sites are slightly wider than rural channel widths (Figure 6.1). The rural sites that plot above the urban trendline tend to be located close to disturbed areas such as excavations, bridges and culverts. The urban sites that plot below the rural trendline may be attributed to their location relative to the development history of Springfield. While these reaches are typically located in highly urbanized areas, these areas are in older parts the city with no recent development and have stable grass or treed buffers. The overall trend displays urban channels as being about 10% wider at bankfull. Corresponding mean bankfull depths in urban channels are slightly deeper than rural channels (Figure 6.2).

Urban channels at 1 km^2 drainage areas have about 9% deeper mean depths than rural channels; urban channels at 10 km^2 display about 5% greater mean depths than rural channels. Rural sites that plot above the urban trendline tend to be main stem reaches or reaches with stable riparian buffers of grass on one bank and trees on the other side. The urban sites that plot well below the rural trendline tend to be reaches with stable riparian buffers (grass, shrubs and ivy) or have some bedrock influence. A comparison of maximum bankfull channel depths for rural and urban reaches show similar trends to mean bankfull depths (Figure 6.3). Trendlines show urban channels have about 15% greater maximum depths at about 1 km^2 drainage areas and 13% greater max depths at drainage areas of 10 km^2 than rural channels. In general, both mean bankfull depths and maximum bankfull depths are slightly greater in urban channels. The differences tend decrease slightly downstream as land use and topographic characteristics become more balanced among sample reaches.

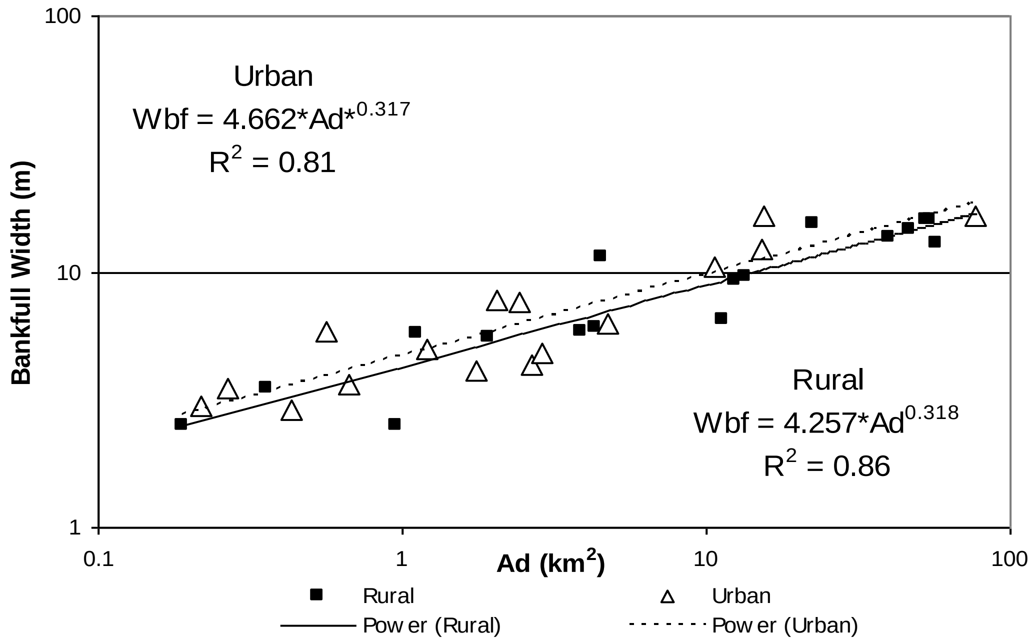


Figure 6.1 Bankfull channel width vs. drainage area.

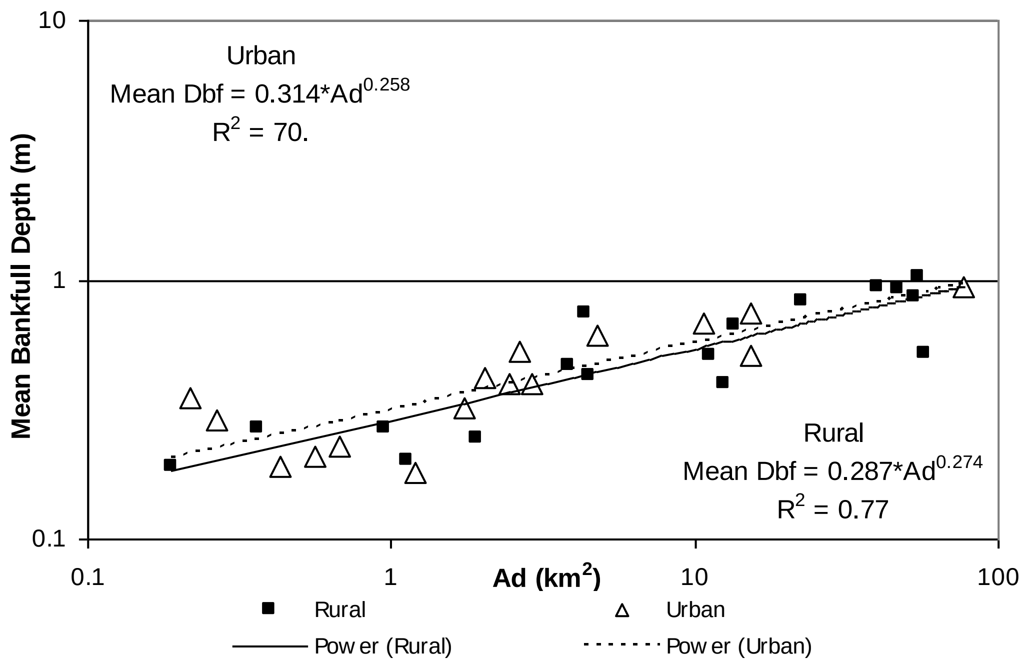


Figure 6.2 Mean bankfull depth vs. drainage area.

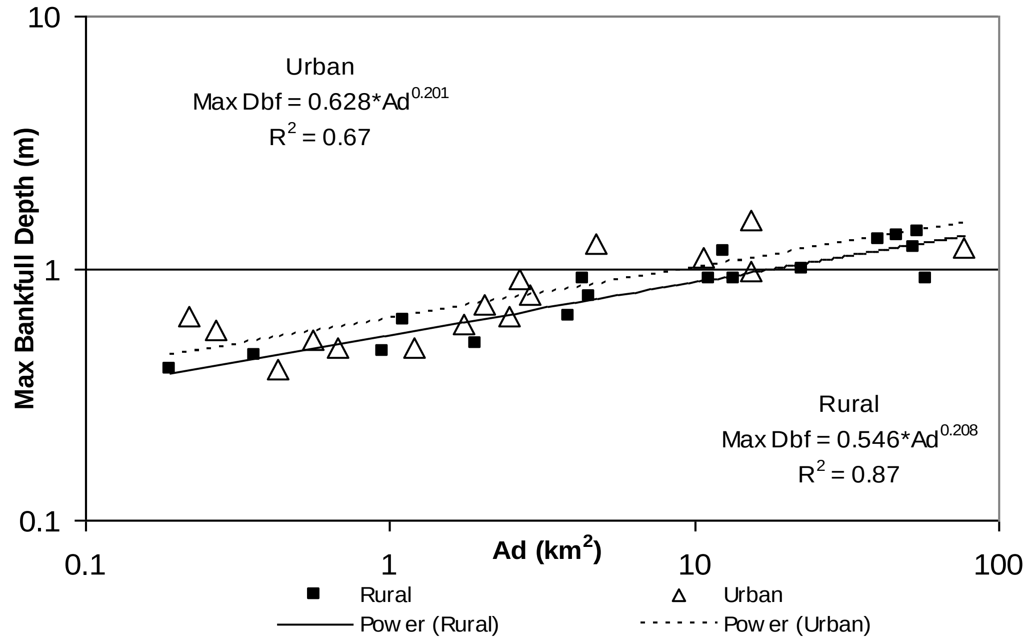


Figure 6.3 Maximum bankfull depth vs. drainage area.

Bankfull width:depth ratio plots for rural and urban channels show high amounts of scatter and no discernable difference between the two (Figure 6.4). This was expected after examining the bankfull widths and mean depths that follow consistently similar scatterplot trends. Bankfull width:depth ratios for both urban and rural channels average about 15 at 1 km^2 and 17 at 10 km^2. Conversely, bankfull channel cross-sectional area plots suggest that urban channels have somewhat larger cross-sectional areas than rural channels (Figure 6.5). Cross-sectional areas for urban channels at 1 km^2 drainage areas are about 19.5% greater; cross-sectional areas for urban channels at 10 km^2 drainage areas are about 15% larger. The cross-sectional area plot seemingly contains one rural outlier that plots significantly smaller than reaches of comparable drainage area. This particular main stem reach (site 36, Ad = 57 km^2) contains significant gravel bar deposition and channel filling that may be providing a geomorphic control that disturbs systematic channel forming processes. Nevertheless, cross-sectional area plots display watershed trends that suggest urban channels are 15-20% larger than rural channels. Summaries and comparisons for both urban and rural, bankfull and total channel geometry are provided in Table 6.1. Difference percentages are provided to assess watershed trends between rural and urban channels at drainage areas of 1, 10 and 50 $km^{2'}$s. Difference percentages for each channel property are based on the equation: ((urban-rural)/rural) x100.

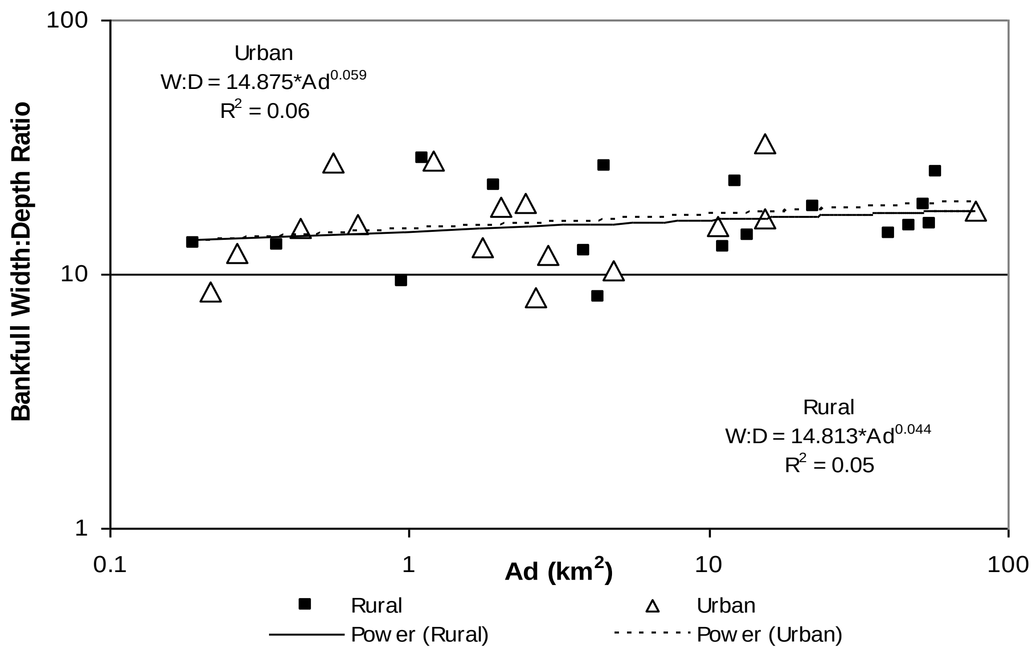


Figure 6.4 Bankfull width:depth ratio vs. drainage area.

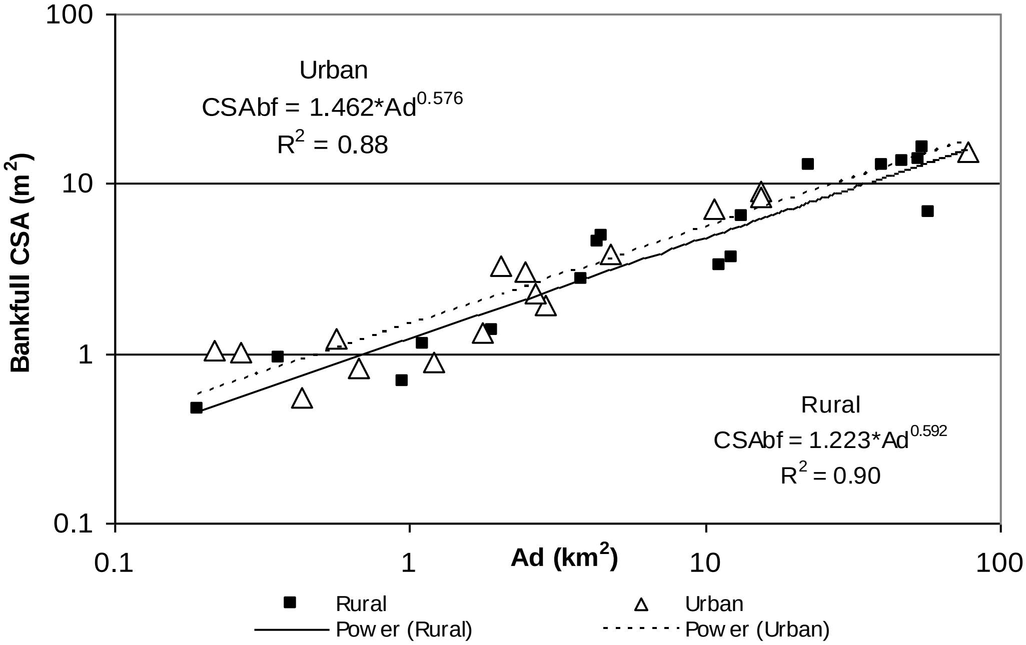


Figure 6.5 Bankfull cross-sectional area vs. drainage area.

Total Channel Morphology

Total channel (TC), for this study, is defined as the entire channel that exceeds the bankfull indicators up to the valley floor or low terrace (see Figure 4.1). In general, the TC cross-sectional areas for all SDS streams are about 2-3 times greater than the bankfull cross-sectional areas (Figure 6.6). Total:bankfull cross-sectional area ratio scatterplots show that rural channels generally have greater total channel capacities compared to bankfull capacities when compared to urban channels (Figure 6.7). Essentially, it indicates that urban bankfull channel cross-sectional areas occupy more cross-sectional area within their respective total channels. Further field surveying is needed to establish whether rural channels have higher or steeper banks than urban channels to account for this.

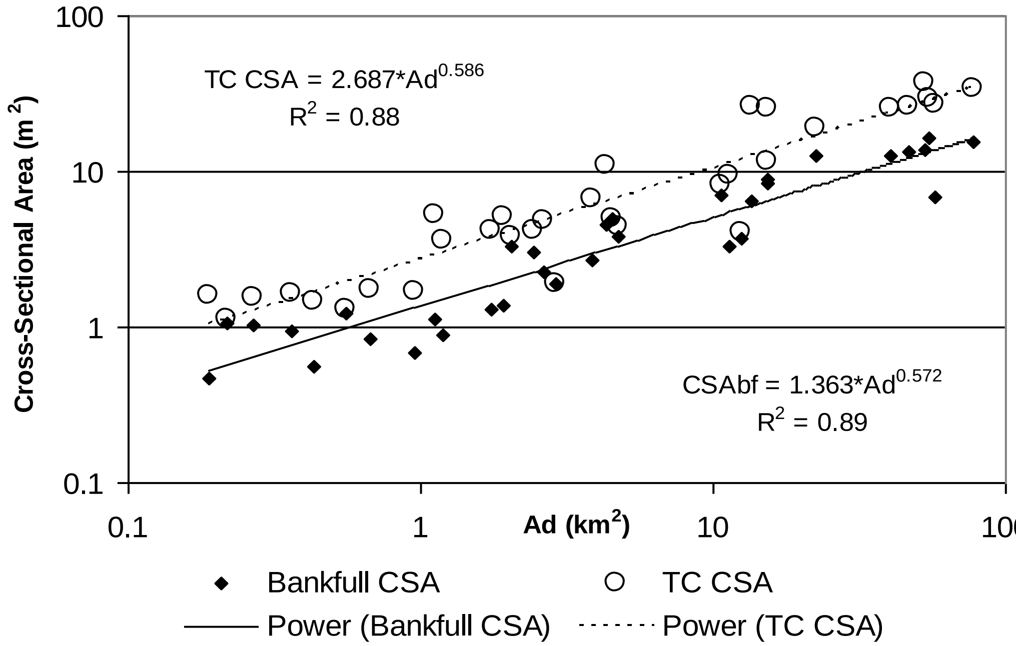


Figure 6.6 Total channel and bankfull channel cross-sectional areas vs. drainage area.

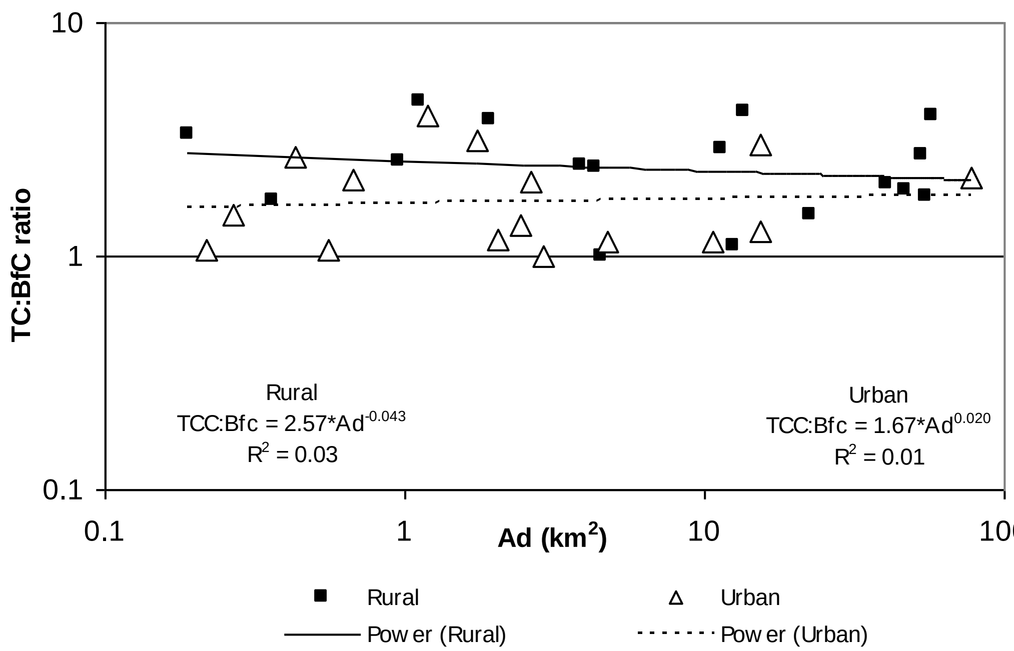


Figure 6.7 Urban and rural TC cross-sectional area compared to urban and rural bankfull cross-sectional area.

Total channel widths for rural sites appear to be somewhat larger than urban channels (Figure 6.8). Rural TC widths are about 14% greater at drainage areas <1 km^2 and about 9% wider at drainage areas near 10-20 km^2. This trend is in contrast to bankfull widths where urban channels were generally wider. Differences between TCs with riparian buffers >30% grass and <30% grass are not apparent (Figure 6.9 A). Similarly, TCs that have riparian buffers with >40% grass and <40% grass also show little difference (Figure 6.9 B). The high amount of scatter suggests the influence of riparian type on TC width is not evident. Similarly, if the high and low outliers did not exist, the trends for each classification appear the same. Greater rural TC widths may be more related to previous bank-slumping, followed by vegetative healing processes as channels recover from historical land clearing.

TC mean depths for rural channels are generally deeper and displayed less scatter than urban channels of similar drainage area (Figure 6.10). Urban TC mean depths are approximately 12% and 6% less than rural at 1 and 10 km^2 respectively. TC maximum depths for rural channels <10 km^2 appear to be greater than urban sites of similar drainage area (Figure 6.11). Urban TC max depths are about 14% and 7% less than rural at 1 and 10 km^2 respectively. The scatterplot for TC width:depth ratio displays a high amount of variability for both rural and urban channels (Figure 6.12). The width:depth plots for both urban and rural channels show decreasing scatter as drainage area increases. Urban total channels have about 14% and 9% smaller width:depth ratios at 1 and 10 km^2 respectively. TC cross-sectional areas for rural sites are slightly greater than urban channels (Figure 6.13). Rural sites between 1 km^2 and 10 km^2 show this trend the best. Urban total channels have about 23% and 14% smaller cross-sectional areas at 1 and 10 km^2 respectively.

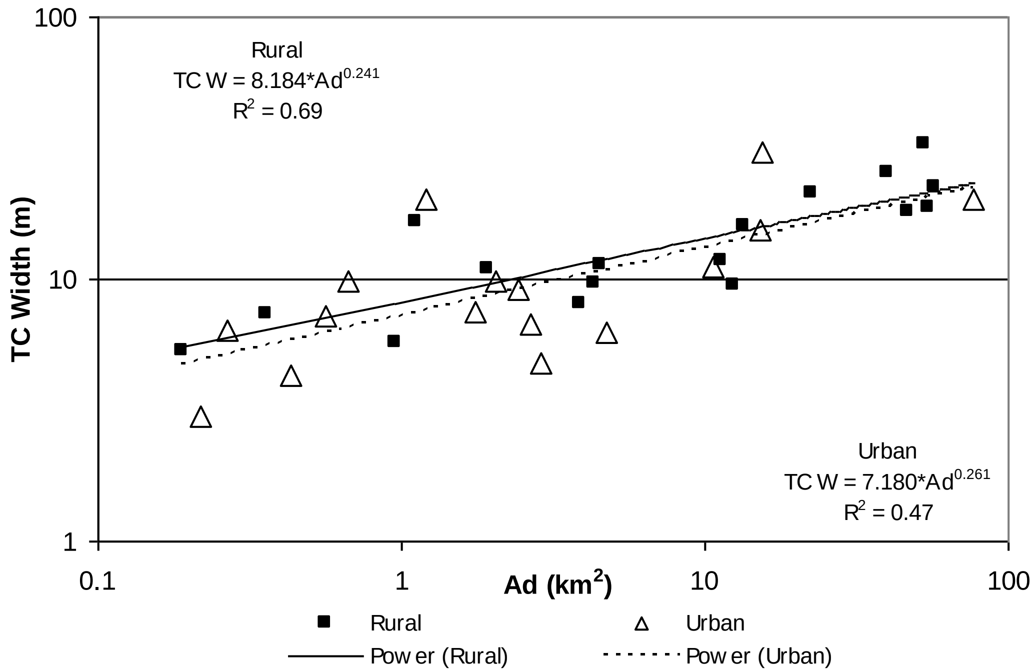
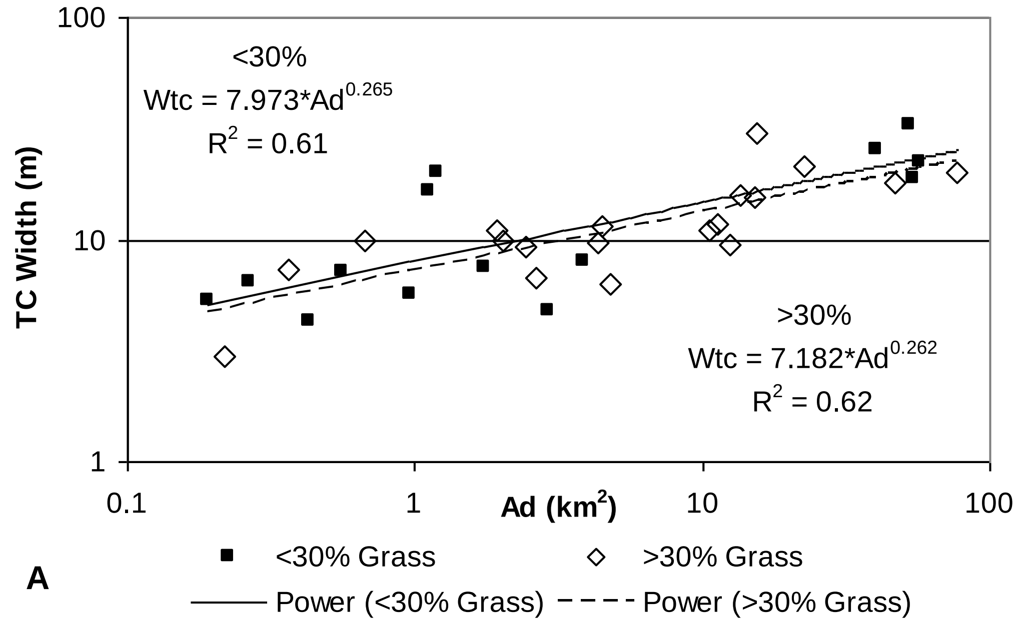


Figure 6.8 Total channel widths vs. drainage area.



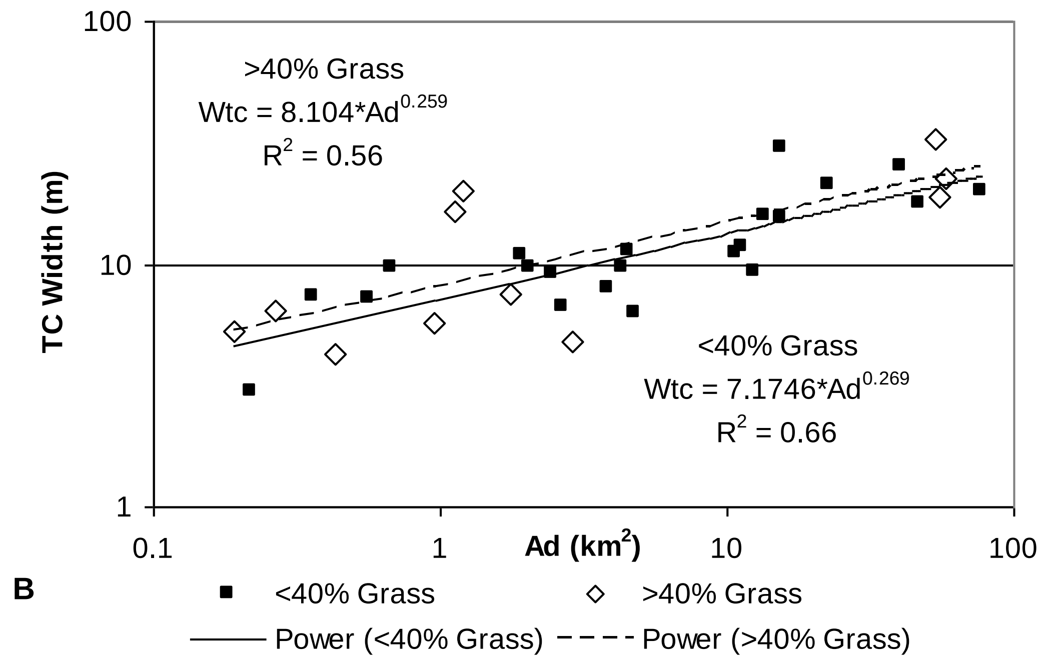


Figure 6.9 Total channel width vs. buffer type. (A) Comparison of total channels with > or < 30% grass buffers and (B) > or < 40% grass buffers.

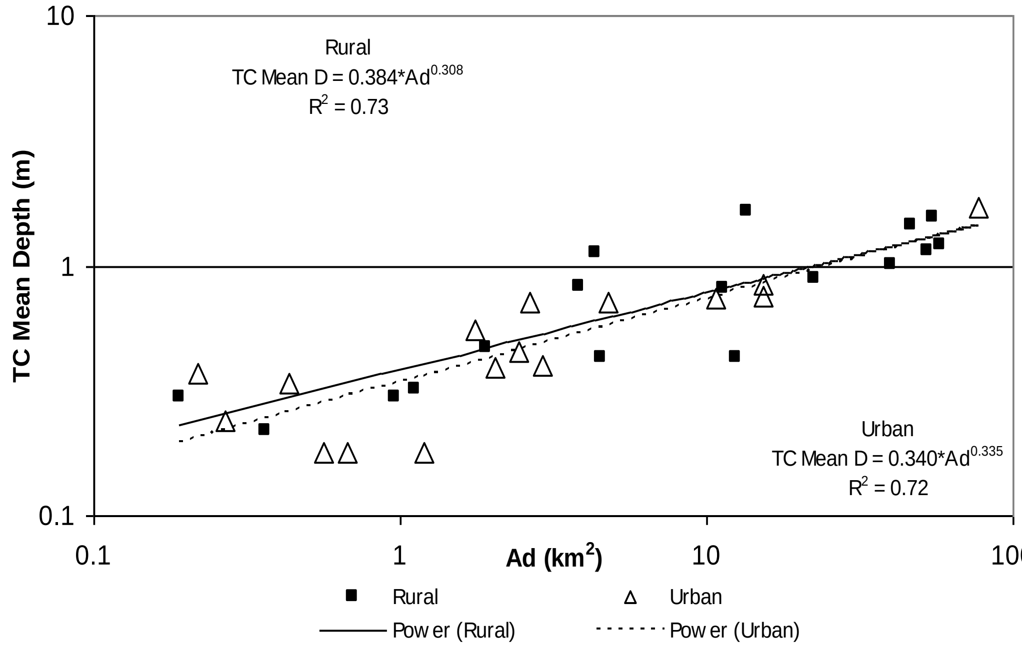


Figure 6.10 Total channel mean depth vs. drainage area.

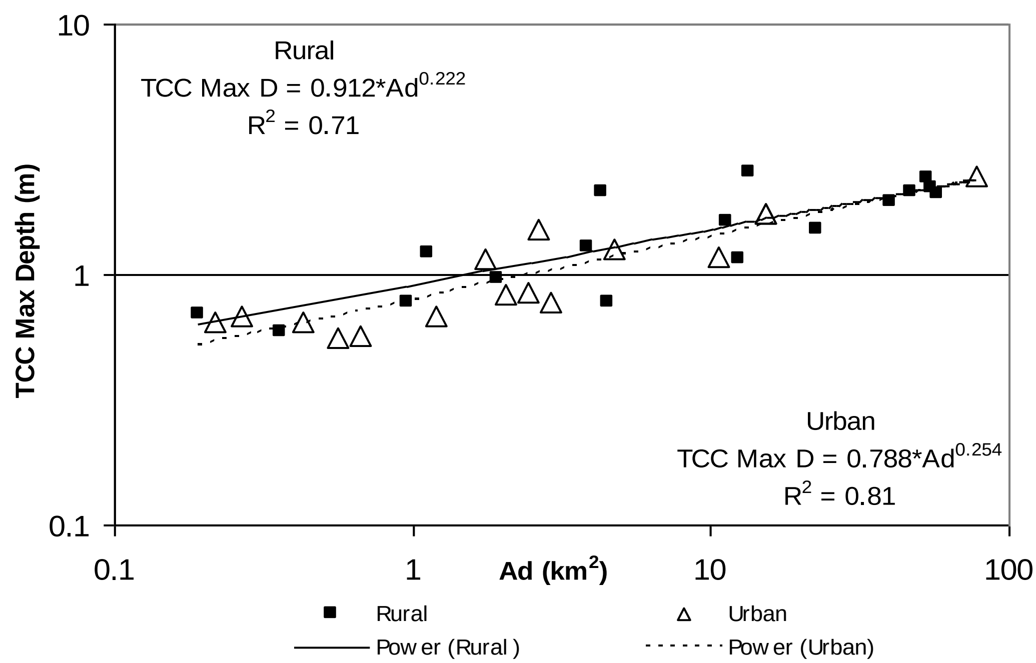


Figure 6.11 Total channel maximum depth vs. drainage area.

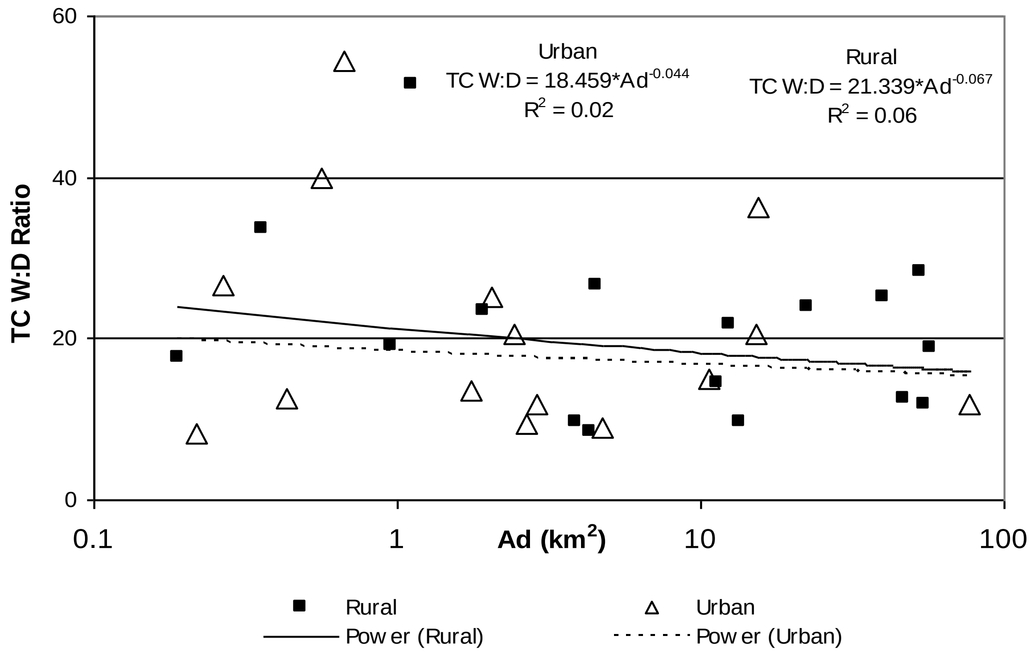


Figure 6.12 Total channel width:depth ratio vs. drainage area.

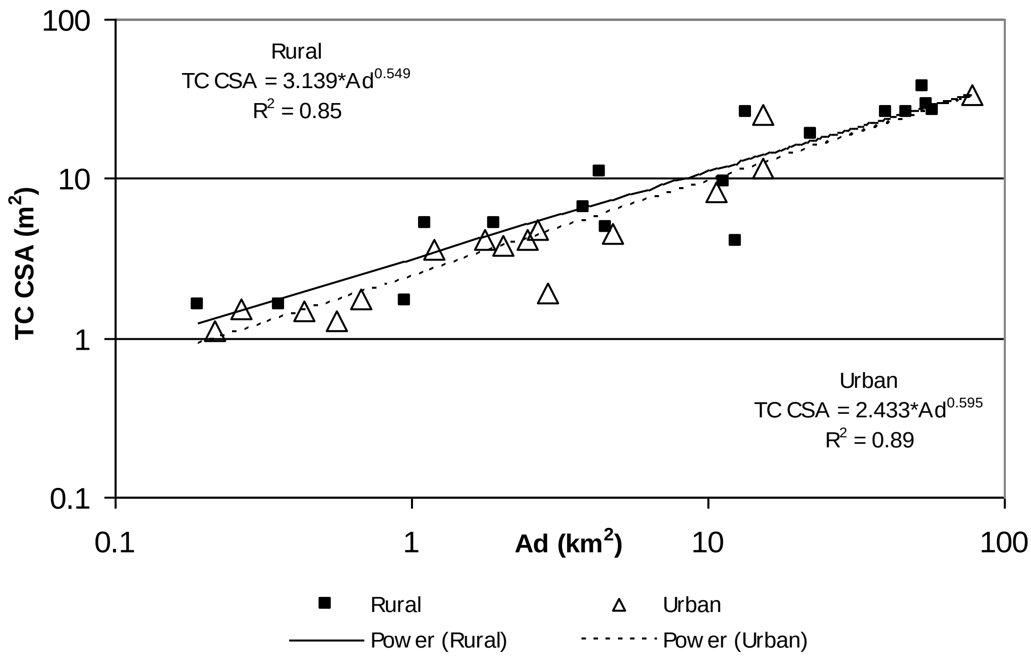


Figure 6.13 Total channel cross-sectional area vs. drainage area.

Table 6.1 Comparison of channel geometry regression equation results.

Channel Properties			Predicted Values		
			Drainage Area (km^2)		
			1	10	50
Bankfull:	Width (m):	Rural	4.3	8.9	14.8
		Urban	4.7	9.7	16.1
		Diff (%)	*9.5*	*9.3*	*9.1*
	Mean Depth (m):	Rural	0.3	0.5	0.8
		Urban	0.3	0.6	0.9
		Diff (%)	*9.4*	*5.5*	*2.8*
	W:D Ratio:	Rural	14.8	16.4	17.6
		Urban	14.9	17.0	18.7
		Diff (%)	*0.4*	*3.9*	*6.5*
	CSA (m^2):	Rural	1.2	4.8	12.4
		Urban	1.5	5.5	13.9
		Diff (%)	*19.5*	*15.2*	*12.3*
Total Channel:	Width (m):	Rural	8.2	14.3	21.0
		Urban	7.2	13.1	19.9
		Diff (%)	*-12.3*	*-8.1*	*-5.1*
	Mean Depth (m):	Rural	0.4	0.8	1.3
		Urban	0.3	0.7	1.3
		Diff (%)	*-11.5*	*-5.8*	*-1.6*
	W:D Ratio:	Rural	21.3	18.3	16.4
		Urban	18.5	16.7	15.5
		Diff (%)	*-13.5*	*-8.8*	*-5.4*
	CSA (m^2):	Rural	3.1	11.1	26.9
		Urban	2.4	9.6	24.9
		Diff (%)	*-22.5*	*-13.8*	*-7.2*

LONGITUDINAL PROFILE

Basin and Reach Slope

The following watershed characteristics section is offered as information to assist in the understanding of the link between watershed factors and channel planform morphology. Figure 6.14 displays the 75% channel length for each study site. Site elevations for SDS study reaches are shown in Figure 6.15. This plot shows the high variability that typically occurs among site elevations and their respective drainage areas. 75% basin slopes attained from USGS digital line graphs in a GIS show watershed characteristics. The 75% basin slope plot (Figure 6.16) displays the concave profile of a watershed when viewed from the side as stated by Cooke and Doornkamp (1974). Watershed slopes are steepest near the divide and become gentler as one nears the terminus. Watershed slope characteristics influence channel longitudinal profile and planform.

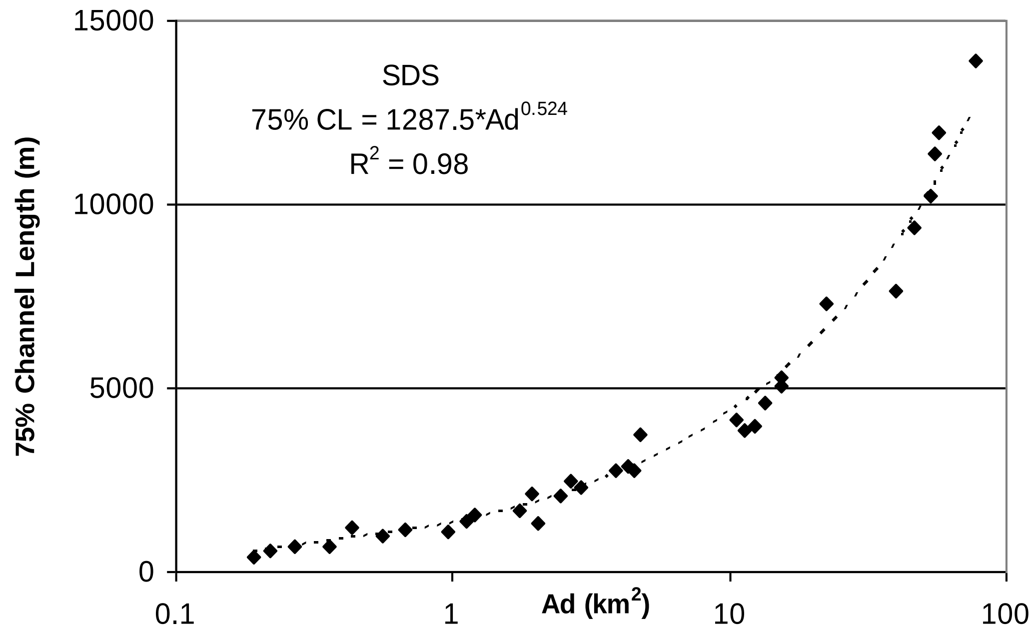


Figure 6.14 75% channel length vs. drainage area.

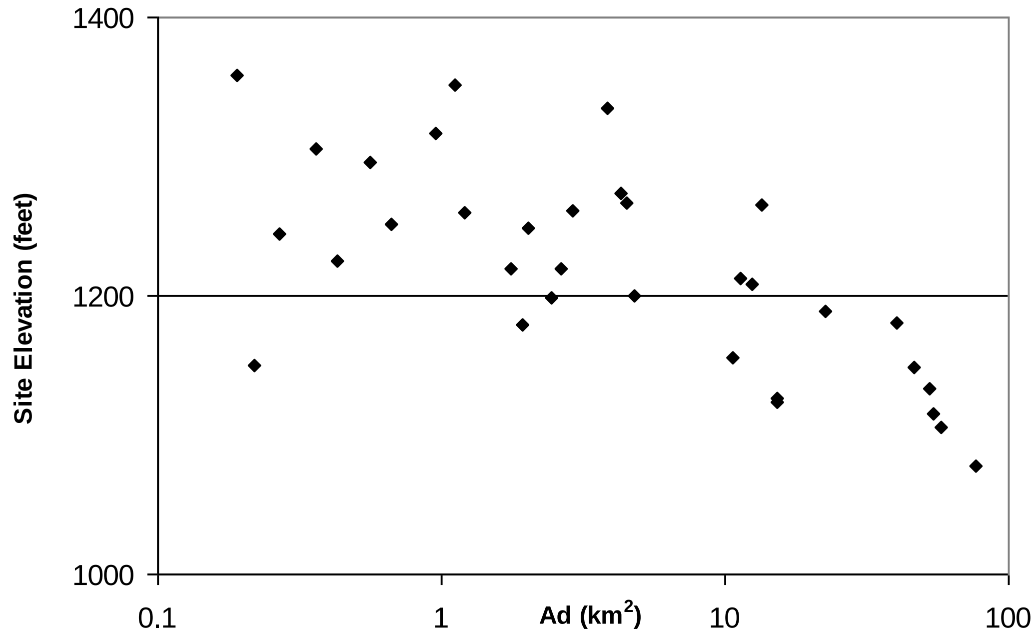


Figure 6.15 Site elevation in feet above mean sea level.

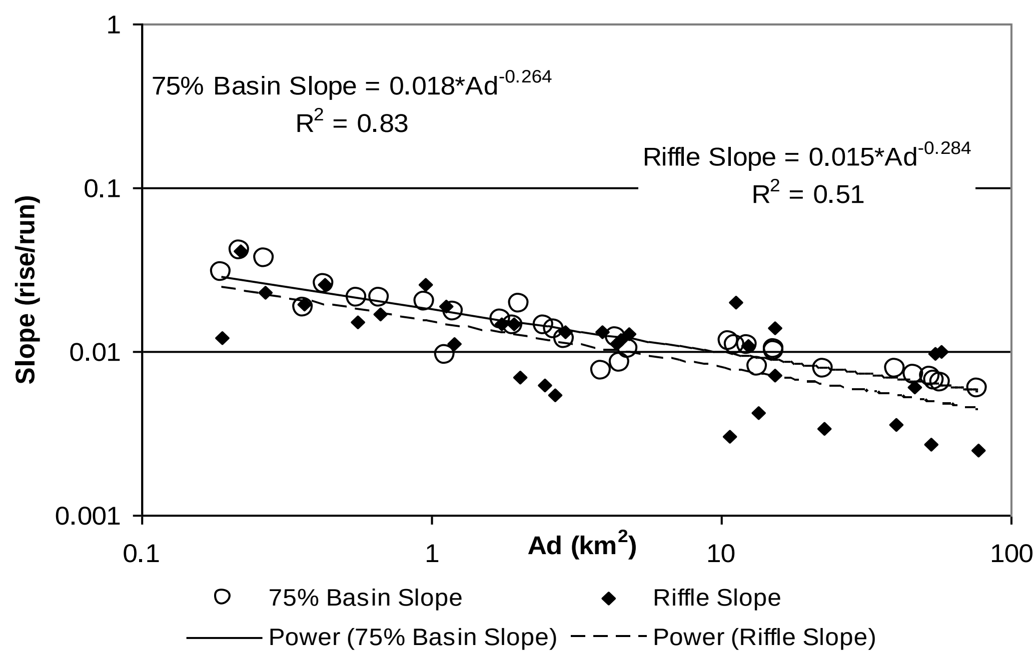


Figure 6.16 75% basin and reach slope for SDS channels.

Riffle and Pool Morphology

Figure 6.17 shows maximum residual pool depths for rural channels being generally deeper than urban channels. Outliers include site 24, a rural bedrock reach (Ad 13.45 km^2) and site 3 (Ad, 1.92 km^2), the other rural outlier, which may have plotted low due to similar geologic factors (bedrock bluff outcrops) noted during field data collection. Urban maximum residual pool depths are about 47% and 32% lower at drainage areas of 1 and 10 km^2 respectively. Both urban and rural reaches at the lower end of the watershed tend to plot similarly.

Riffle-to-riffle spacings for rural survey reaches <10 km^2 are generally greater than urban reaches (Figure 6.18). Rural sites that plotted below the urban trendline were identified as either step-pool reaches with debris jams or reaches with excessive gravel deposition. Large clasts and short step-pool sequences often make riffle and pool identification difficult to assess in the field (Leopold 1994). Outliers excluded, riffle-to-riffle spacing is greater in rural channels. Pool-to-pool spacing for rural sites generally follow the same trends as the riffle-to-riffle spacing. Rural sites with drainage areas <10 km^2 have greater pool spacing than urban sites with comparable drainage areas (Figure 6.19). Sites that plotted well below the urban trendline are either bedrock controlled or have experienced extensive gravel bar deposition that prevents an accurate assessment of pool spacing. Additionally, rural wooded reaches sometimes become jammed with large woody debris that interferes with pool formation. In general, pool-to-pool spacing is greater for rural channels.

Riffle-pool spacing (Figure 6.20) for rural sites adheres to the same trends displayed on riffle-to-riffle and pool-to-poll scatter plots. Rural channels appear to have greater riffle-pool spacings. The rural reaches that plotted well below the urban trendline are bedrock controlled; or channels with large woody debris that clogs channels and interferes with riffle-pool formation. Other rural outlier sites are reaches that have experienced gravel deposition in the channels that makes riffle-pool definition difficult. Both urban and rural riffle-pool spacing becomes more erratic at drainage areas >15 km^2. Rural channels also display greater riffle-riffle spacing when compared to bankfull width (Figure 6.21). Nevertheless, the large amount of scatter, particularly in rural channels, makes it difficult to clearly understand riffle-pool spacing.

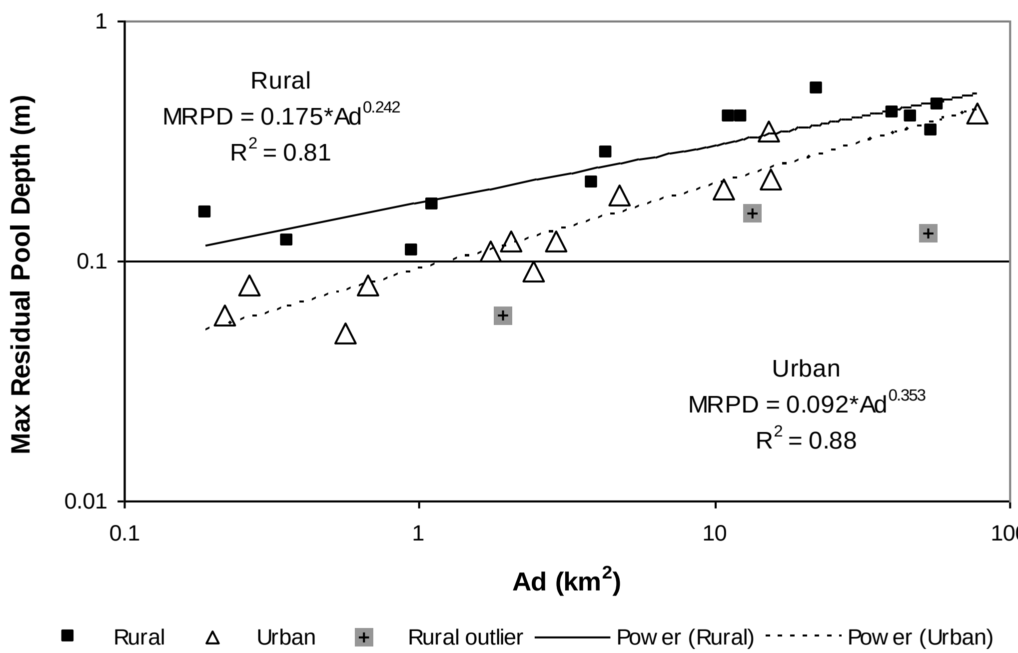


Figure 6.17 Maximum residual pool depths vs. drainage area (sites 10, 11, 23, and 29 omitted, no well defined pools).

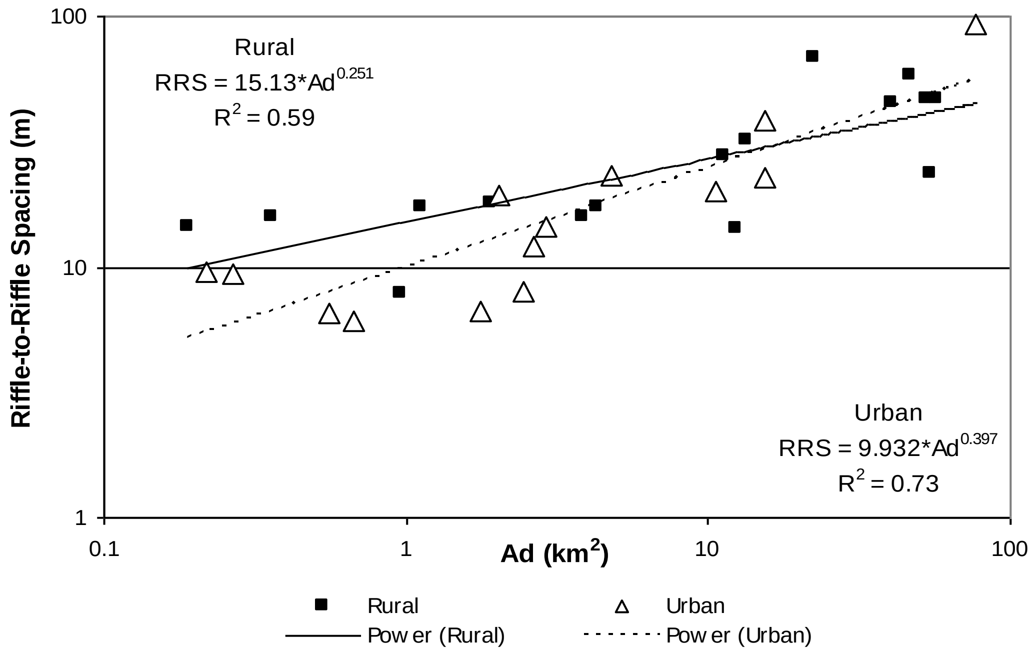


Figure 6.18 Riffle-to-riffle spacing vs. drainage area (sites 10, 11, and 29 omitted).

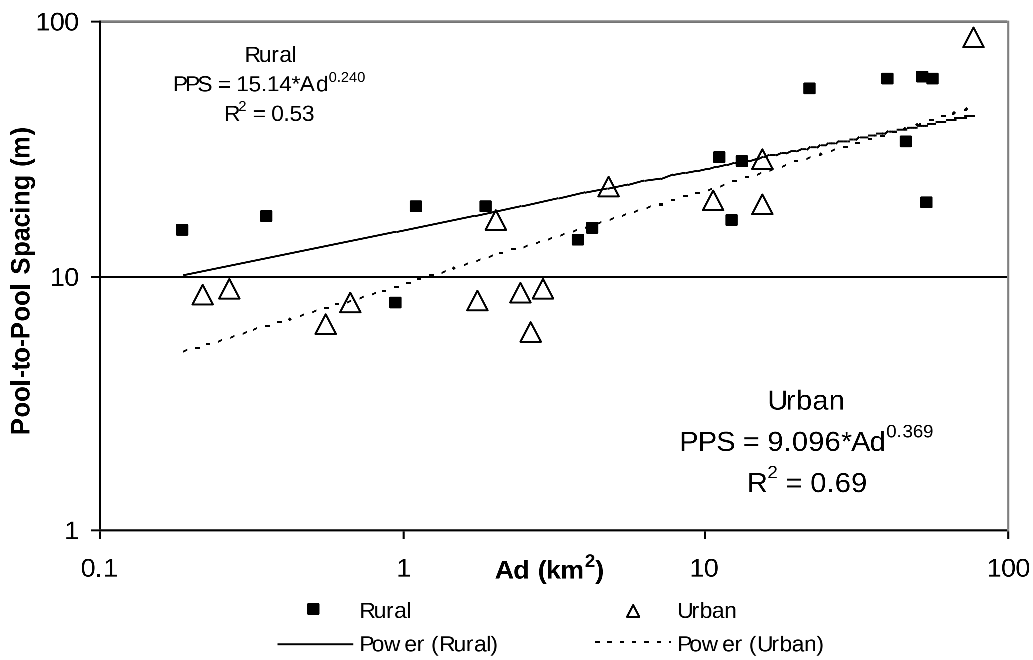


Figure 6.19 Pool-to-pool spacing vs. drainage area (sites 10, 11, and 29 omitted).

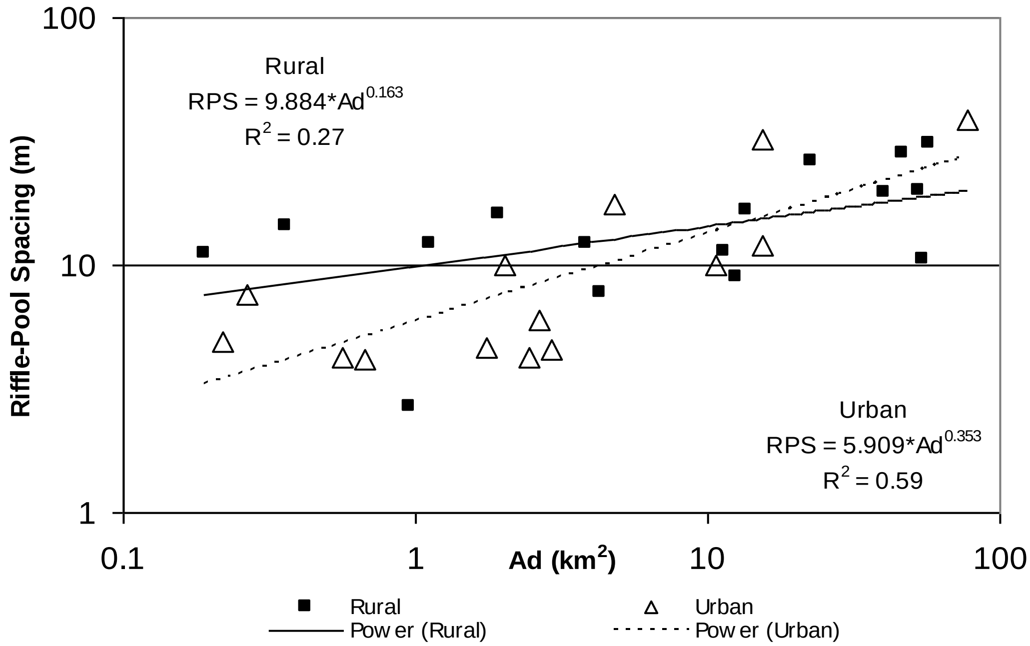


Figure 6.20 Riffle-pool spacing vs. drainage area (sites 10, 11, and 29 omitted).

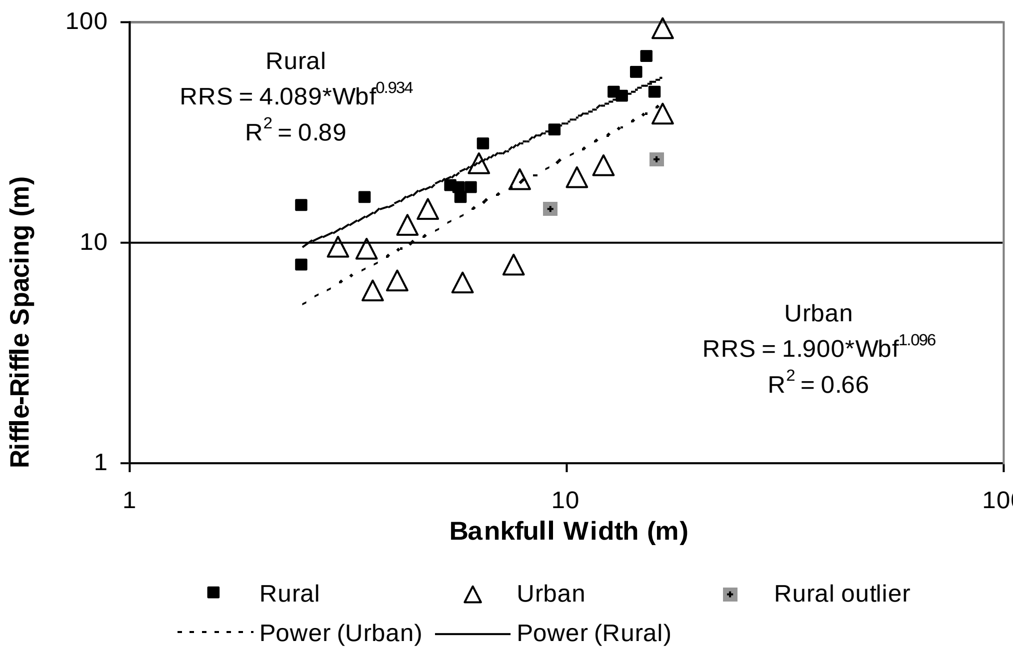


Figure 6.21 Riffle-riffle spacing vs. bankfull width (outliers are bedrock reaches, sites 10, 11, and 29 omitted).

PLANFORM

Sinuosity

Sinuosities were derived from high-resolution aerial photos. Scatterplots show greater sinuosities and higher variability among rural channels draining areas <10 km^2 (Figure 6.22). Overall, urban sinuosity plots much lower than rural channels and shows less variability (Table 6.2). However, two populations seem to exist in the data set; one a seemingly higher trend (>1.15), and a low trend (<1.1). The rural reaches with sinuosities >1.15 are located in both wooded lots and open pastures with treed banks. These reaches have channel slopes ranging from low (.0044) to high (.0260). Additionally, these high sinuosity reaches are main stem (4th order), as well as 1st, 2nd and 3rd order streams. Further data collection is necessary to determine if a geologic control may be responsible for the high sinuosities. The scatterplot showing the relationship between valley width and sinuosity is provided in an attempt to explain these trends (Figure 6.23). However, the relationship between sinuosity and valley width attained from a digital soil map is uncertain. With outliers removed from regression equation, sinuosity appears to increase as valley width increases. The reaches with sinuosities >1.5 are all rural having both forest and grass as the dominant riparian buffer types. Additionally, the reaches with sinuosities >1.5 have valley widths ranging from 50-200 meters; a characteristic shared with reaches that have sinuosities <1.1.

Meander amplitudes for rural sites are generally higher than urban sites. Trendline analyses at 1km^2 shows rural channels have about 39% greater meander amplitudes (Figure 6.24). The trendline at 10 km^2 indicates that rural channels have about 41% greater meander amplitudes. When plotted versus bankfull width, rural meander amplitudes are 39-43% greater than urban channels (Figure 6.25). Similar trends exist in channels draining areas >10 km^2 when meander amplitude is plotted versus total channel width. In channels draining <10 km^2, the plots are more variable (Figure 6.26). The Meander wavelength scatterplot shows no distinct trends between rural and urban channels (Figure 6.27). Similarly, when plotted versus bankfull channel width, meander wavelengths show scattered spatial trends (Figure 6.28). The urban channels display more variability than rural channels. However, variability is relatively high among rural channels also. Nevertheless, urban channels are generally less sinuous, but distribution of meandering channels is difficult to explain with the analysis here.

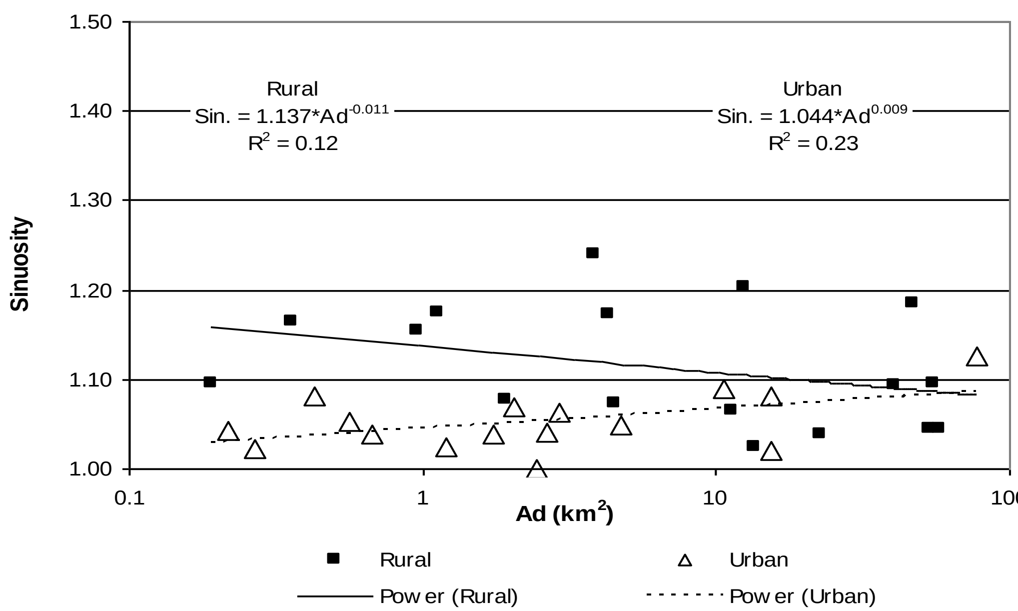


Figure 6.22 Sinuosity vs. drainage area.

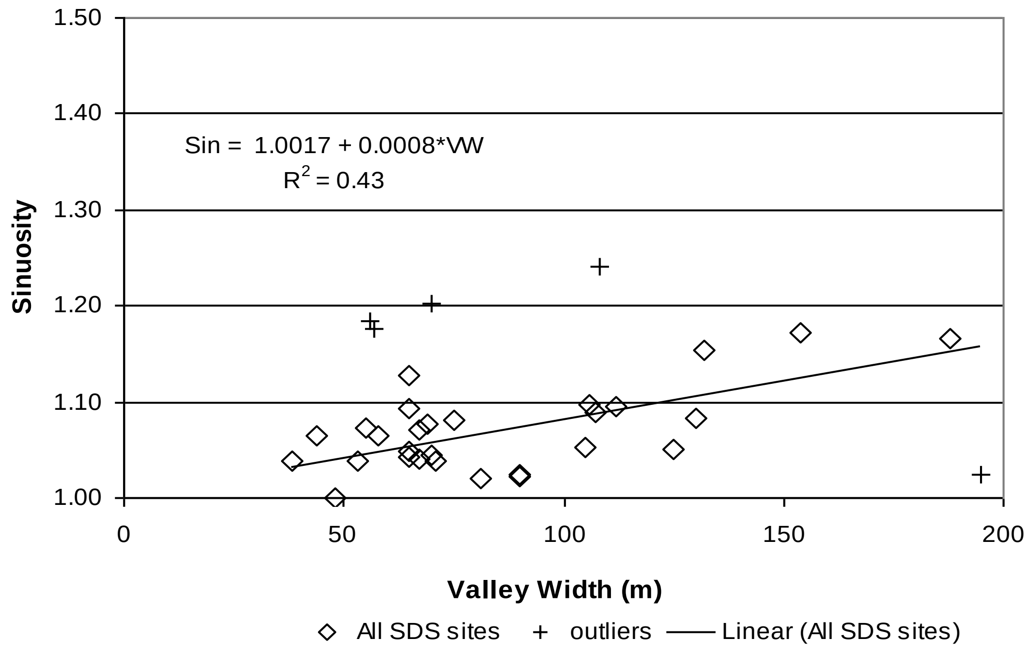


Figure 6.23 Sinuosity vs. valley width.

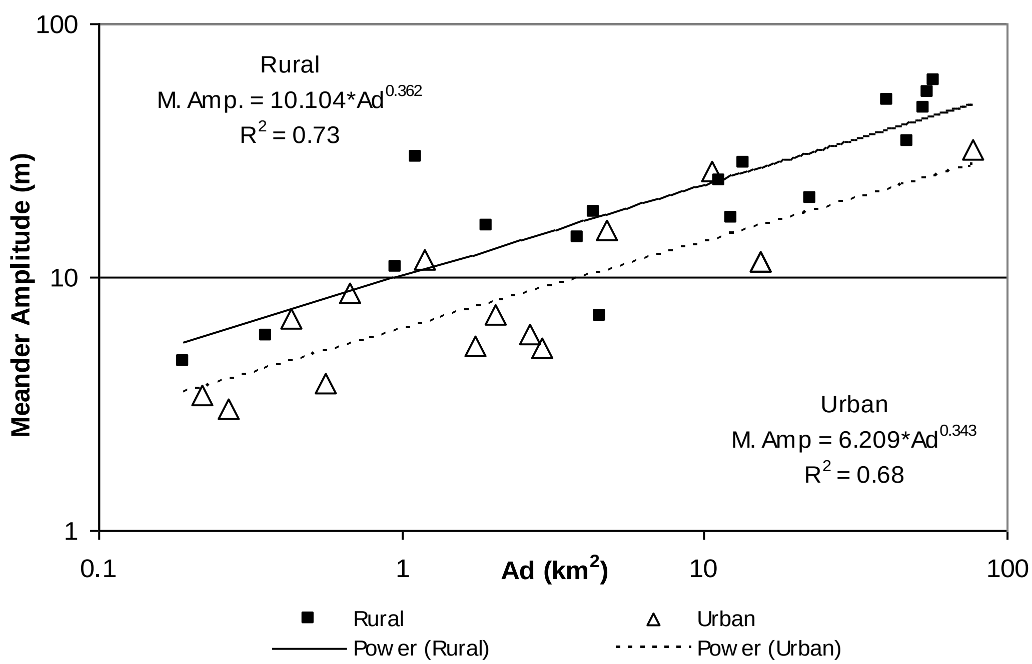


Figure 6.24 Meander amplitude vs. drainage area.

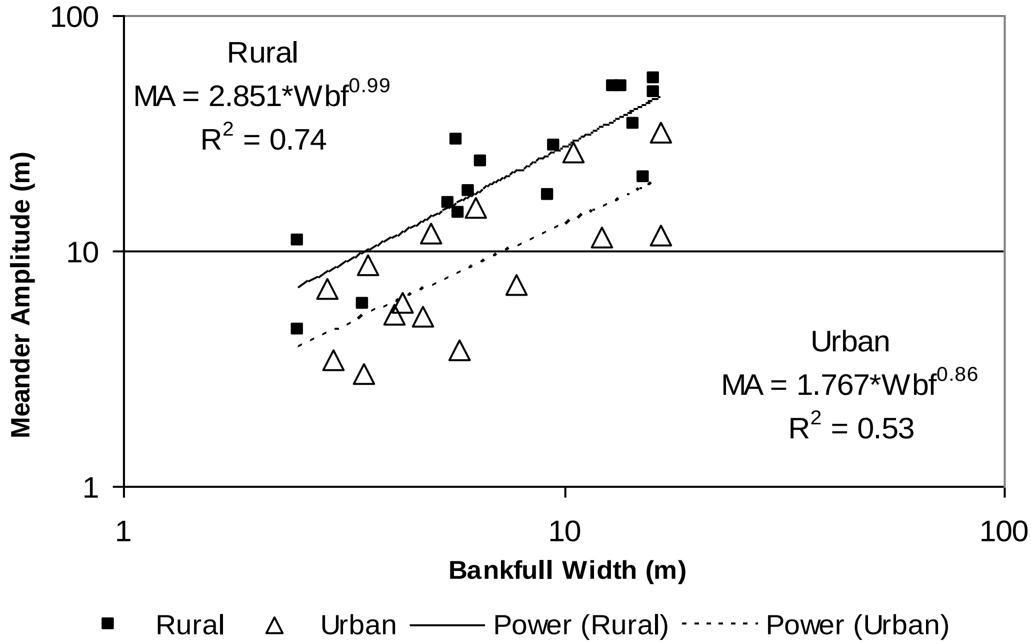


Figure 6.25 Meander amplitude vs. bankfull width.

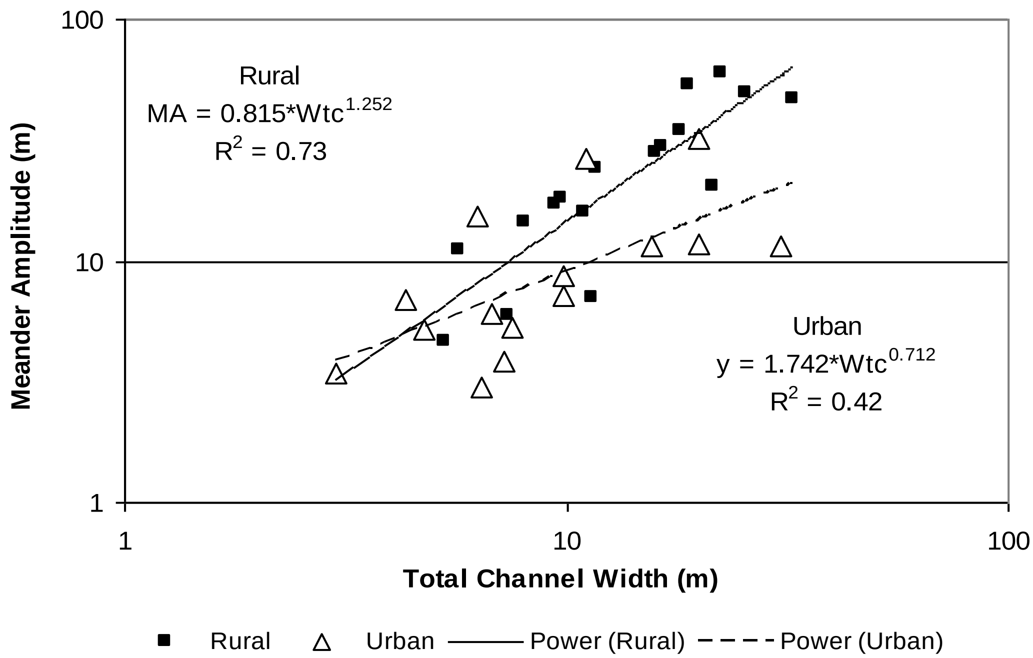


Figure 6.26 Meander amplitude vs. total channel width.

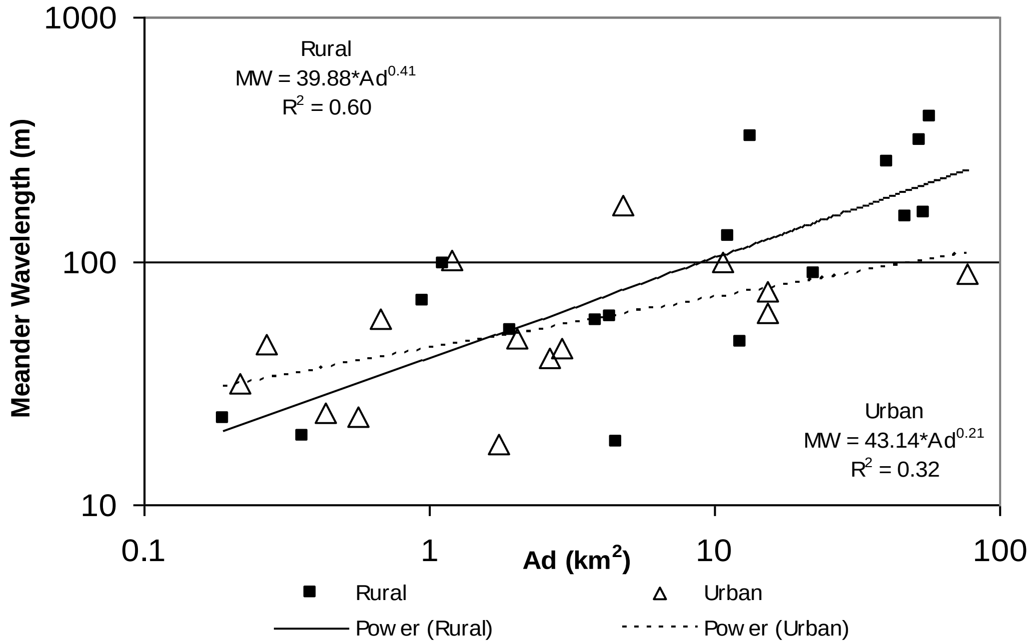


Figure 6.27 Meander wavelength vs. drainage area.

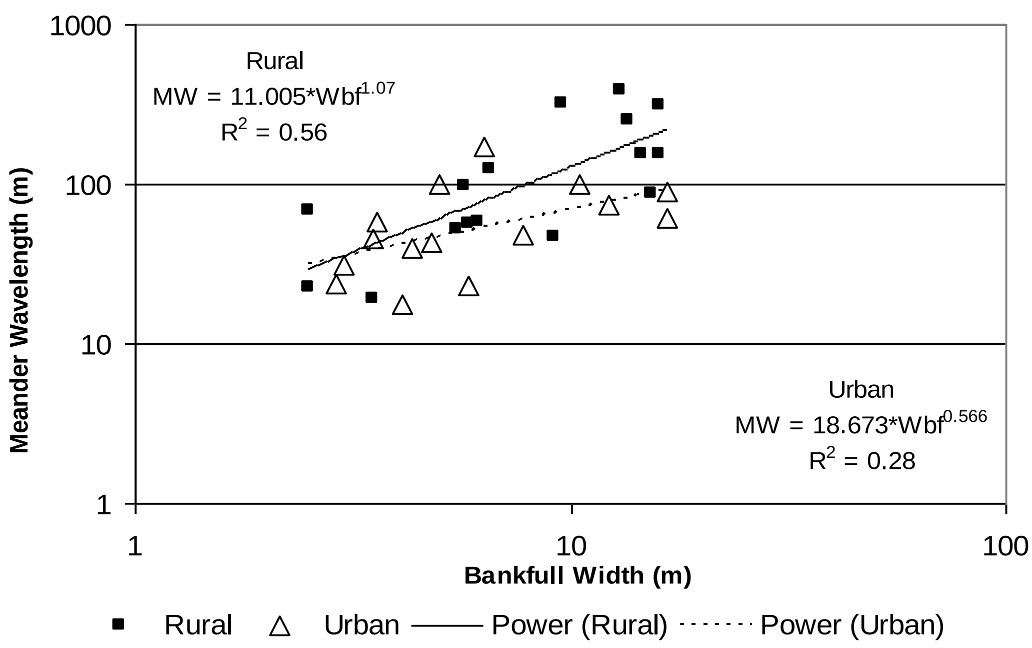


Figure 6.28 Meander wavelength vs. bankfull width.

Table 6.2 Comparison of longitudinal profile and planform regression equation results.

Channel Properties		Predicted Values		
		Drainage Area (km^2)		
		1	10	50
Riffle-Riffle Spacing (m):	Rural	15.13	26.97	40.39
	Urban	9.93	24.78	117.09
	Diff (%)	*-34.36*	*-8.12*	*189.90*
Riffle-Pool Spacing (m):	Rural	9.88	14.39	27.22
	Urban	5.91	13.32	53.00
	Diff (%)	*-40.22*	*-7.41*	*94.71*
Pool-Pool Spacing (m):	Rural	15.14	26.31	67.28
	Urban	9.10	21.27	90.11
	Diff (%)	*-39.92*	*-19.14*	*33.93*
Maximum Residual Pool Depth (m):	Rural	0.18	0.31	0.45
	Urban	0.09	0.21	0.37
	Diff (%)	*-47.43*	*-32.12*	*-18.84*
Meander Wavelength (m):	Rural	39.88	198.30	509.72
	Urban	43.14	69.96	159.10
	Diff (%)	*8.17*	*-64.72*	*-68.79*
Meander Amplitude (m):	Rural	10.10	41.64	95.83
	Urban	6.21	23.76	52.33
	Diff (%)	*-38.55*	*-42.95*	*-45.39*
Sinuosity (channel length/valley length):	Rural	1.14	1.09	1.06
	Urban	1.04	1.08	1.10
	Diff (%)	*-8.18*	*-0.71*	*3.97*

SEDIMENT AND BANK MATERIAL

Median Sediment

Median bed sediment diameters show high variability among rural and urban channels (Figure 6.29). However, the rural channels generally have smaller median bed sediment diameter. Gravel deposition from historical and recent land use may be responsible for the high variability in both urban and rural channels. The low rural outlier is adjacent to a new golf course development which is likely introducing small cherty gravel into the channels. The high rural outlier is located downstream of a bridge, but it is unclear why the D50 is so high. The high urban outlier is located in an older residential and commercial portion of the SDS Watershed. The high D50 for this site may be a result of increased discharges moving large channel material or historical construction fill.

Maximum Clast Size

The mean maximum clast size for rural channels is generally lower than in urban channels (Figure 6.30). This trend is most evident in the urban channels with drainage areas $<10\ km^2$. Factors such as fill material from road construction and excavation may be responsible for the larger clasts sizes found in urban channels. The low, rural outlier cluster contains two sites downstream of a golf course development where recent land clearing has taken place. The third site in the rural cluster has experienced gravel deposition, but drains areas with no recent development. This may suggest that the gravel from past land clearing is moving through the SDS in episodic waves and covering the larger clasts. The high, urban outlier cluster is most likely a result of road construction fill entering the channels. If both the rural and urban outlier clusters were removed, there is not much difference between maximum clast size trends.

Slope and Median Sediment

Spatial trends of slope:D50 sediment ratio versus drainage area are shown in Figure 6.31. In sub-basins smaller than 1km^2 the trend is uncertain. However, rural channels tend to display higher slope:D50 sediment ratios in reaches draining areas greater than 1km^2. This trend can also be seen in Table 6.3. Summaries of D10, D50, mean, D84 and max clasts are listed in Table 6.3.

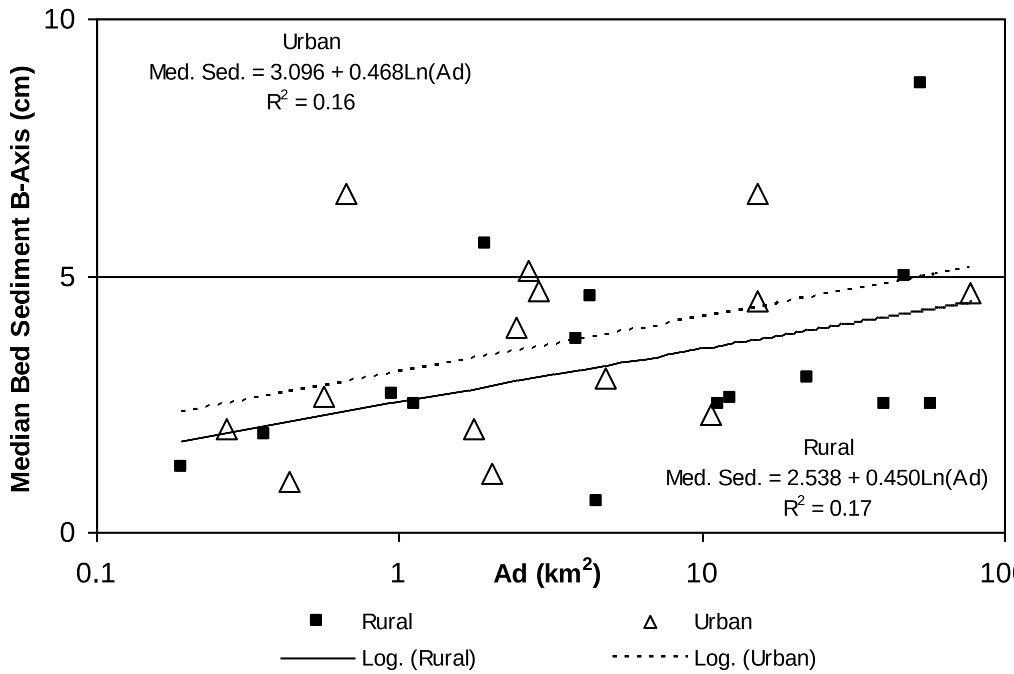


Figure 6.29 Median bed sediment vs. drainage area (bedrock sites 1 and 24 omitted).

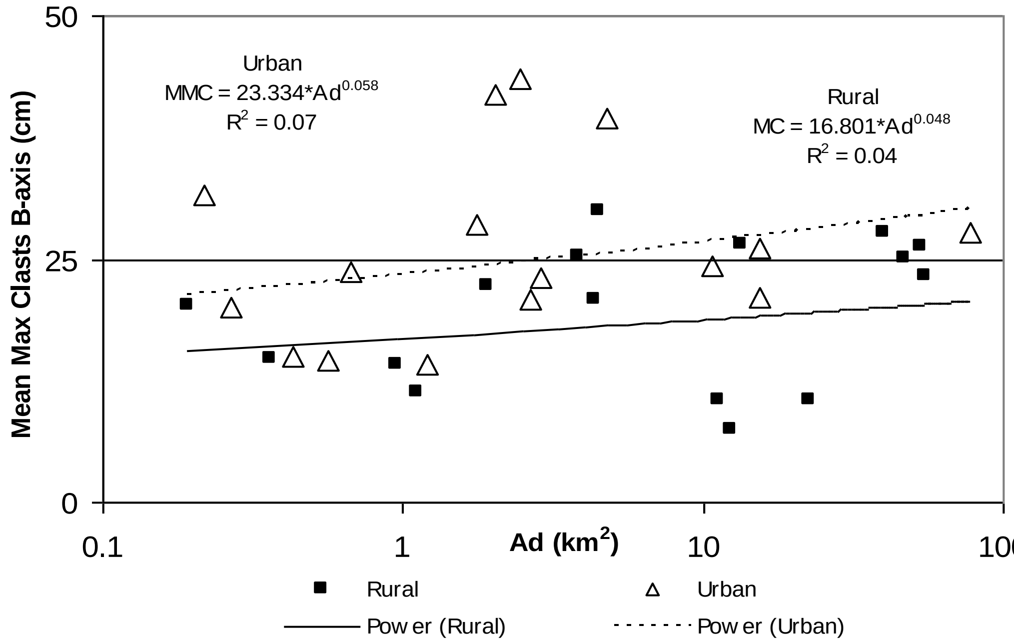


Figure 6.30 Mean maximum clasts vs. drainage area.

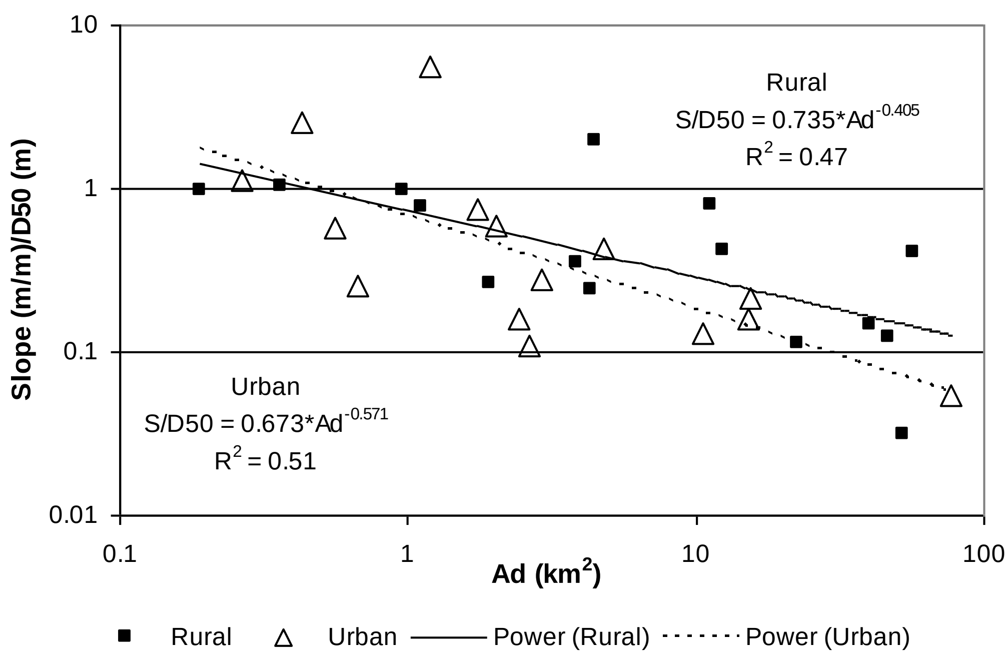


Figure 6.31 Slope/D50 sediment vs. drainage area (bedrock sites 1, 19 and 24 omitted).

Table 6.3 Summary of sediment data.

Sediment Properties			Drainage Area		
			<1 km^2	1-10 km^2	>10 km^2
D10 (cm):	Rural:	mean	0.6	1.5	1.3
		median	0.2	2.0	1.0
		stdv.	0.8	0.9	1.5
		Cv%	119.0	58.6	107.9
		n	3	5	9
	Urban:	mean	0.7	1.0	1.2
		median	0.2	0.2	0.9
		stdv.	1.3	1.1	1.4
		Cv%	177.2	118.5	114.6
		n	5	7	4
D50 (cm):	Rural:	mean	2.0	3.4	3.0
		median	1.9	3.8	2.5
		stdv.	0.7	1.9	2.6
		Cv%	37.3	56.9	78.1
	Urban:	mean	2.5	2.9	4.5
		median	2.0	3.0	4.6
		stdv.	2.5	1.9	1.8
		Cv%	101.4	64.2	39.0
Mean (cm):	Rural:	mean	2.6	4.3	4.0
		median	3.1	4.7	3.2
		stdv.	0.9	1.6	2.8
		Cv%	36.7	36.4	62.3
	Urban:	mean	3.8	4.0	6.1
		median	3.2	4.0	6.2
		stdv.	2.6	2.1	1.9
		Cv%	67.6	52.1	31.3
D84 (cm):	Rural:	mean	4.0	6.7	5.2
		median	4.2	7.0	5.0
		stdv.	0.9	2.3	3.5
		Cv%	22.0	34.2	59.5
	Urban:	mean	6.2	5.9	10.8
		median	5.7	6.0	10.3
		stdv.	4.4	3.2	3.4
		Cv%	70.7	55.2	36.5
Max Clasts Size (cm):	Rural:	mean	16.4	22.0	19.7
		median	14.7	22.3	24.2
		stdv.	3.3	6.9	8.6
		Cv%	20.3	31.4	39.0
	Urban:	mean	20.9	30.3	24.8
		median	20.0	28.6	25.2
		stdv.	7.0	11.6	2.9
		Cv%	33.6	38.3	11.7

CHAPTER 7

RESULTS

CHANNEL DISCHARGE AND STREAM POWER

Channel geometry, including width, mean depth, and cross-sectional area, was addressed in Chapter 6. These parameters, along with mean velocity, are used to calculate discharge. Computed discharges for each urban and rural SDS site were then compared with discharges derived from two U.S. Geological Survey equations for estimating Q2-100 discharges for urban and rural Missouri streams. The urban Q2 discharge estimates are slightly greater than Region II rural discharge estimates when compared to the 1:1 line in Figure 7.1. The difference percentages between the Region II rural and the Urban equations are as follows: (1) Urban 27% greater at drainage areas of 1 km^2, (2) Urban 65.5% greater at drainage areas of 10 km^2, (3) Urban 99.2% greater at drainage areas of 50 km^2. Discharge calculations should be evaluated with care because channel cross-sectional geometries are variable within a given reach. Additionally, velocity does not remain constant at a certain width or depth (Cooke and Doornkamp 1974). These factors may distort the true discharge characteristics of a reach. Sites 15, 22 and 34 were omitted from this chapter as in Chapter 6.

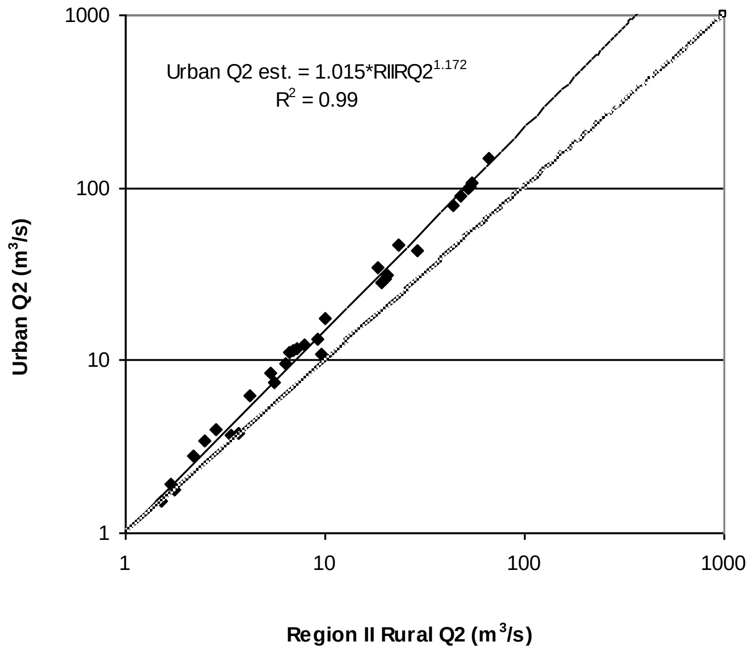


Figure 7.1 Region II Rural Q2 vs. Urban Q2 estimate.

ROUGHNESS AND VELOCITY

Manning's "n" and velocities were calculated using the Chow (1959) method and the Manning velocity equation respectively. Manning's "n" values display no certain trend throughout the watershed (Figure 7.2). Most Manning's "n" values range from 0.035 - 0.065 for both urban and rural channels. The mean Manning's "n" for rural and urban channels are 0.053 and 0.051 respectively. The Cv%'s for rural and urban Manning's "n" are 15.9% and 13.6% respectively. Similarly, calculated velocities for urban and rural channels show no noticeable difference (Figure 7.3). The mean velocities for rural and urban channels are 1.06 and 0.99 m/s respectively. The Cv%'s for rural and urban channels are 26.2% and 23.4% respectively. The bedrock outliers were removed from regression analysis.

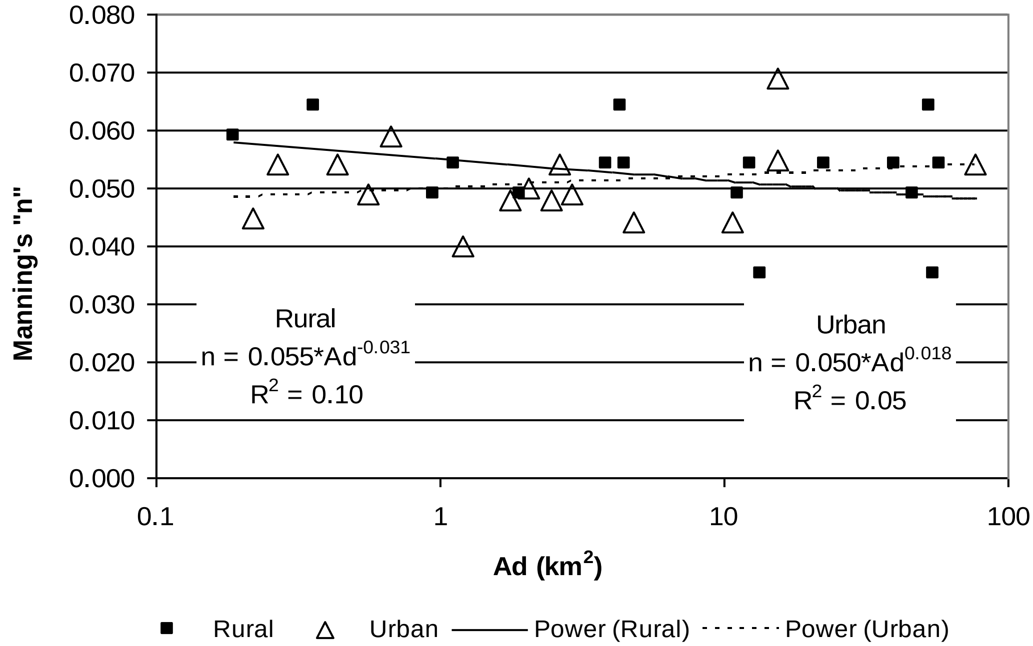


Figure 7.2 Manning's "n" vs. drainage area.

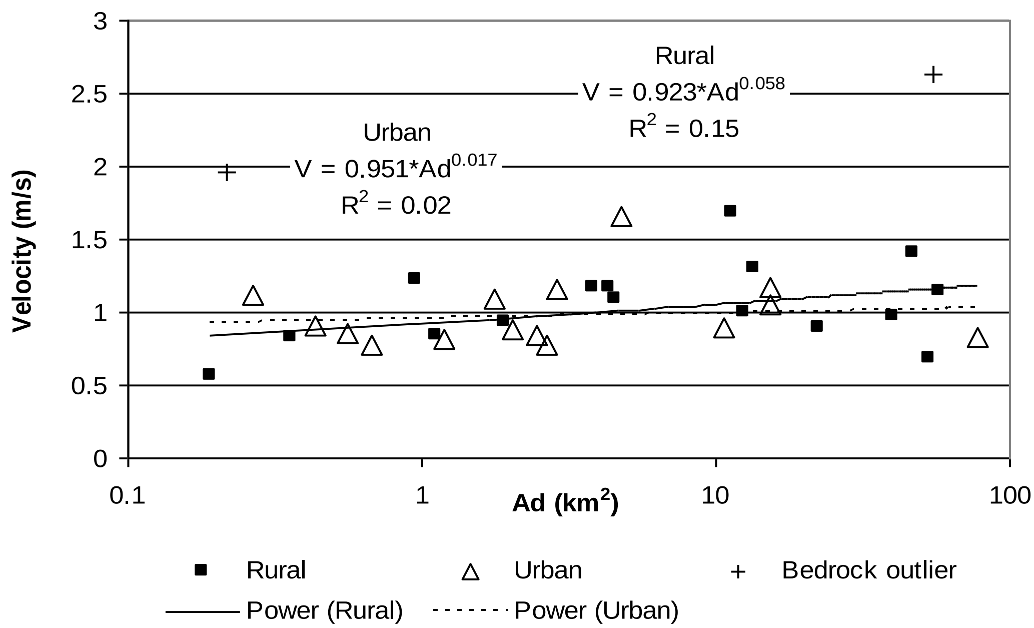


Figure 7.3 Bankfull velocity vs. drainage area.

CHANNEL DISCHARGE

Bankfull Discharge

Bankfull discharges computed for both rural and urban SDS channels plotted considerably lower than the Missouri Region II Rural discharge estimate (Figure 7.4). Additionally, no noticeable differences between rural SDS and urban SDS discharges can be detected. Bankfull discharge for all SDS channels also plotted significantly lower than discharge estimates for urban Missouri channels (Figure 7.5). Calculated bankfull discharges for all SDS channels are in general agreement with respective bankfull cross-sectional areas. Figure 7.6 shows the bankfull discharge as a near one-to-one relationship with bankfull cross-sectional area. Summaries for urban and rural discharge characteristics are provided in Table 7.1.

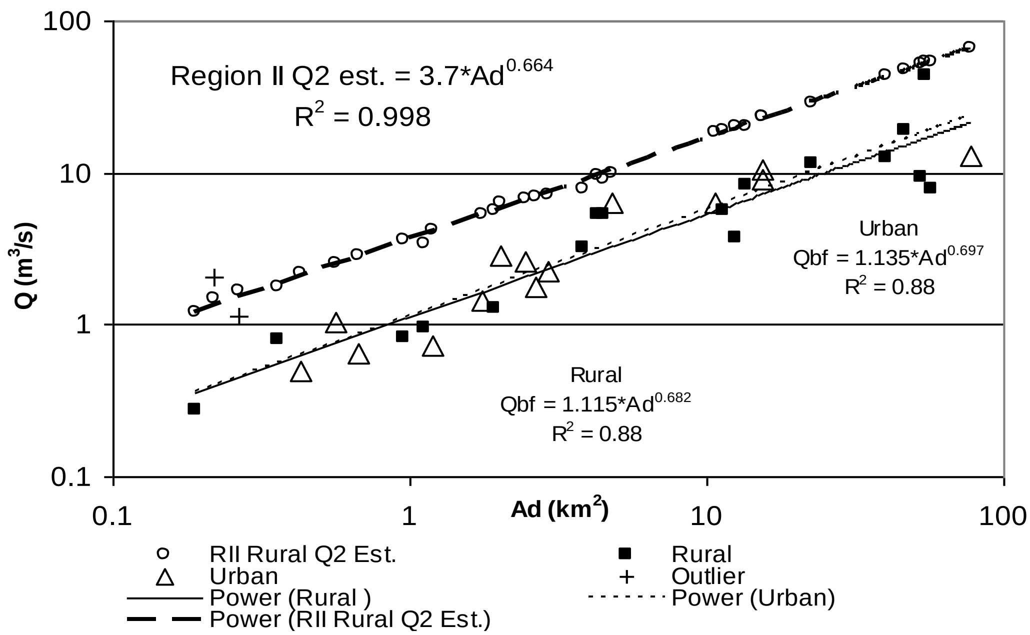


Figure 7.4 Region II Rural discharge estimate and SDS rural and urban discharges vs. drainage area.

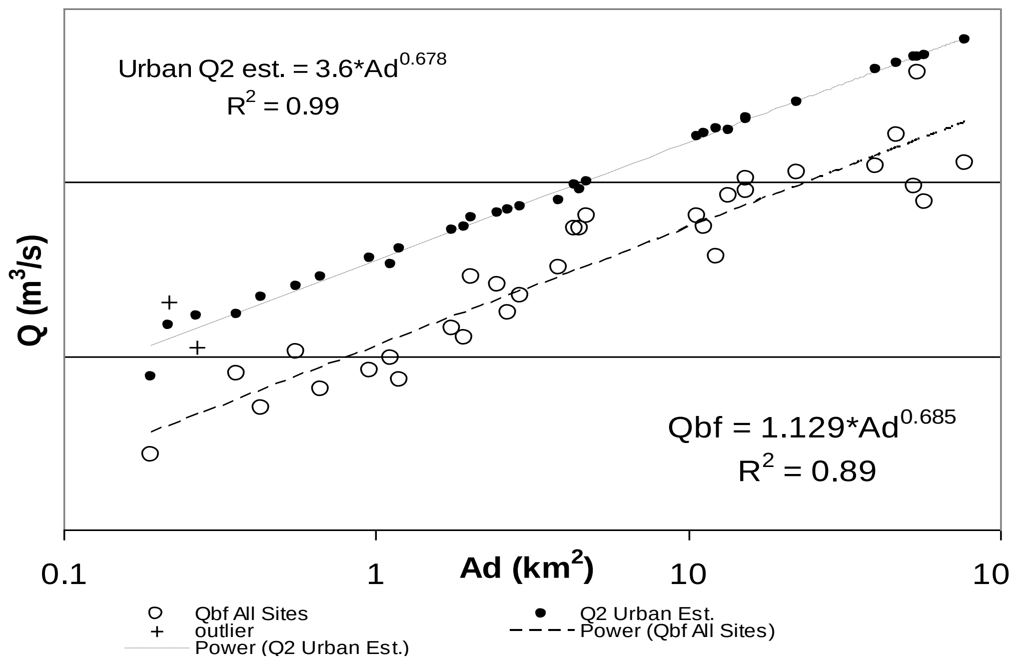


Figure 7.5 Urban discharge estimate and SDS bankfull discharge vs. drainage area.

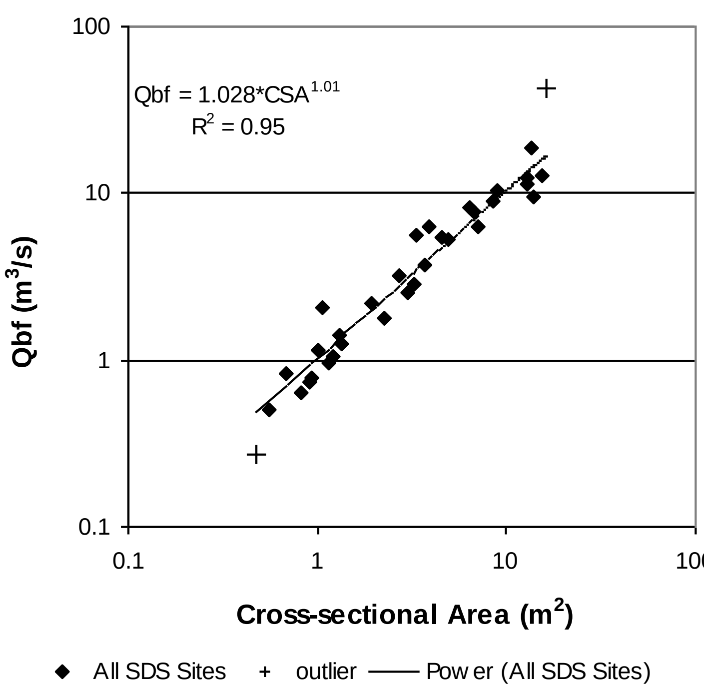


Figure 7.6 Bankfull discharge vs. bankfull cross-sectional area.

Total Channel Discharge

The same process for calculating bankfull discharge was used to calculate total channel discharge. However, the Manning's "n" was lowered by 0.005 to account for reach scale differences between the bankfull and total channel. Furthermore, riffle slope was replaced by map channel slope in the Manning Equation since the topographic map slope would better reflect the valley floor control on total channel flow. Calculated discharges for the total channel plot closer to the Region II Rural Q2 estimate equation trendline when compared to the bankfull discharge calculations (Figure 7.7). The total channels with drainage areas >10 km^2 displayed less variability than channels <10 km^2. The outlier at about 13 km^2 is a bedrock-controlled reach that is moderately entrenched (based on field survey notes and B4c Rosgen classification) which may explain the high discharge capacity. About half of the total channels display the capacity to contain the Region II Rural Q2 estimate. Fourteen of the 32 SDS sites plotted above the Region II Rural Q2 estimate, 8 rural and 6 urban. Figure 7.8 shows the near 1:1 relationship of total channel discharge with total channel cross-sectional area.

Comparison of 2-Year Discharges

Comparisons of 2-year discharge regression lines are shown in Figure 7.9. As stated earlier, the Urban 2-year estimate plots significantly higher than the bankfull discharge for SDS channels. The total channel and Region II Rural estimate regression lines plot essentially the same and converge with the Urban 2-year estimate in drainage areas <1 km^2.

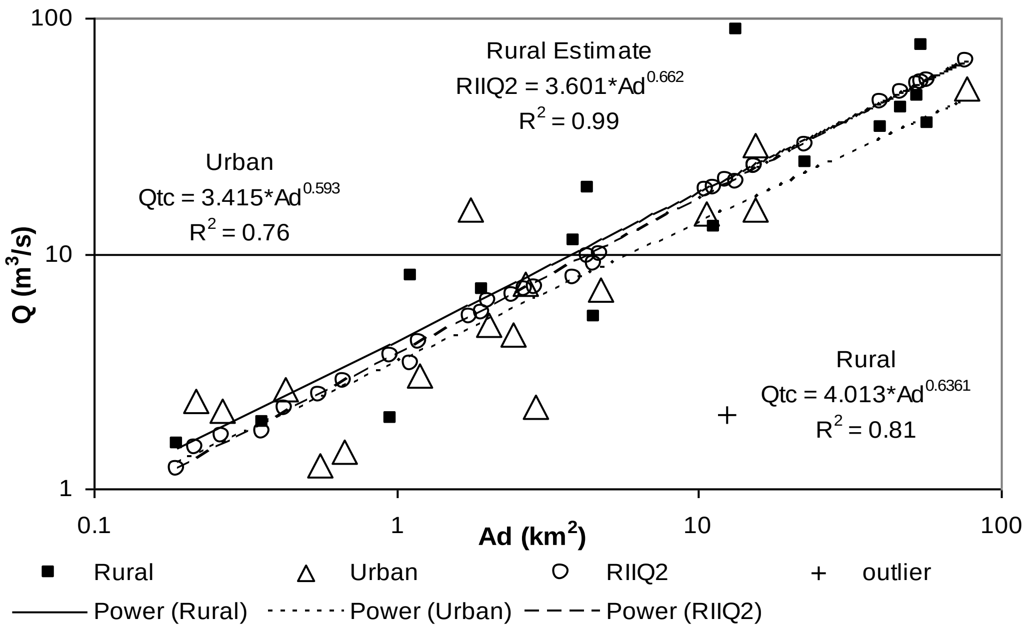


Figure 7.7 SDS rural and urban total channel discharges and Region II rural discharge estimate vs. drainage area.

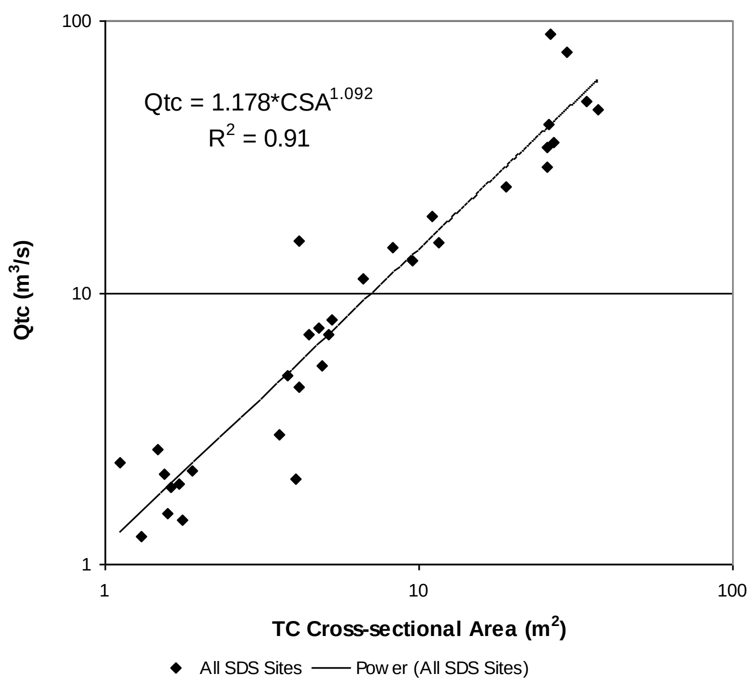


Figure 7.8 Total channel discharge vs. total channel cross-sectional area.

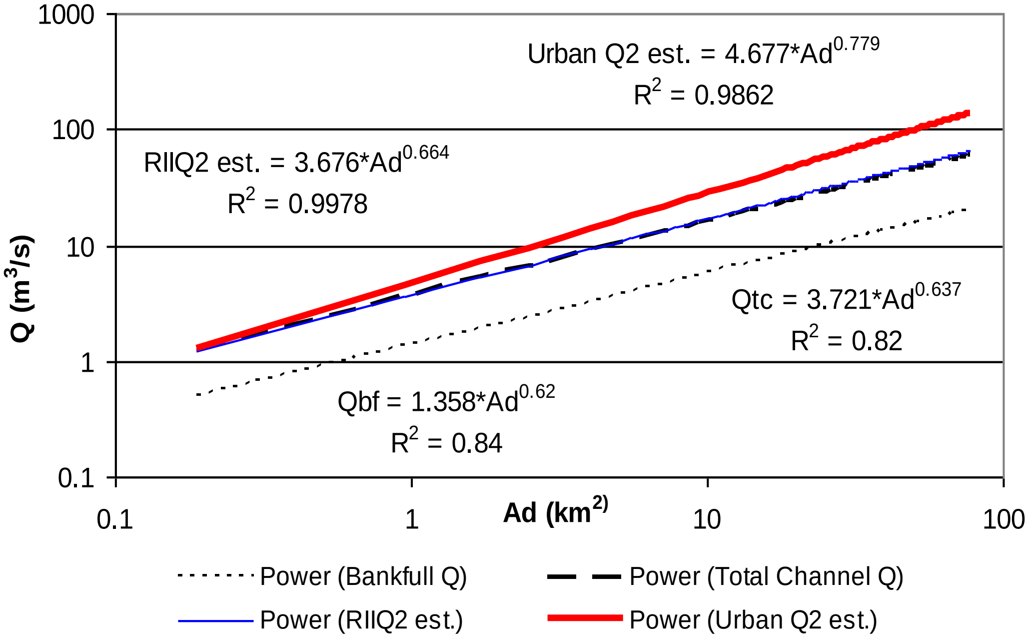


Figure 7.9 Bankfull, total channel, Urban Q2 est. and Region II Rural Q2 est. vs. drainage area.

STREAM POWER RELATIONSHIPS

Mean stream power is defined as the power per unit wetted area of a defined reach expressed in Watts/m^2 (Rhodes 1987). It can also be thought of as the intensity of power at a cross-section and is indicative of the transport competence or the largest diameter of sediment that can be moved by the stream. Mean stream power plots for the SDS generally show no drainage area trends (Figure 7.10). Nearly all the reaches, rural and urban, plot between 10 and 100 W/m^2. Bankfull stream power versus cross-sectional area appears to plot higher for rural streams throughout the watershed (Figure 7.11). However, the high amount of scatter displayed makes trends difficult to assess. The relationship between bankfull mean stream power and maximum clasts is also unclear (Figure 7.12). Total channel stream power also displays no clear watershed trend but is about two times greater than bankfull mean stream power (Figure 7.13). The means for bankfull and total channel mean stream power are 43.9 W/m^2 and 87.2 W/m^2 respectively for all SDS channels. The Cv%'s for bankfull and total channel mean stream power are 68.6% and 78.5% respectively. Stream power is highly variable in rural and urban streams throughout the SDS (Figure 7.14). No discernable trends or spatial patterns exist in the watershed to explain stream power characteristics. Summaries for discharge and stream power are provided in Table 7.1.

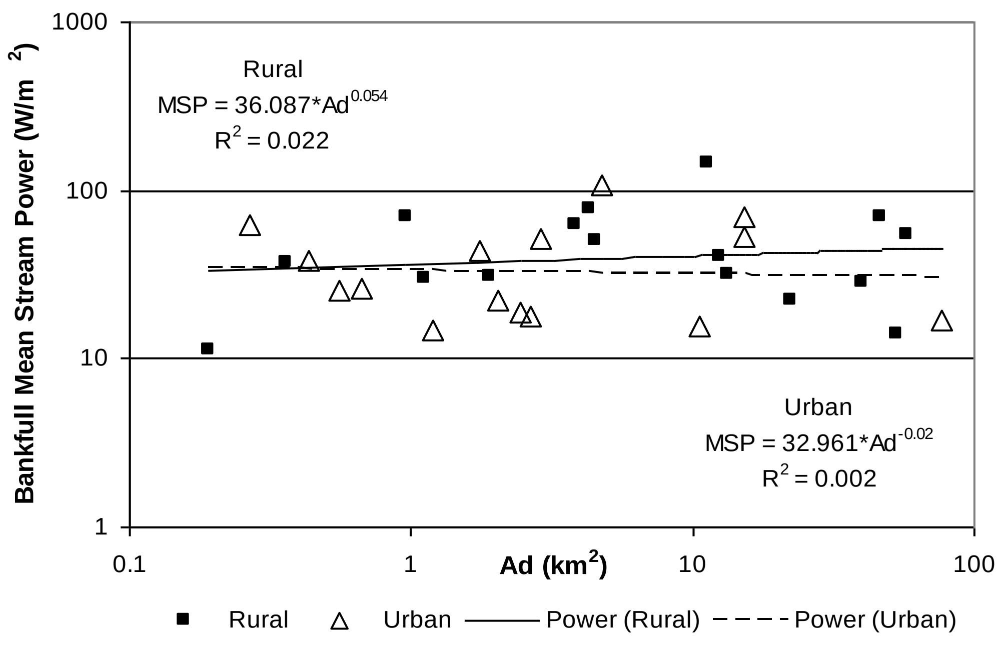


Figure 7.10 Bankfull mean stream power vs. drainage area (bedrock sites 1 and 19 omitted).

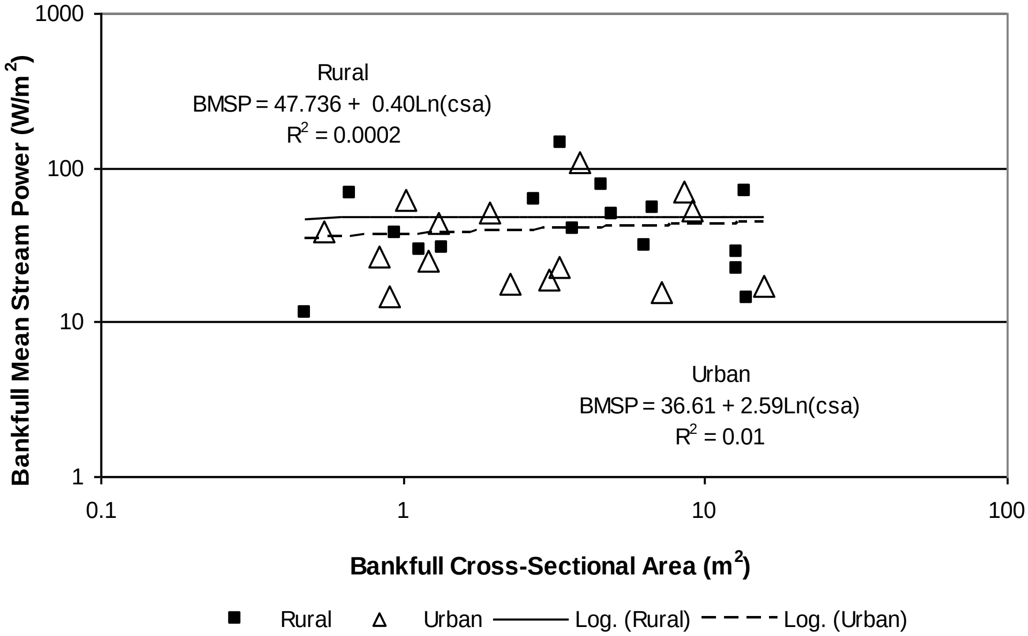


Figure 7.11 Bankfull mean stream power vs. cross-sectional area (bedrock sites 1 and 19 omitted).

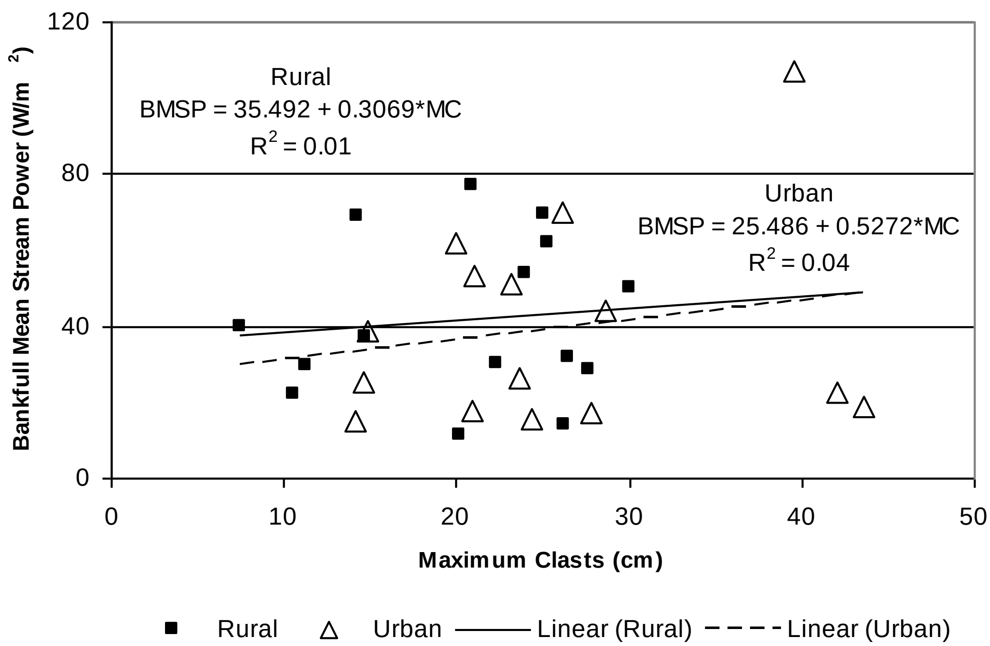


Figure 7.12 Bankfull mean stream power vs. maximum clasts (bedrock sites 1 and 19 omitted).

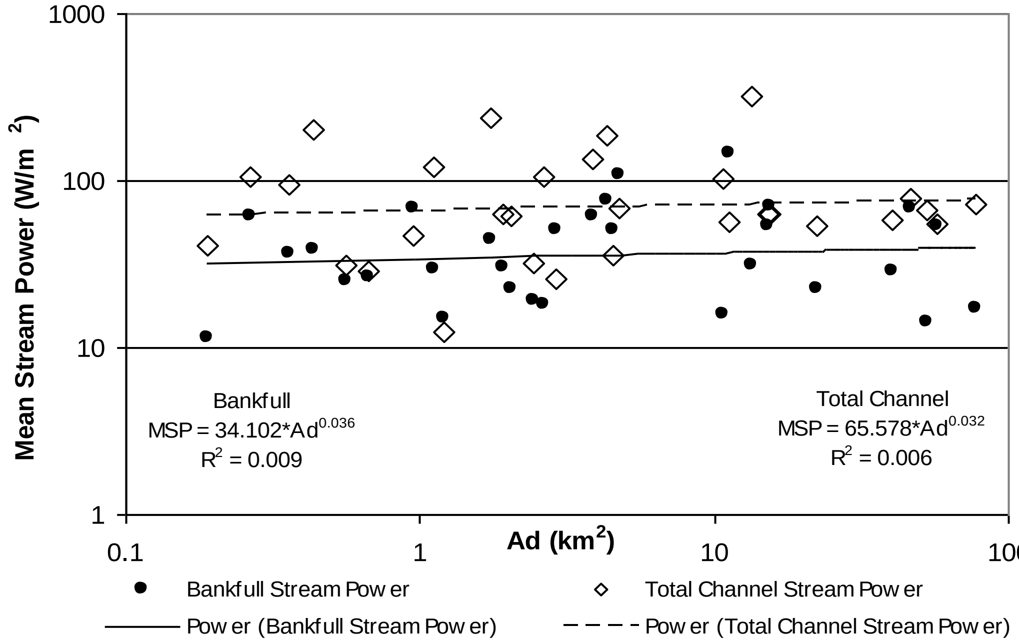


Figure 7.13 Bankfull and total channel mean stream power vs. drainage area (bedrock sites 1 and 19 omitted).

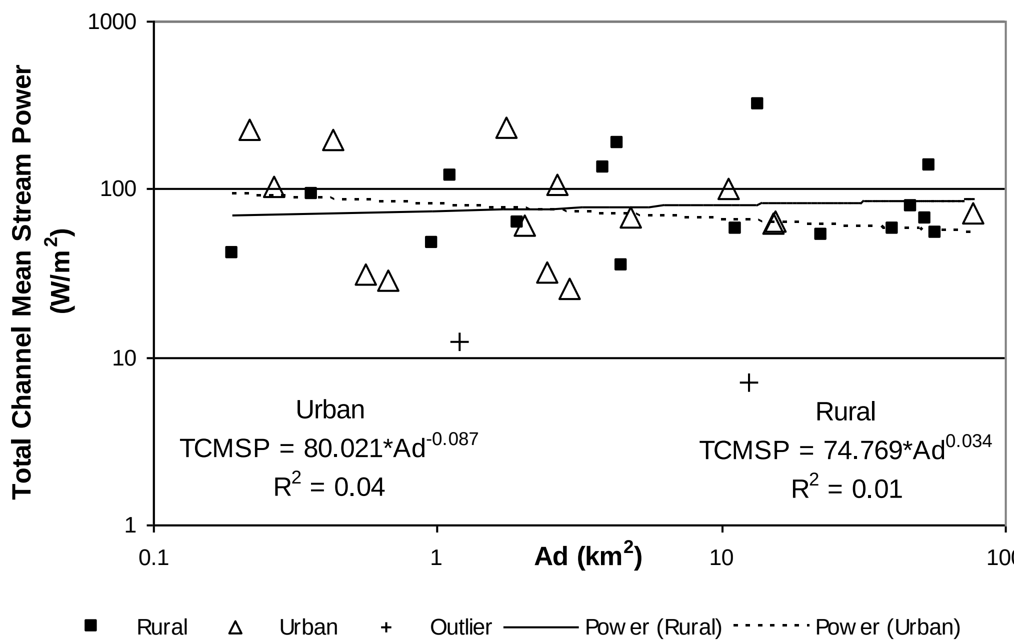


Figure 7.14 Total channel mean stream power vs. drainage area.

Table 7.1 Discharge and stream power summary table.

Discharge and Stream power Properties		Predicted Values		
		Drainage Area (km^2)		
		1	10	50
Manning's "n":	Rural	0.055	0.051	0.049
	Urban	0.050	0.052	0.054
	Diff (%)	*-9.091*	*1.767*	*10.118*
Velocity (m/s):	Rural	0.92	1.05	1.32
	Urban	0.95	0.99	1.06
	Diff (%)	*3.03*	*-6.25*	*-20.14*
Bankfull Q (m^3/s):	Rural	1.12	5.36	77.26
	Urban	1.14	5.65	86.33
	Diff (%)	*1.79*	*5.37*	*11.74*
Total Channel Q (m^3/s):	Rural	4.01	17.36	209.07
	Urban	3.42	13.38	136.11
	Diff (%)	*-14.90*	*-22.94*	*-34.90*
Bankfull Mean Stream Power (W/m^2):	Rural	36.09	40.86	50.48
	Urban	32.96	31.48	29.11
	Diff (%)	*-8.66*	*-22.97*	*-42.33*
Total Channel Mean Stream Power (W/m^2):	Rural	74.77	80.86	92.36
	Urban	80.02	65.49	46.60
	Diff (%)	*7.02*	*-19.00*	*-49.54*

SUMMARY

Discharges for both bankfull channel and total channel were calculated and compared with discharge estimate regression equations. Calculated bankfull discharges for SDS rural and urban channels were notably lower than Missouri Region II Q2 and Urban Q2 discharge estimates. Total channel discharge for SDS urban and rural channels plots closer to the Missouri Region II Rural Discharge estimate. Furthermore, no noticeable trend exists between SDS urban and rural total channel discharges. Stream power trends appear to vary randomly in the watershed between 10 and 100 Watts/m^2. Additionally, there appears to be no relationship between stream power and channel morphology

CHAPTER 8

DISCUSSION

SOURCES OF GEOMORPHIC VARIABILITY

Logistical Limitations

Choosing potential study reaches proved to be difficult at times. Problems encountered while conducting this study include private property access, human channel alterations and unforeseen disturbances in survey reaches unknown until aerial photo and GIS assessment was complete. Choosing a “natural” survey reach was the first criterion. Essentially, this meant finding an accessible stream reach that was not affected by human-made structures. Surveys sites were established as far as possible from human alterations and structures such as bridges, culverts and rip-rap. The issue of private property eliminated the access to a number of promising stream reaches. If unfettered access to more rural sites were possible, the differences seen between rural and urban channels may be more striking.

Measurement Error

Data collection for this study was based on standard operating procedures and proven techniques set by established geomorphic guidelines and prominent authorities on the subject. Consistency and attention-to-detail were adhered to during both the field and lab analysis phases. Nevertheless, data collection errors exist in every scientific study. These can exist as deviating cross-sectional areas or slopes within a given reach. Additionally, sinuosity measurements from aerial photos may not be entirely accurate. As an additional means to minimize error, measurements and bankfull designations for each survey reach were double-checked by my thesis advisor in the form of computer lab assistance and during field visits.

Reach-Scale Variability in Channel Form

Cross-sectional geometry can change substantially within a single reach (Brookes and Sear 1996). This variability is displayed in the following analysis of triplicate survey reaches. Triplicate cross-sectional data was gathered for five reaches at three successive riffles in the SDS. Three of these reaches were located along the main stem and one each at a 2nd and 3rd order stream. Table 8.1 shows the bankfull widths, mean depths, maximum depths, width:depth ratios and cross-sectional areas for each triplicate reach. The mean, standard deviation and coefficient of variance percentages are also displayed in Table 8.1.

Site 6, a 2nd order stream, displays moderate variability within the study reach. Bankfull widths for each survey riffle are 4.9, 6.3, and 6.1 meters with a Cv% of 13.1%. Mean bankfull depths are 0.52, 0.61 and 0.44 meters with a Cv% of 16.3%. Cross-sectional areas for the reach are 2.55, 3.84 and 2.68 m^2 respectively with a Cv% of 23.5%. High Cv% percentages in this reach may be attributed to higher discharges from recent upstream development. Additionally, it was noted in the field that fill material had been added to the adjacent terrace during road construction. Unconsolidated fill material could aid bank scouring processes and lead to inconsistent channel geometry.

Site 33, a 3rd order stream displayed fairly consistent channel geometry in spite of the gravel deposition located within the reach. This reach is pinned against a bluff and flanked by a floodplain or low terrace. Bankfull channel widths are 8, 6.5 and 7.2 meters with a Cv% of 10.4%. Mean bankfull depths are 0.52, 0.51 and 0.58 meters with a Cv% of 7.1%. Maximum bankfull depths and width;depth ratios are very consistent at each cross-section. Cross-sectional areas for the reach are 4.16, 3.32 and 4.18 m^2 with Cv% of 12.7%.

Sites 27, 35 and 36 are SDS main stem reaches. Sites 27 and 35 are located about 450 meters apart and have similar morphologies. Both survey reaches are pinned against a bluff and flanked by a wide floodplain or low terrace. Channel geometry for site 27 was fairly consistent. Bankfull widths are 13.5, 15.9 and 13.9 meters. The mean bankfull depths are 0.94, 0.74 and 0.73. The cross-sectional areas for site 27 are 12.69, 12.24, 10.15 meters. Cv%'s for bankfull width, depth and cross-sectional area were 8.9, 13.7and 11.6% respectively. Site 35 displayed the most consistent channel geometry of the five triplicate reaches. The bankfull widths are 15.3, 14.5 and 16.9 meters. The mean bankfull depths are 0.82, 0.83 and 0.72 meters. The cross-sectional areas for the three survey riffles are remarkably close at 12.55, 12.02 and 12.77 m^2. The Cv%'s for width, depth and cross-sectional area are all less than 8%. The width:depth ratios for sites 35 and 27 also indicate consistent channel geometries for these two closely located, main stem reaches.

Site 36, with a drainage area of 57.4 km^2, is the other main stem triplicate survey reach. The location of site 36 is in the middle of a pasture, flanked on both sides by low terraces or valley floor, with no bluff influence. Cross-sectional area and symmetry are inconsistent with Cv%'s ranging from 39.8% for cross-sectional area, to 6.8% for bankfull channel width. High variation in this stream reach may be due to gravel deposition below the downstream cross-section. The presence of healed bank-slumps that make bankfull stage identification difficult at this reach could also contribute to the cross-sectional disparity at this reach. The three bankfull channel widths were similar at 14.6, 13.0 and 14.7 meters. However, the mean bankfull depth measurements displayed great inconsistencies at 0.57, 0.53, and 0.97 meters. The depth measurements are based on the bankfull stage indicators that were present at the survey reach. Likewise, maximum depths at this reach displayed a relatively high Cv% at 38.8. The cross-sectional areas (8.32 and 6.89 m^2) and width:depth ratios (25.6 and 24.5) for the two upstream riffles do not follow the watershed trends with respect to drainage area. The last riffle in reach 36 follows the watershed trend more closely with a cross-sectional area of 14.26 m^2.

Table 8.1 Evaluation of triplicate survey reaches.

Site #	6	33	35	27	36
Drainage Area (km^2)	4.8	11.3	22.5	40.2	57.4
Stream Order (Strahler)	2	3	4	4	4
Bankfull Widths (m)					
A	4.9	8	15.3	13.5	14.6
B	6.3	6.5	14.5	15.9	13.0
C	6.1	7.2	16.9	13.9	14.7
mean	5.8	7.2	15.6	14.4	14.1
standard deviation	0.76	0.75	1.22	1.29	0.95
Cv%	13.1	10.4	7.9	8.9	6.8
Mean Bankfull Depths (m)					
A	0.52	0.52	0.82	0.94	0.57
B	0.61	0.51	0.83	0.77	0.53
C	0.44	0.58	0.72	0.73	0.97
mean	0.52	0.54	0.79	0.81	0.69
standard deviation	0.09	0.04	0.06	0.11	0.24
Cv%	16.3	7.1	7.7	13.7	35.3
Width:Depth Ratio					
A	9.4	15.4	18.7	14.4	25.6
B	10.3	12.7	17.5	20.6	24.5
C	13.9	12.4	23.5	19.0	15.2
mean	11.2	13.5	19.9	18.0	21.8
standard deviation	2.3	1.6	3.2	3.3	5.8
Cv%	20.9	12.0	16.0	18.1	26.4
Max Depth (m)					
A	0.93	0.90	1.20	1.30	0.90
B	1.25	0.90	1.00	1.30	0.90
C	0.75	0.90	1.10	1.10	1.68
mean	0.98	0.90	1.10	1.23	1.16
standard deviation	0.25	0.00	0.10	0.12	0.45
Cv%	25.9	0.0	9.1	9.4	38.8
Cross-sectional Area (m^2)					
A	2.55	4.16	12.55	12.69	8.32
B	3.84	3.315	12.04	12.24	6.89
C	2.68	4.176	12.17	10.15	14.26
mean	3.03	3.88	12.25	11.69	9.82
standard deviation	0.71	0.49	0.27	1.36	3.91
Cv%	23.5	12.7	2.2	11.6	39.8

Karst Influence on Discharge-Area Relationships

The role of karst in influencing geomorphic trends in the SDS is not totally understood. The underlying karst geology of the SDS with its numerous sinkholes and losing reaches may be accountable for lower discharge calculations. Figure 8.1 shows the distribution of sinkholes in the watershed. Sinkhole area was calculated to be approximately 0.95 km^2, or about 1.2% of the watershed. The entire drainage area of the SDS is 78.52 km^2; however the "effective" topographic watershed area (Aeff) of the entire SDS is 77.57 km^2. Sinkholes are most prevalent in the north central and west central portions of the watershed. Incidentally, channels in these areas of highest karst concentrations were not surveyed. The amount of discharge diverted into swallow holes in the main stem is also unknown. The effect of karst drainage may be to reduce the magnitude of the 2-year or bankfull discharge (Martin 2001).

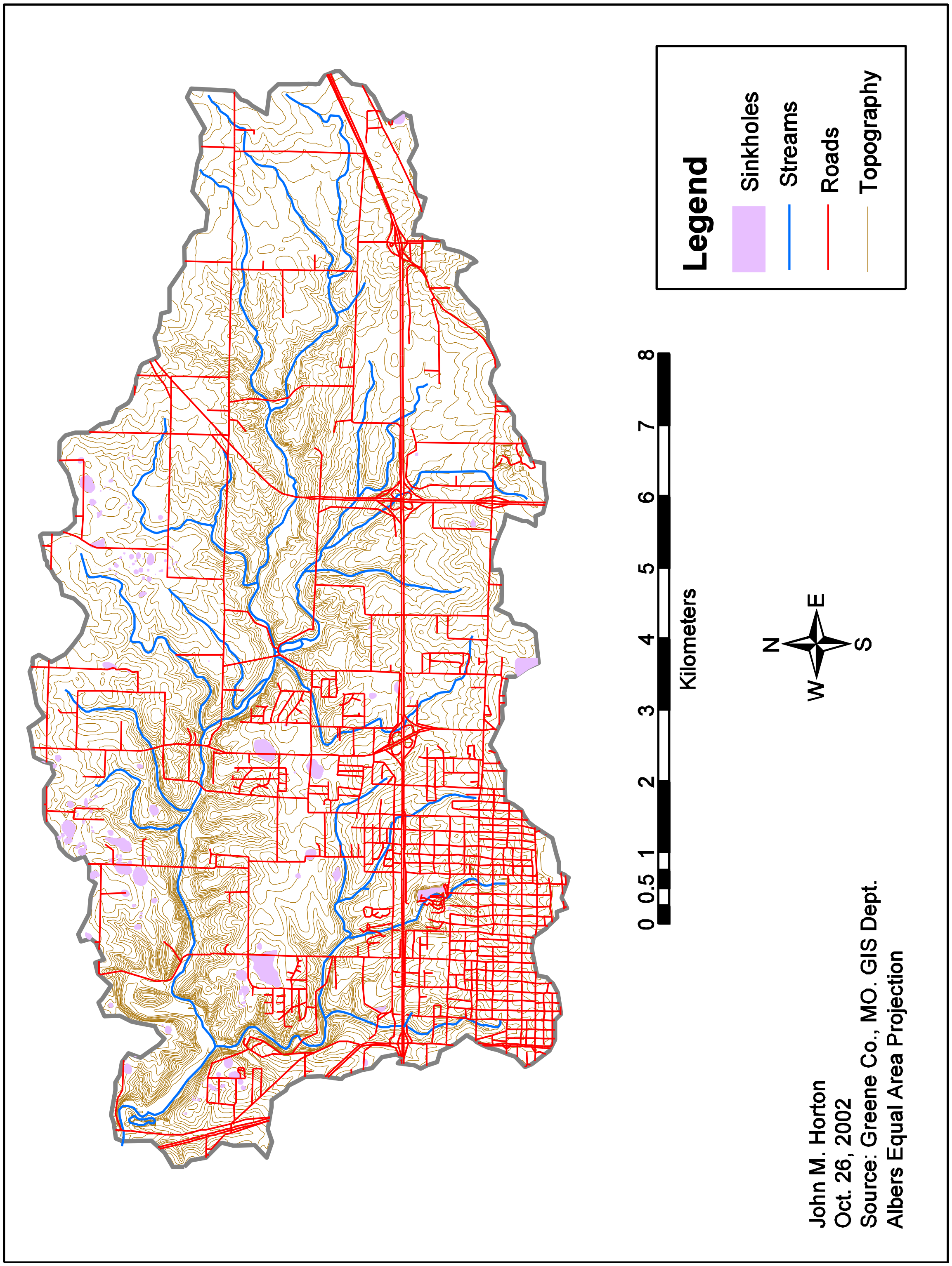


Figure 8.1 Sinkhole distribution in the South Dry Sac Watershed.

URBAN INFLUENCE ON STREAM GEOMORPHOLOGY

Differences between urban and rural channel morphology were discussed in Chapter 6. The observations in Table 8.2 summarize the basic findings of this study. References to other studies with similar findings are listed. Overall, urban and rural channel geometry differences are subtle, but there is seems to be some difference. Urban bankfull channel cross-sectional area is slightly larger than the rural counterparts. Rural total channel dimensions, or meander belts, are larger than urban total channels. Longitudinal profiles for rural channels exhibit greater maximum residual pool depths and greater pool-riffle spacing. Plan differences occur in the form of greater meander amplitudes in rural channels. In addition, sinuosity appears to be more variable in rural channels, but lower in urban channels <10 km^2. Spatially, urban reaches draining areas >10 km^2 seem to be less sensitive to change. This may be due to the greater mix in land use, sluggish hydrograph and karst influence that lessens the channel altering discharges. The urban reaches draining the <10 km^2 may be influenced more by local land use and flashy discharges that accomplish more geomorphic change.

Findings in other studies are comparable with the results found in the SDS. The Pizzuto et al. (2000) study in Pennsylvania and the Doll et al. (2002) study in North Carolina both used a research approach similar to the SDS research. Rural and urban bankfull width trendlines for the SDS and Doll et al. (2002) generally run parallel to one another (Figure 8.2). However, the disproportion between urban and rural North Carolina channels is bigger than SDS channels. Bankfull mean depths for both rural and urban North Carolina channels are greater and show a greater disproportion than both rural and urban SDS trends (Figure 8.3). Subsequently, cross-sectional area trends reflect the width and mean depth relationships previously discussed for both SDS and North Carolina channels (Figure 8.4). Doll's et al. (2002) results are more comparable to the results found in the SDS. Pizzuto's findings show an even greater disparity between urban and rural channels with drainage areas less than 1 km^2. Furthermore, the rural and urban trendlines converge as drainage area increases in the Pennsylvania watersheds. It is important to note that Pizzuto's study included only channels with drainage areas up to 45 km^2, thus comparisons between larger drainage areas are not possible. Table 8.3 offers a summary of difference percentages between urban and rural channel geometry found in the three studies.

Table 8.2 Urban versus rural bankfull channel morphology.

Channel Morphology	South Dry Sac	Reference
Bankfull width	Urban channels 10% wider	Pizzuto et al. 2000
Bankfull mean depth	Urban channels 5-9% greater depths	Schumm et al. 1984; Leopold 1973
Bankfull cross-sectional area	Urban bankfull CSA 15-20% larger	Doll et al. 2002; Hammer 1972
Riffle-to-riffle spacing	Riffle spacing greater in rural channels <10 km^2	n/a
Pool-to-pool spacing	Pool spacing greater in rural channels <10km^2	n/a
Maximum Residual pool depth	Urban channels have 32-47% lower residual pool depths	Pizzuto et al. 2000
Sinuosity	Sinuosity is lower for urban channels, but highly variable for rural	Arnold et al. 1982; Pizzuto et al. 2000
Meander wavelength	Inconclusive	n/a
Meander amplitude	40% lower in urban channels	Pizzuto et al. 2000

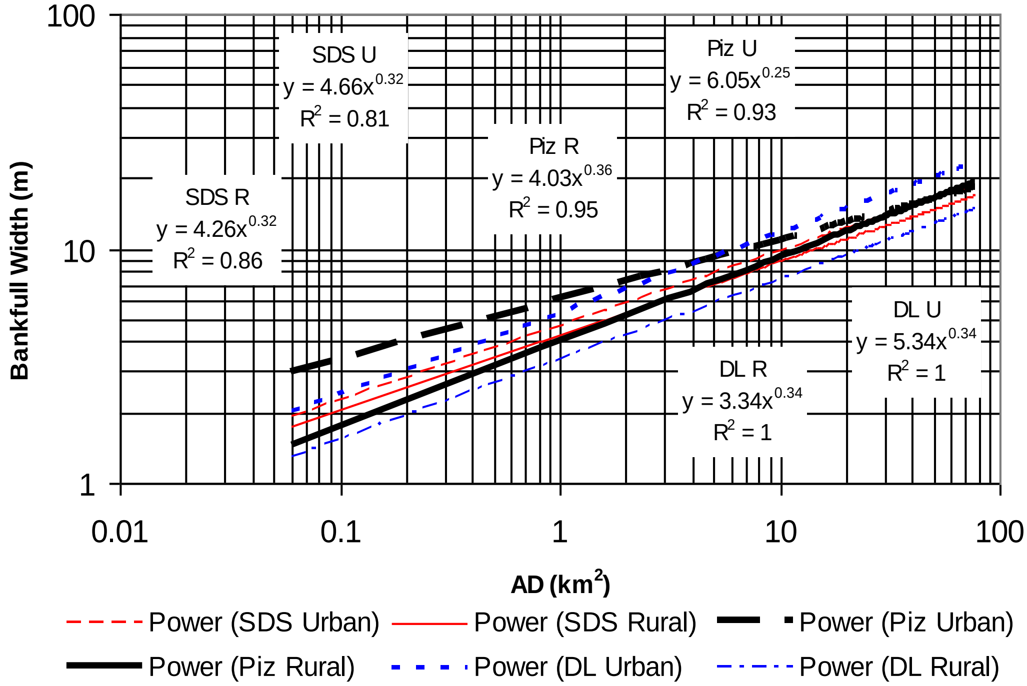


Figure 8.2 Comparison of bankfull widths.

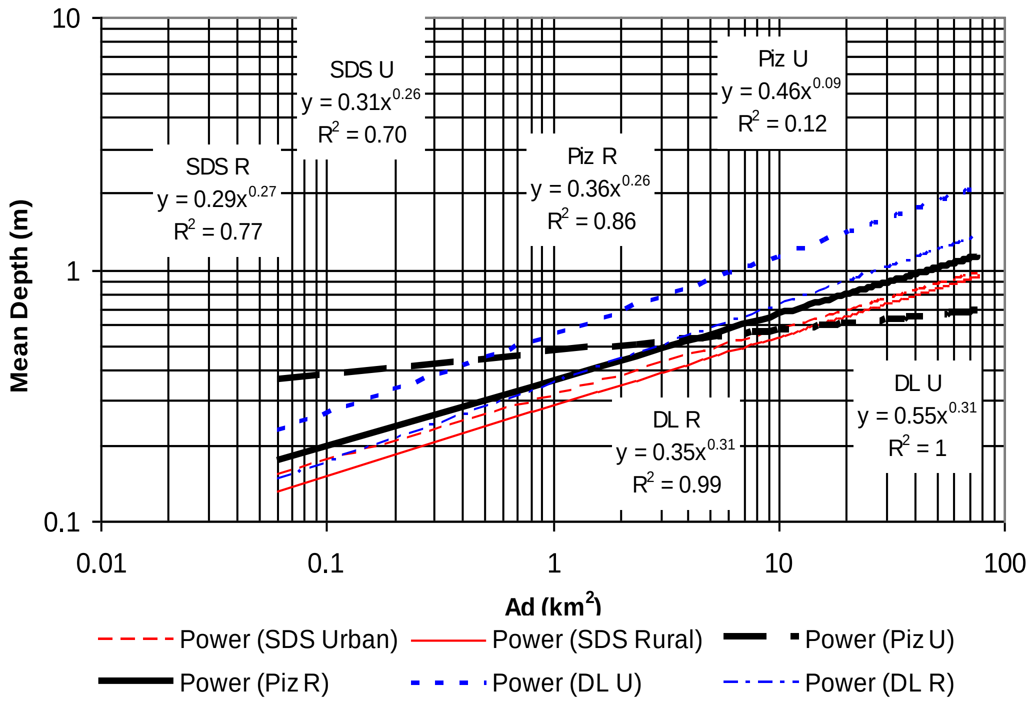


Figure 8.3 Comparison of bankfull mean depths.

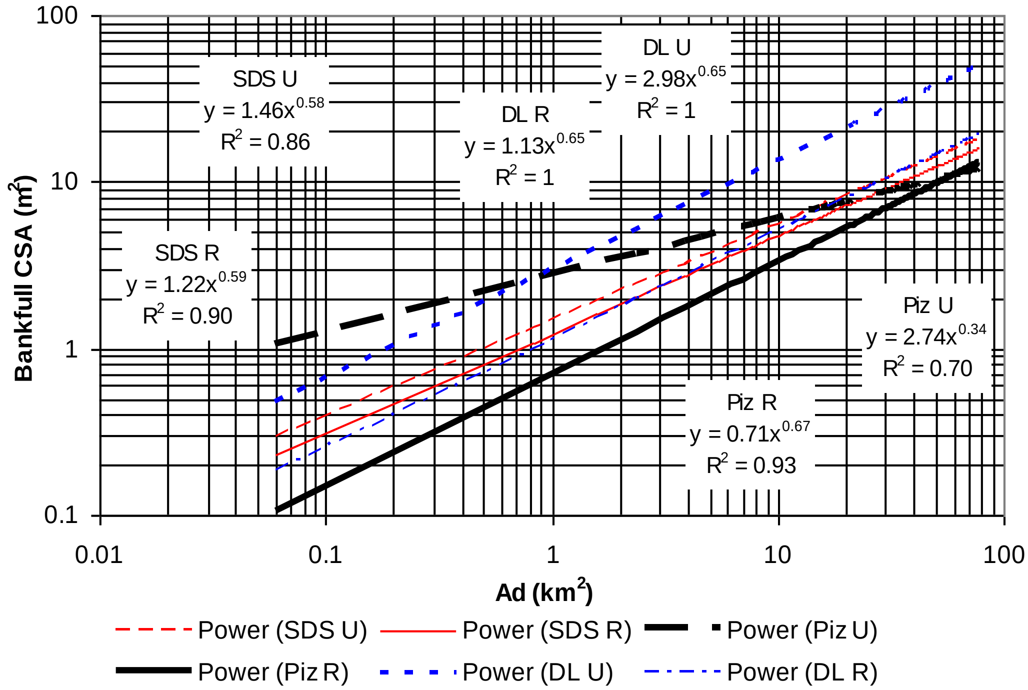


Figure 8.4 Comparison of bankfull cross-sectional areas.

Table 8.3 Comparison of difference percentages for SDS, Pennsylvania and North Carolina streams.

Study	Drainage Area (km^2)	Difference Percentages of Predicted Values between Urban and Rural Channels		
		Bankfull Width (m)	Bankfull Mean Depth (m)	Cross-sectional Area (m^2)
South Dry Sac:	1	10%	7%	20%
	10	10%	5%	14%
Pizzuto (2000):	1	50%	28%	282%
	10	17%	-14%	80%
Doll (2002):	1	60%	57%	163%
	10	60%	57%	163%

IMPLICATIONS FOR RESTORATION

Objectives for Restoration

This study offers guidelines for restoring channel cross-sectional geometry, longitudinal profile and planform for disturbed and channelized streams within the SDS and adjacent watersheds. The guidelines provided in this study are intended for the restoration of basic stream type and geomorphological conditions found in Springfield Plateau streams. Additionally, the restoration guidelines offered here are intended to assist ecological and aesthetic improvement of Ozark Plateau streams in urbanized areas. Additional benefits gained from channel and floodplain restoration may be flood control and greenways for recreation. Channel restoration begins by identifying the objectives for restoration. Rosgen (1996) proposes a four-step process before embarking on a stream channel restoration project. They are as follows: (1) *What are the observed problems?* ; (2) *What caused the problem?;* (3) *What stream type should this be?;* (4) *What is the probable stable form of the stream type under the present hydrology and sediment regime?*

The observed problems for urban streams of the Springfield Plateau include channels that have eroded banks, scour and incision, and channelization by concrete or excavation. Gravel waves and sedimentation caused by development and past land disturbances are also problems that are responsible for stream degradation. Second, the problems for a potential restoration watershed were most likely caused by urbanization, poor stormwater planning and past land use disturbance. Understanding the watershed factors that have contributed to the problem is salient. As an example, if the watershed land use that caused degradation is still in place, restoring the channels may not be the wise course of action. Knowing bankfull discharge, land use changes and sediment regimes of the particular channel is imperative to identifying the problem.

Third, finding the appropriate stream type for the reach depends on what the future potential of the reach will be. Fundamentally this means that watershed factors must also be taken into account and restoration designs should be established to fit the channel to the watershed it is located in, not vice versa. The probable stable channel form for restoring many Springfield Plateau streams is the C type-- but with low sinuosity. This precept is based on the notion that the reference reaches in the SDS are in “stable form” or in near equilibrium. The belief that SDS channels are in near equilibrium is supported only by the fact that urban and rural channel geometry trendlines display about 10% differences. Evidence to suggest this is difficult to provide, but rural channels are perceived to be somewhat stable.

Fourth, the geology, land cover and slope are similar for most Springfield Plateau streams in relation to drainage area. However, the geomorphology of the valley must be considered when devising a restoration plan for a particular reference reach. Rosgen reaffirms that successful channel restoration is dependant on the interconnectedness of channel geometry, planform and longitudinal profile. Furthermore, the planner should remain focused on what the stream type potential is, and not the current state of the channel.

Equations for Channel Geometry Restoration

Cross-sectional restoration will provide the rehabilitation reach with a channel in which to contain various discharge events. Also, it is intended to replicate the historic or pre-disturbance form (Brookes and Sear 1996). Equations for restoring channel geometry were derived from both urban and rural channels because the similarities in channel cross-sectional geometry size. Trendlines and restoration equations are averages of both rural and urban channels of the SDS.

Restoring proper bankfull channel width in an urban watershed is foremost. The restoration equation offered in Figure 8.5 was derived from both urban and rural channel plots discussed in Chapter 6. The near identical trendline slopes and 10% difference between rural and urban widths provided a practical restoration equation. The equation for restoring mean bankfull depth was derived on a similar basis as bankfull width. The mean bankfull depths for urban and rural channels were comparable to one another. Logically, the restoration equation was again derived from the average of both urban and rural channels. The restoration equation for mean bankfull channel depth is shown in Figure 8.6. Restoration of the cross-sectional area is important because it must convey the low flow discharge and remain stable during flood events. The equation for restoring bankfull cross-sectional area is presented in Figure 8.7. Similar to width and mean depth, the cross-sectional area restoration equation was derived from the average of rural and urban SDS channels. Figure 8.8 provides a reference for maximum depth restoration. Total channel equations are also provided in Figures 8.5-8.8 to provide restoration dimensions for the construction of meander belts to contain bankfull channel overflow.

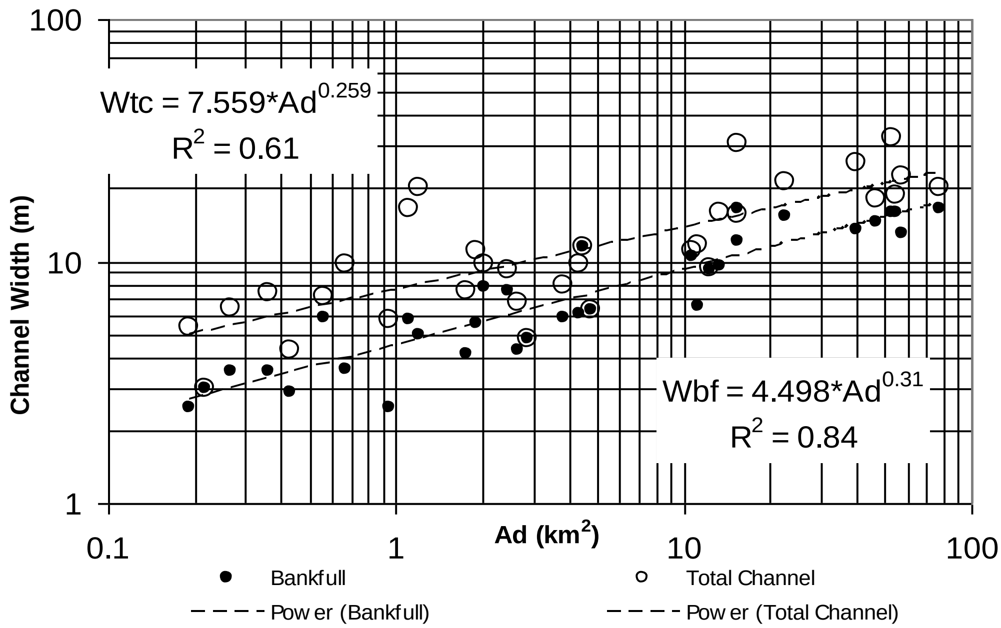


Figure 8.5 Restoration equation and graph for bankfull and total channel width.

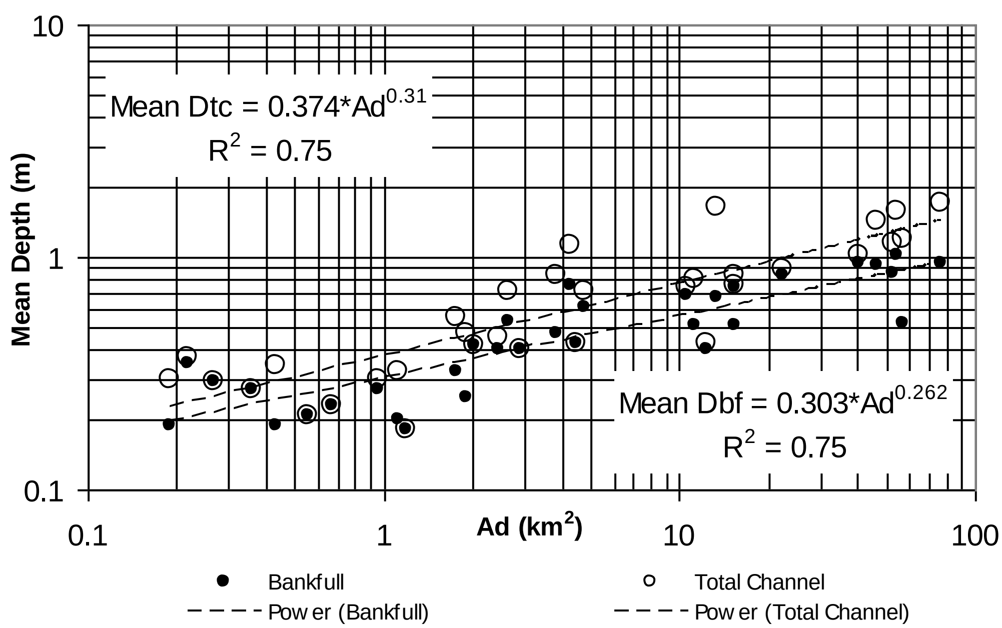


Figure 8.6 Restoration equation and graph for mean bankfull and total channel depth.

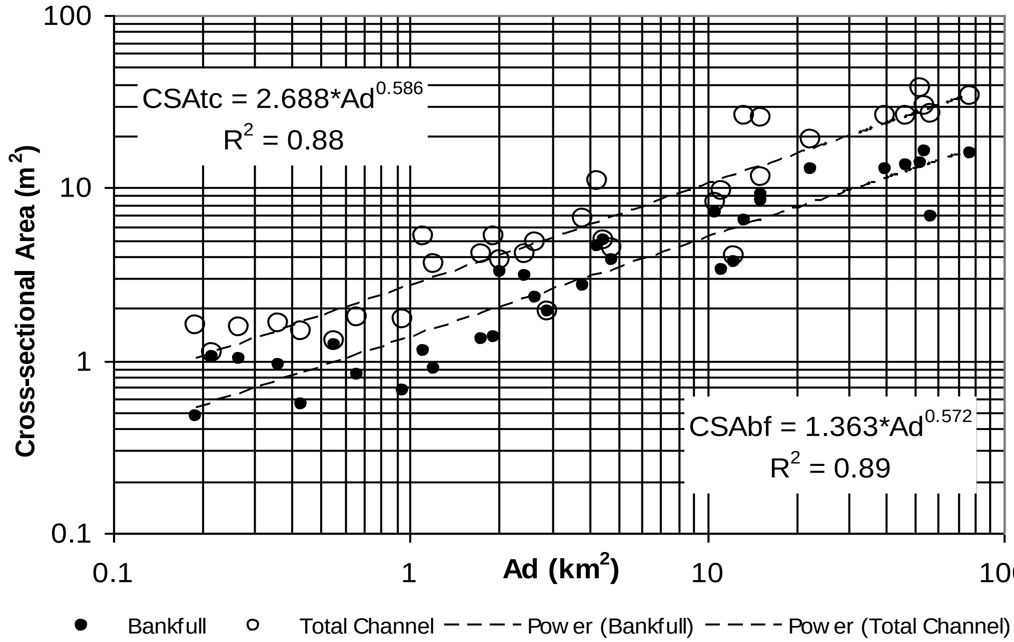


Figure 8.7 Restoration graph and equation for bankfull and total channel cross-sectional area.

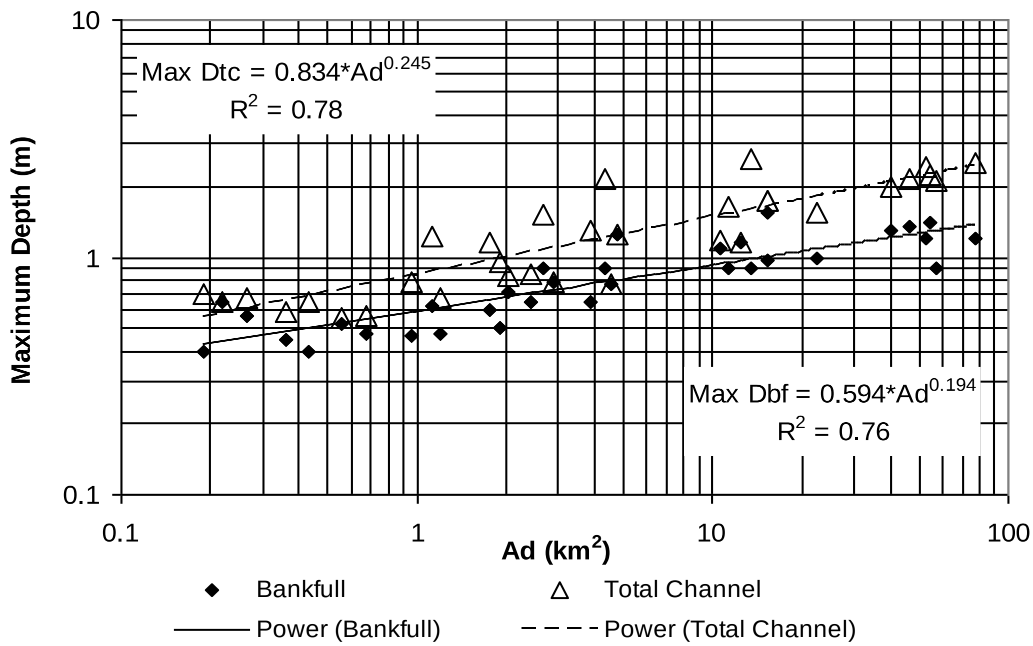


Figure 8.8 Restoration graph and equation for bankfull and total channel maximum depth.

Equations for Longitudinal Profile Restoration

Riffle and pool spacing restoration equations are derived as averages of both rural and urban SDS channels. The equation in Figure 8.9 guides the location of riffle heads, or the topographic high points within the channel. The restoration equation for pool spacing is offered in Figure 8.10. This equation will direct the establishment of the deepest portion within the pool, or the topographic low points between the riffles. Pool-riffle spacing is also dependant on slope factors and discharge. Reach slope equations are offered later in the text. Maximum residual pool depth restoration will be used in concert with the pool spacing equation. The depth equation guides the establishment of pool depths at the points specified by the pool spacing equation (Figure 8.11). The maximum residual pool depth equation was derived from both rural and urban SDS channels.

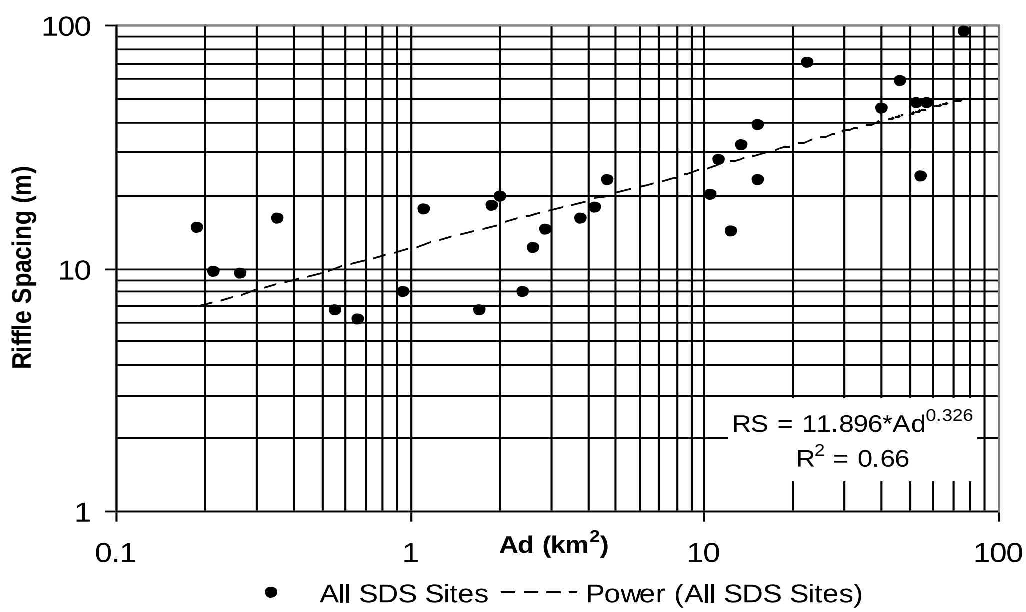


Figure 8.9 Restoration equation and graph for riffle spacing.

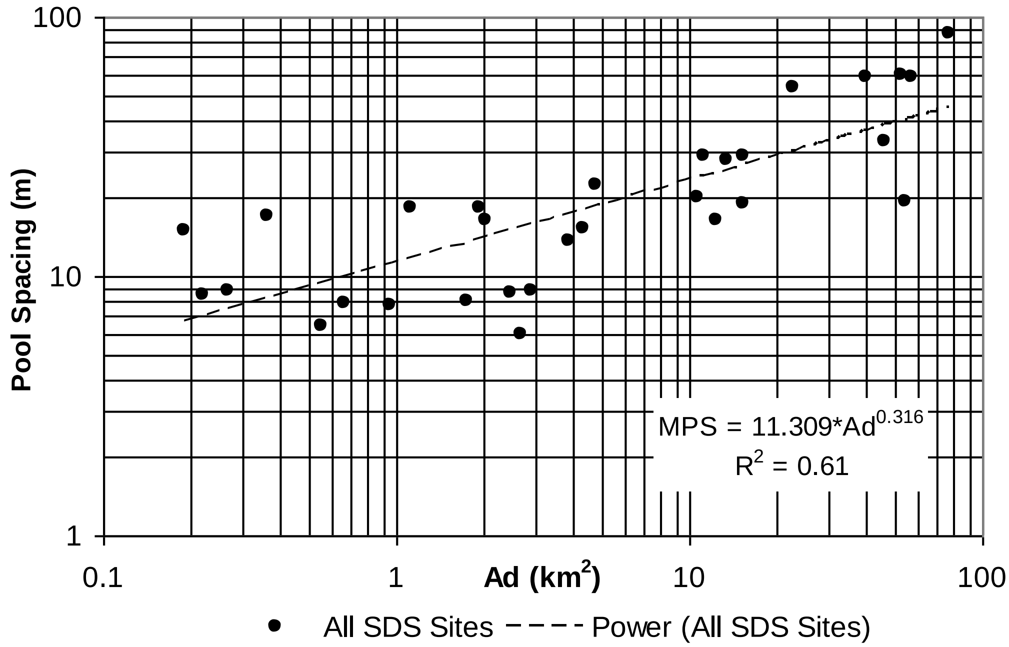


Figure 8.10 Restoration equation and graph for pool spacing.

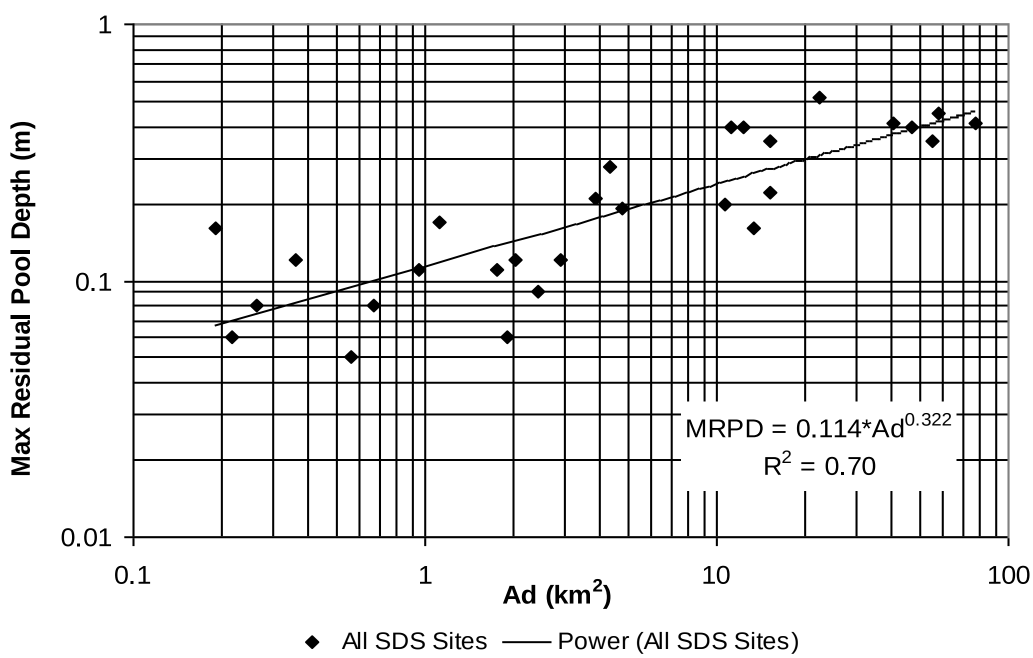


Figure 8.11 Restoration equation and graph for maximum residual pool depth.

Equations for Planform Restoration

Planform restoration may be the most difficult aspect of stream restoration. Deciding whether to restore a channel to a meandering, sinuous stream is dependant on reach factors. Land availability and riparian property ownership issues will factor heavily into this decision. Meander amplitude restoration for Springfield Plateau channels can be aided by the equation offered in Figure 8.12. Meander wavelength restoration can be referenced in Figure 8.13. Both equations were derived from rural and urban SDS survey reaches. Channel sinuosity in the SDS for both urban and rural reaches, as seen in Chapters 5 and 6, is low and highly variable. Restoring channel sinuosity similar to rural channels may help alleviate high discharge velocities. Channels may also regain sinuosity naturally if proper bank and vegetative material is in place. The sinuosity equation in Figure 8.14 is offered as supplemental tool. Historical data and pre-disturbance air photos can also guide sinuosity restoration. Additional planform restoration equations can be derived from plots that show the relationship between bankfull channel width and meander amplitude/wavelength (Figures 8.14 and 8.15).

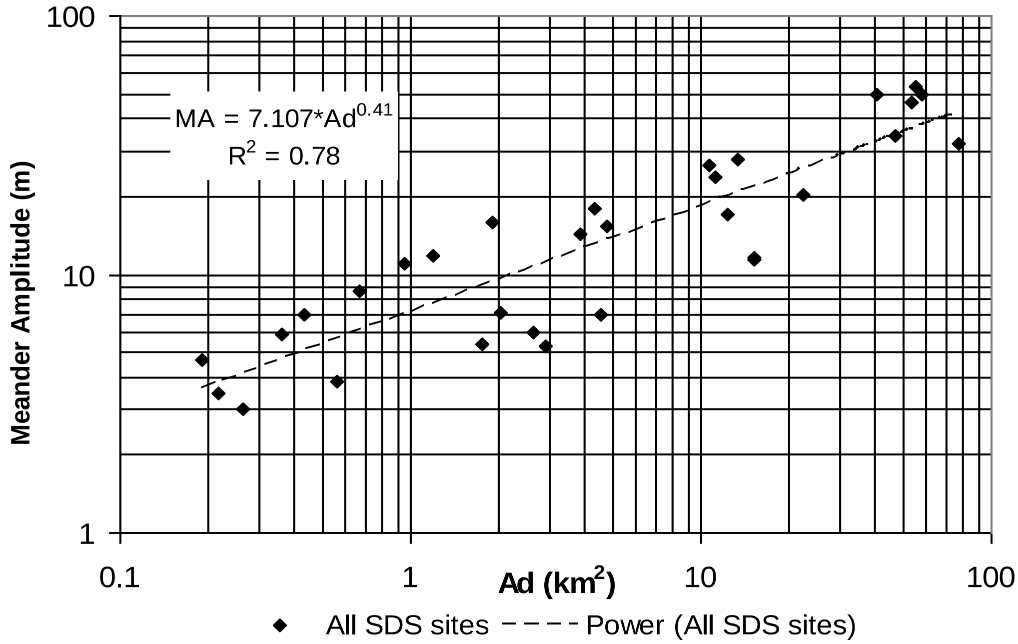


Figure 8.12 Meander amplitude restoration equation and graph.

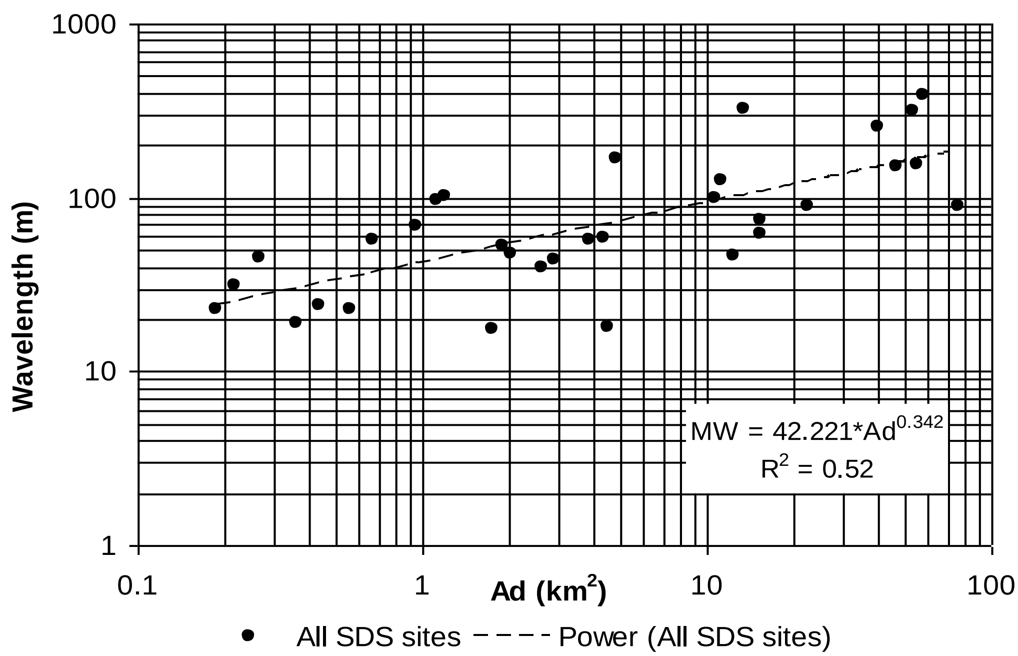


Figure 8.13 Meander wavelength restoration equation and graph.

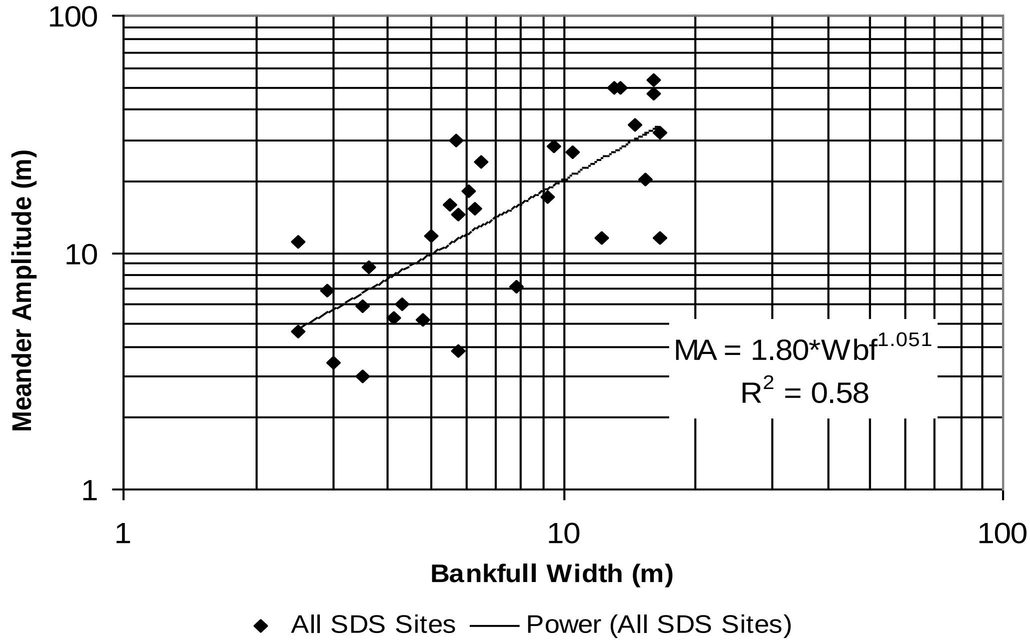


Figure 8.14 Meander amplitude vs. bankfull width restoration equation.

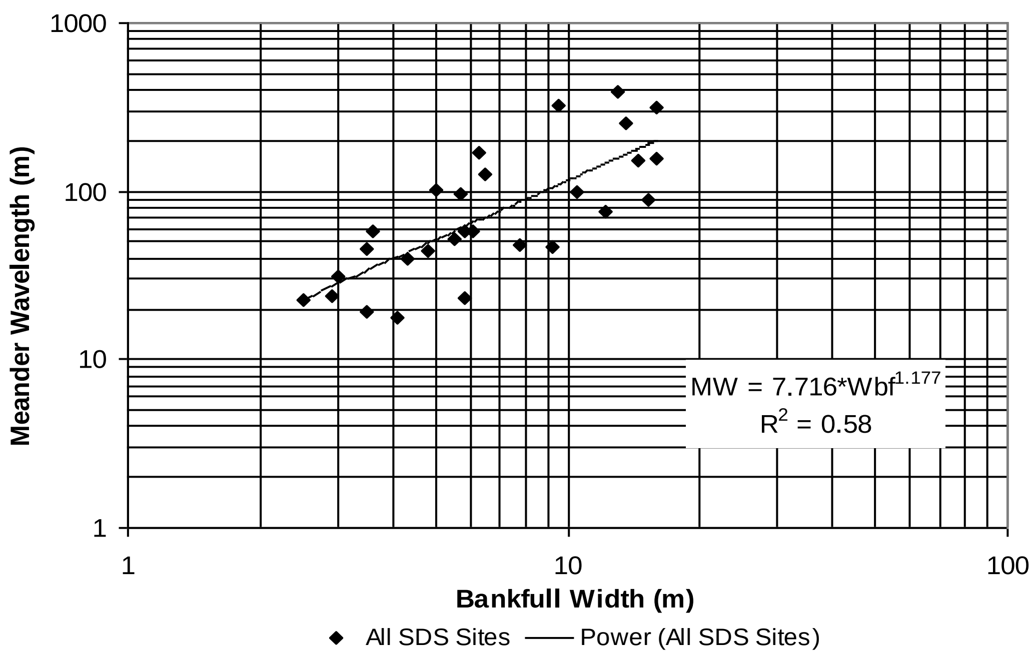


Figure 8.15 Meander wavelength vs. bankfull width restoration equation.

Equations for Slope and Drainage Area

Basin slope will be used for augmenting longitudinal profile restoration (see Figure 6.16). However, reach factors for the restoration channel should ultimately determine the slope of the restoration reach. If pre-disturbance slope data is available, it should be utilized. Local geology and morphological factors will also influence the restoration of reach slope. Subsequently, the slopes offered in Figure 6.16 are provided only as references. It will give the planners a close approximation of the slope that needs to be implemented given a certain drainage area.

Bed Material Restoration

Proper bed material is another consideration when restoring channel longitudinal profile. Figure 8.16 shows the relationship between slope and median sediment. This equation can also be used to supplement slope and sediment restoration. The appropriate sized bed material will assist in pool-riffle self-formation (Brookes and Sear 1996). SDS channels are composed of both mobile gravel and bedrock reaches. Similarly, other Springfield Plateau streams marked for restoration should include bed material conducive to pool-riffle self-formation where bedrock outcrops do not occur. Riffle gravel should be of assorted sizes to insure interlocking and stability of the riffle. This will also ensure that the Manning's "n" values for the restoration reaches will imitate those of reference reach channels (Table 7.1). The D10, D50 and D84 sediment sizes for the restoration reach should be based on a particular SDS reference reach of matching stream order and comparable drainage area. The D10-84 and max clasts sediment sizes for restoration are shown in Figure 8.17.

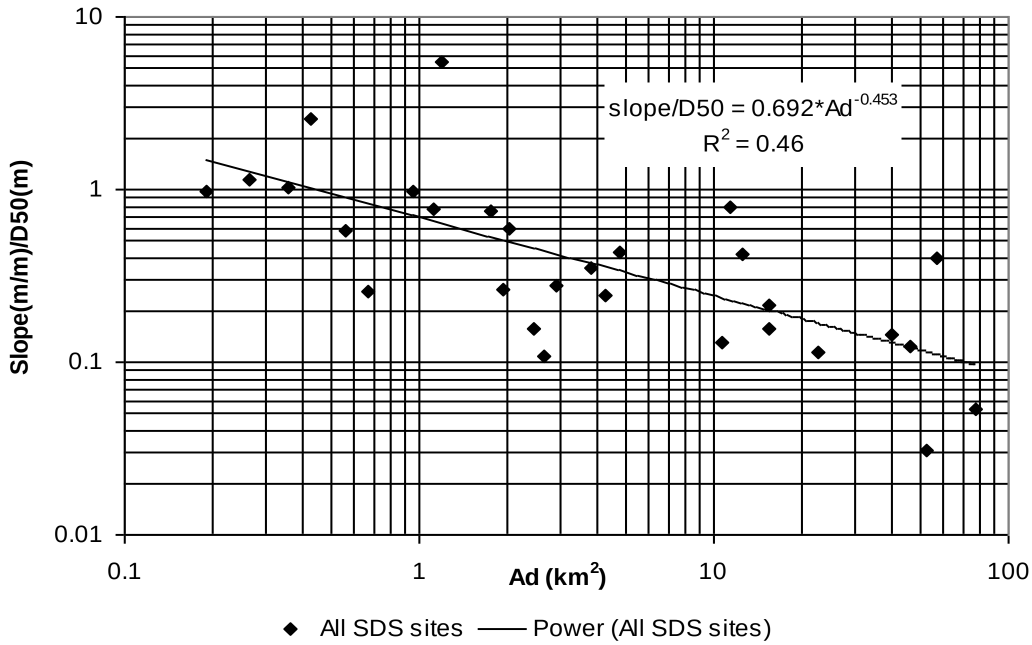


Figure 8.16 Slope/D50 sediment vs. drainage area (bedrock sites 1, 19 and 24 omitted).

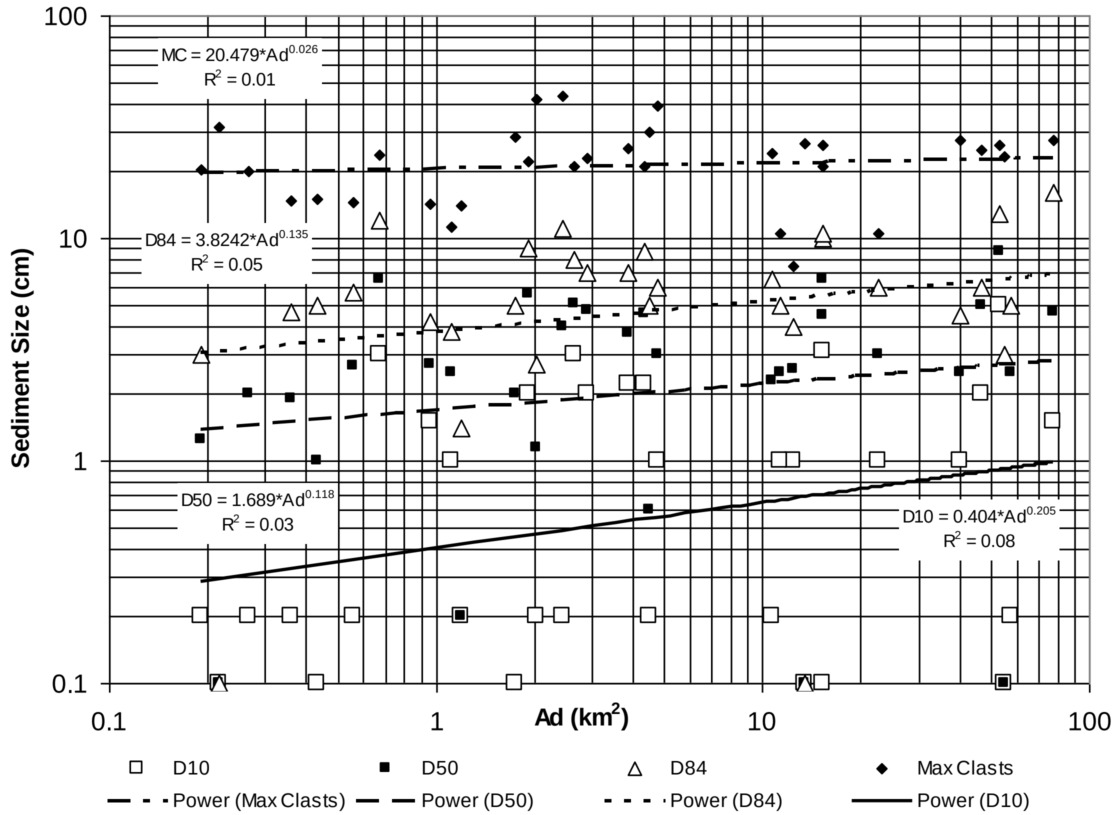


Figure 8.17 D10, D50, D84 and Max clast bed sediment restoration graph.

STATUS OF SOUTH DRY SAC STREAMS

Classification

The Rosgen Level II Classification was found to be somewhat useful for classifying SDS channels. The majority of SDS reaches surveyed fell under the classification of type C stream. The streams deviating from the C type classification were usually the result of anomalous geologic circumstances or position within the watershed. Stream reaches close to bedrock or with rock outcroppings display disproportionate cross-sectional areas (usually larger) in relation to their respective drainage area. The streams affected by watershed position were the confluence site (34) and a reach (site 22) located a few hundred meters from the watershed divide. The confluence site (surveyed approximately 50 meters from the Little Sac River) displayed disproportionate width:depth ratios in relation to the upstream geometry of nearby main stem reaches. Site 22 displayed massive cross-sectional area in relation to its drainage area. However this is most likely due to enormous amounts channel altering discharge from the upstream parking lots and development. Additionally, the other reaches not in agreement with the C classification seem to be a product of recent land-clearing or bedrock influence.

Urban Influence

Clear evidence of the influence of urban land-use on channel morphology does not appear conclusive. Although some trends seem to suggest rural channels have smaller bankfull cross-sectional geometries and more stable bedform. Recent land-use change (i.e. clearing for developments and roads) in rural areas may have the most bearing on channel morphology changes. This seems to be manifested as fresh gravel being introduced into channels, thereby changing cross-sectional area and bedform features. It also appears that once the gravel moves out of the system, channel geometry reestablishes itself. This may be why many urban reaches without recent sub-basin development, and that possess stable riparian vegetation, plot close to rural channels of comparable drainage area. Additionally, the high clay content in the SDS soils gives banks greater resistance to erosive forces. This could enable the cross-sectional areas of both urban and rural channels to remain relatively intact, even with moderate increases in discharge and stream power. Moreover, it is possible that rural channels are still showing disturbance morphology related to land clearing and row cropping in the past. Historical overbank sedimentation up to 1 m thick has been observed in cut bank exposures as evidence of geomorphic influence.

Bankfull versus Total Channel

Most of the reaches surveyed in the SDS have bankfull indicators positioned below elevations equal to the valley floor. Nearly all channels possess a relatively narrow meander belt, referred to in this study as a total channel. Within this total channel there exists the bankfull channel, most occupying roughly 25-50% of the total channel cross-sectional area (100% in several cases). Episodes of accelerated historical overbank deposition along SDS channels may be contributing to the vertical development of the incised form. Therefore, it is not completely understood if SDS channels are truly incised since obvious indication of bed elevation changes are not always present in 2nd order streams or larger. If system-wide incision has occurred in these streams, then it is on the order of <0.5 meters in most cases.

Channel Discharge Capacity

Bankfull channels for both urban and rural channels do not appear adequate to contain 1.5-2 year discharges when compared to discharge estimate equations. Furthermore, the capacity of the total channel is adequate to contain the 2-year discharge estimates in about half of the urban and rural total channels. Dominant discharge, which is capable of eroding and depositing bed load and channel-forming, is on the order of the 1-year flood magnitude in these streams.

Bed Material

SDS streams change from mobile bed material into bedrock controlled beds within the same reach. Field descriptions of cross-sections also reveal that it is somewhat common for bedrock outcrops to be covered with a thin veneer of gravel in many survey reaches. Median and maximum clasts sizes are highly variable throughout the watershed, but may be greater in urban reaches. Slope/D50 ratio plots indicate that rural channels tend to have smaller median sediment sizes as slope increases.

Gravel Waves

Extensive gravel bar deposition (or waves) was detected in several main stem and 3rd order stream reaches of the SDS. Sites 35 (Ad=22.5 km^2) and 36 (Ad=57.4 km^2), both main stem survey reaches, are particular locations where gravel waves occur but are preceded by relatively stable reaches. These trends are similar to findings by Jacobson (1999) in other Ozark watersheds. Site 33 (Ad=11.3 km^2), a 3rd order stream, is another survey reach with a notable gravel wave. This reach, however, is downstream of a sizable golf course and apartment complex development that may be the source of the gravel influx. Recent land clearing may have caused erosion and dislodged the chert gravel within the soil, subsequently enabling storm runoff to carry the gravel into channels. Temporal monitoring of gravel wave passage downstream could give insight to the morphologic changes occurring in the watershed. Cross-sectional and bedform surveying after major discharge events is one approach to this issue. Documenting gravel wave migration and bedform changes can improve our understanding of the changes that occur during certain discharge events of various duration and magnitude. Additionally, pinpointing the sources of gravel should be examined. Gullying, surface erosion from construction and floodplain/bed erosion may all be contributing to gravel introduction into channels.

CHAPTER 9

CONCLUSIONS

The South Dry Sac Watershed has undergone many changes since European settlement began. Land in the watershed was first cleared for agricultural and followed by the encroachment of Springfield urbanization. The purpose of this study was to quantify the physical properties of streams and describe the influence of land-use on stream channel morphology and discharge characteristics of the South Dry Sac Watershed. The results of this study indicate that urban channels have slightly different morphologies when compared to rural channels.

The primary conclusions of this study are:

1. Restoration guidelines and equations outlined in this study will provide a basis for channel restoration within the Springfield Plateau and degraded channels of the South Dry Sac.

Data, equations and guidelines are offered in this study for two purposes. First, findings are discussed to provide watershed managers with an understanding of fluvial geomorphology processes within the South Dry Sac Watershed. Second, data collected in the South Dry Sac is analyzed and transformed into equations and guidelines to provide geomorphologists and watershed managers with a set of equations that describe channel morphology to augment stream restoration work.

2. The Rosgen Level II classification is useful for South Dry Sac channels when the variance for sinuosity and other "continuum of variables" allowances are utilized.

Most South Dry Sac channels have low sinuosity (<1.2). The Rosgen stream classification worked for the low sinuosity South Dry Sac streams when the +/- 0.2 units allowance for sinuosity was employed. Most channels were determined to be type C streams, or more specifically C4. The finding was in general agreement with another study conducted in an adjacent watershed (Martin 2001). The C stream type is defined as a "slightly entrenched, meandering, gravel-dominated, riffle-pool channel with a well developed floodplain" (Rosgen 1996). Most channels were deemed to be moderately to slightly entrenched with low sinuosity and high width:depth ratios. Only six of 36 reaches were classified as A, B and F types. Watershed position (wide alluvial valley near a confluence) and recent land-use changes (vegetation removal followed by gravel being introduced into channels) seem to be responsible for these reaches deviating from the C type.

3. Urban bankfull channel cross-sectional area is slightly larger than rural channels. Conversely, rural total channel cross-sectional area is slightly larger than urban total channels.

Scatterplot analysis indicates that urban bankfull channels are slightly wider (10%) than rural channels. Similarly, urban bankfull channels seem to be slightly deeper (10%) than rural channels. Further field investigation is needed to determine if channel incision is responsible for present form. Bankfull cross-sectional area is a product of width and mean depth; therefore urban channels have greater (15-20%) cross-sectional areas than rural channels. In contrast, cross-sectional areas of rural channels are greater than urban total channels due to wider meander belts and higher sinuosity.

4. Urban channel longitudinal profiles display lower residual pool depths than rural channels.

Rural channels generally have deeper residual pool depths than urban channels. Scatters plots also indicate that rural channels have greater riffle-to-riffle spacing and greater pool-to-pool spacing than urban channels.

5. Channel planform differences occur as greater meander amplitudes and higher sinuosity in rural channels.

Sinuosity for rural channels tends to be greater than urban in channels draining less than 10 km^2. Likewise, meander amplitudes for rural channels appear greater than urban channels. Meander wavelengths for both rural and urban channels are highly variable and no strong evidence suggests any difference between rural and urban channels.

6. Discharge estimates derived from rural and urban regression equations differ significantly from calculated bankfull discharges for South Dry Sac channels. No differences exist between urban and rural stream power trends.

The calculated bankfull discharges (from Manning's *n*, velocity, mean depth, width) for SDS channels are somewhat lower than estimated discharges derived from regional equations. Total channel discharges plotted closer to the regression equation estimates. Moreover, the role of karst and its influence on discharge are not well understood within the South Dry Sac. The losing reaches and numerous sinkholes may contribute to the disparity in discharge estimates and calculated bankfull discharge because of losses to sub-surface drainage.

Further investigation into the amount of runoff diverted into sinkholes and swallow holes is needed. Stream power plots indicate no differentiating spatial trends between rural and urban channels.

7. Further monitoring and research is considered necessary for gaining a temporal understanding of the effects of land use on channel morphology in the South Dry Sac Watershed.

Field data collection for this study took place over the course of about 1.5 years. Since the data collection phase has ended, several different bankfull events have occurred. Monitoring of cross-sectional geometry and bedform at triplicate sites may give insight into the changes that are occurring and have occurred since data collection has ended. Also, continued monitoring of several noted stable and unstable reaches will add to this study.

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Appendix A

Survey Reach Information

Site #	GPS Location Easting (UTM NAD 83 Zone 15)	GPS Location Northing (UTM NAD 83 Zone 15)	Section, Township-Range
1	473420	4125836	SE1/4 of SE1/4 Sec. 36, T30N R22W
2	474792	4125807	NW 1/4 of SE 1/4 Sec. 31, T30N R21W
3	476241	4126099	SW1/4 of NE1/4 Sec. 32, T30N R21W
4	475939	4125542	SE1/4 of Sw1/4 Sec. 32, T30N R21W
5	478348	4123829	NE1/4 Sec 5, T29N R21N
6	477793	4124252	NE1/4 Sec 5, T29N R21N
7	472433	4124262	NE1/4 Sec 3, T29N R22N
8	474075	4122288	SW1/4 Sec. 1, T29N R22W
9	472673	4122749	SW1/4 Sec. 2 T29N R22W
10	472909	4122531	SW1/4 Sec. 2 T29N R22W
11	480025	4123352	NE1/4 Sec. 4 T29N R21W
12	483261	4123508	NE1/4 Sec. 2 T29N R21W
13	483261	4123149	SE1/4 Sec. 2 T29N R21W
14	480474	4125050	NW1/4 Sec. 3 T29N R21W
15	480043	4125730	NE1/4 of SE1/4 Sec. 34 T30N R21W
16	480645	4126135	SE1/4 of NW1/4 Sec. 35 T30N R21W
17	475838	4122259	SW1/4 Sec. 7 T29N R21W
18	472455	4124428	NW1/4 Sec. 2 T29N R22W
19	472785	4124399	NW1/4 Sec. 2 T29N R22W
20	473181	4123814	NW1/4 Sec. 2 T29N R22W
21	472655	4122259	SW1/4 Sec. 2 T29N R22W
22	478832	4121697	SW1/4 Sec. 4 T29N R21W
23	475125	4123498	NW1/4 Sec. 1 T29N R22W
24	481253	4124527	NE1/4 Sec. 3 T29N R21W
25	481488	4121830	NE1/4 Sec. 3 T29N R21W
26	474467	4121830	SW1/4 Sec. 1 T29N R22W
27	477672	4124495	NE1/4 Sec 5, T29N R21N
28	476924	4123163	SW1/4 Sec. 5 T29N R21W
29	476023	4123070	Sw1/4 Sec. 6 T29N R21W
30	483197	4124858	NE1/4 Sec. 2 T29N R21W
31	471399	4126638	NE1/4 Sec. 35 T30N R22W
32	474703	4121828	SW1/4 Sec. 1 T29N R22W
33	478540	4124003	NE1/4 Sec 5, T29N R21N
34	471101	4126610	SE1/4 of NW1/4 Sec. 35 T30N R22W
35	478224	4124509	NE1/4 Sec 5, T29N R21N
36	472848	4125535	SW1/4 of SE1/4 Sec. 36 T30N R22W

Site #	Location Description
1	200 m downstream (W) of bridge on FR 151
2	150 m downstream (W) of bridge FR 159
3	down steep hill 50 m NE of intersection FR 88 and FR 165
4	200 m downstream (W) FR 165
5	150 downstream of Valley Water Mill Rd.
6	150 m upstream of intersection of Barnes and Valley Water Mill Rd.
7	200 m downstrem of Stage Coach
8	E of Campbell and W of Doling Park Circle drive, 100 m upstream of
9	Between Norton Rd. and I-44, 75 m upstream
10	50 downstream (N) of Evergreen
11	50 m downstream (W) of Ingram Mill Rd., parallel to Hwy 65
12	75 m downstream (W) FR 197
13	150 m SW of Grandview and FR 197
14	100 m S of Bluegrass Rd., Northwest of Hwy 65
15	200 m S of FR 88, behind house and barn
16	200 m N of FR 88, behind house
17	100 SE of church off National
18	150-200 m downstream of site 7
19	E/SE of site 18
20	100 m downstream (W) of Stage Coach, 1/4 mile W off Grant
21	50 m downstream (N) of Livingston E of Kansas Expwy
22	100 m downstream (N) of Kearney
23	25 m upstream (E) of Summit between Caravan and Snider
24	200 m W of FR 189
25	Trib. Of mainstem 75 m upstream of site 24
26	100 m upstream (SW) of intersection of Benton and Talmage
27	100 m downstream of bridge and USGS gage, below VWM
28	10 m E of Stewart St. between Smith and McClernon
29	100 m SW of Fremont and McClernon, 10 m upstream of big tree in
30	150 m downstream (W) of FR 197
31	200 m upstream of bridge on FR 141
32	150 m upstream (SE) of intersection Benton and Talmage
33	100 m upstream of bridge VWM Rd.
34	50 upstream of Little Sac and SDS confluence
35	200 m upstream of bridge (USGS gage) on Barnes Rd
36	About 400-500 m downstream of Site 1, 75 m downstream of rip-rap

Site #	Notes
1	SDS main stem, Lost Hill
2	SDS main stem
3	downstream of illegal dumping
4	SDS main stem
5	VWM trib.
6	Grandview Branch
7	Pea Ridge
8	Doling Park trib.
9	Dickerson Park Zoo trib.
10	in woodlot
11	New golf course
12	upper SDS main stem
13	In woodlot S of house
14	In woodlot
15	Swale in pasture below pond
16	adjacent to small pond
17	close to chainlink fence
18	Pea Ridge
19	Small trib. of Pea Ridge
20	Pea Ridge
21	in woodlot
22	Drive in theater
23	
24	SDS main stem
25	
26	
27	SDS main stem
28	Old golf course
29	
30	
31	
32	
33	
34	SDS main stem
35	SDS main stem
36	SDS mainstem, Lost Hill

Appendix B

Bankfull and Total Channel Cross-Sectional Geometry

Site#	Bankfull Width (m)	Mean Bankfull Depth (m)	Maximum Bankfull Depth (m)	W:D Ratio	Cross-sectional Area (m^2)
1	16	1.02	1.4	15.69	16.32
2	16	0.86	1.2	18.60	13.76
3	5.5	0.25	0.5	22.27	1.36
4	14.5	0.93	1.35	15.59	13.49
5	9.2	0.4	1.16	23.00	3.68
6	6.3	0.61	1.25	10.33	3.84
7	12.2	0.74	1.55	16.49	9.03
8	3.5	0.29	0.57	12.07	1.02
9	7.6	0.4	0.65	19.00	3.04
10	2.9	0.19	0.4	15.26	0.55
11	11.4	0.43	0.77	26.51	4.90
12	5.8	0.47	0.65	12.34	2.73
13	2.5	0.19	0.4	13.16	0.48
14	3.5	0.27	0.45	12.96	0.95
15	7.5	0.07	0.25	107.14	0.53
16	2.5	0.27	0.47	9.26	0.68
17	5.8	0.21	0.52	27.62	1.22
18	16.6	0.51	0.98	32.55	8.47
19	3	0.35	0.65	8.57	1.05
20	10.5	0.68	1.1	15.44	7.14
21	4.1	0.32	0.6	12.81	1.31
22	3.9	0.28	0.5	13.93	1.09
23	4.3	0.53	0.9	8.11	2.28
24	9.5	0.67	0.9	14.18	6.37
25	6.1	0.75	0.9	8.13	4.58
26	3.6	0.23	0.48	15.65	0.83
27	13.5	0.94	1.3	14.36	12.69
28	4.8	0.4	0.78	12.00	1.92
29	5	0.18	0.48	27.78	0.90
30	5.7	0.2	0.62	28.50	1.14
31	16.6	0.94	1.2	17.66	15.60
32	7.8	0.42	0.72	18.57	3.28
33	6.5	0.51	0.9	12.75	3.32
34	35	0.5	1.1	70.00	17.50
35	15.3	0.83	1	18.43	12.70
36	13	0.52	0.9	25.00	6.76

Site #	Total Channel Width (m)	Total Channel Mean Depth (m)	Total Channel Maximum Depth (m)	W:D Ratio	Total Channel Cross-sectional Area (m^2)
1	18.8	1.57	2.22	11.97	29.52
2	32.5	1.15	2.41	28.26	37.38
3	11	0.47	0.96	23.40	5.17
4	18	1.44	2.14	12.50	25.92
5	9.4	0.43	1.16	21.86	4.04
6	6.3	0.71	1.26	8.87	4.47
7	15.5	0.75	1.74	20.67	11.63
8	6.4	0.24	0.68	26.67	1.54
9	9.2	0.45	0.85	20.44	4.14
10	4.3	0.34	0.65	12.65	1.46
11	11.4	0.43	0.77	26.51	4.90
12	8	0.83	1.3	9.64	6.64
13	5.3	0.3	0.7	17.67	1.59
14	7.4	0.22	0.59	33.64	1.63
15	9	0.08	0.26	112.50	0.72
16	5.7	0.3	0.78	19.00	1.71
17	7.2	0.18	0.56	40.00	1.30
18	30.4	0.84	1.74	36.19	25.54
19	3	0.37	0.65	8.11	1.11
20	11.1	0.74	1.18	15.00	8.21
21	7.5	0.55	1.15	13.64	4.13
22	6.6	1.17	1.89	5.64	7.72
23	6.75	0.71	1.51	9.51	4.79
24	16	1.64	2.58	9.76	26.24
25	9.7	1.13	2.14	8.58	10.96
26	9.8	0.18	0.57	54.44	1.76
27	25.5	1.01	1.97	25.25	25.76
28	4.75	0.4	0.78	11.88	1.90
29	20	0.18	0.68	111.11	3.60
30	16.5	0.32	1.22	51.56	5.28
31	20	1.7	2.49	11.76	34.00
32	9.8	0.39	0.83	25.13	3.82
33	11.7	0.81	1.64	14.44	9.48
34	39.1	1.33	2.13	29.40	52.00
35	21.4	0.89	1.53	24.04	19.05
36	22.5	1.2	2.11	18.75	27.00

Appendix C

Longitudinal Profile Measurements

Site #	Map Channel Slope	Map Valley Slope	Riffle or Field Slope	Mean Rif. Space (m)	Std. Dev. Rif. Spac. (m)	CV% Rif. Spac.	n Rif. Spac.
1	0.0041	0.0040	0.0097	23.7	9.6	40.6	2
2	0.005	0.0050	0.0027	47.0	4.2	9.0	2
3	0.0109	0.0109	0.0147	18.0	9.9	56.0	2
4	0.0038	0.0040	0.0061	58.0	41.9	72.2	2
5	0.0036	0.0036	0.011	14.1	4.9	34.7	5
6	0.0077	0.0077	0.0129	23.0	4.4	19.0	3
7	0.0071	0.0072	0.0071	22.7	1.2	5.1	3
8	0.0341	0.0340	0.0227	9.5	1.5	15.3	4
9	0.0071	0.0074	0.0063	8.0	2.9	35.9	3
10	0.0397	0.0384	0.0256	16.0	5.7	35.4	2
11	0.0086	0.0087	0.0117	25.0	7.1	28.3	2
12	0.0113	0.0117	0.0133	15.9	4.1	25.8	3
13	0.0156	0.0160	0.0123	14.4	4.6	32.0	3
14	0.0383	0.0393	0.0194	15.8	4.6	28.9	3
15	0.0152	0.0151	0.0092	0.0	0.0	0.0	0
16	0.0146	0.0151	0.0260	7.9	5.3	66.8	3
17	0.0189	0.0191	0.0153	6.6	0.8	11.8	3
18	0.0071	0.0072	0.014	38.5	19.1	49.6	2
19	0.0365	0.0366	0.0412	9.5	2.4	25.3	2
20	0.0086	0.0088	0.0030	20.0	0.0	0.0	1
21	0.0131	0.0134	0.0149	6.7	1.4	20.8	3
22	0.0685	0.0685	0.0597	6.0	2.5	40.6	3
23	0.0117	0.0119	0.0055	12.0			1
24	0.0070	0.0070	0.0042	32.0	3.5	11.1	2
25	0.0117	0.0118	0.0111	17.5	0.0	0.8	2
26	0.0199	0.0203	0.017	6.1	1.4	22.2	3
27	0.0047	0.0048	0.0036	45.0	2.0	4.4	2
28	0.0074	0.0080	0.0132	14.4	9.4	65.6	3
29	0.0085	0.0086	0.0111	0.0	0.0	0.0	0
30	0.0259	0.0264	0.0191	17.4	3.3	19.1	3
31	0.0032	0.0035	0.0025	93.5	17.7	18.9	2
32	0.0132	0.0132	0.0069	19.5	15.6	80.1	4
33	0.0057	0.0059	0.02	27.7	6.8	24.6	3
34	0.0032	0.0035	0.0029	47.0	19.7	41.9	3
35	0.0051	0.0051	0.0034	69.0	9.9	14.4	2
36	0.0038	0.0039	0.01	47.0	19.0	40.4	3

Site #	Mean Pool Spac. (m)	Std.Dv. Pool Spac. (m)	CV% Pool Spac.	n Pool Spac.	Riffle-pool spac. (m)	MAX Residual pool depth (m)
1	19.3			1	10.5	0.35
2	60.0			1	20	0.25
3	18.5	16.3	87.9	2	16	0.06
4	33.3	13.7	41.2	2	28.3	0.4
5	16.3	6.1	37.5	3	9	0.4
6	22.5	12.0	32.9	2	17.7	0.19
7	19.0	1.4	7.4	2	12	0.35
8	8.8	1.8	20.6	4	7.6	0.08
9	8.7	5.2	59.7	2	4.2	0.09
10				1	0	0
11					0	0
12	13.8	6.6	47.8	2	12.3	0.21
13	14.9	4.1	27.5	2	11.1	0.16
14	17.0	4.2	25.0	2	14.5	0.12
15					0	0
16	7.8	3.2	41.1	2	2.7	0.11
17	6.4	1.0	14.9	2	4.2	0.05
18	29.0	24.0	82.9	2	32.5	0.22
19	8.5	2.1	25.0	2	4.9	0.06
20	20.0			1	10	0.2
21	8.0	1.5	19.1	2	4.6	0.11
22	5.0	1.0	19.8	2	2.45	0.2
23	6.0			1	6	0.01
24	28.0			1	16.75	0.16
25	15.2			1	7.7	0.28
26	7.8	1.7	21.8	2	4.18	0.08
27	59.0	N/A	N/A	1	19.5	0.41
28	8.8	2.8	31.7	2	4.52	0.12
29				N/A	0	0
30	18.4	5.9	32.0	2	12.3	0.17
31	86.0			1	38.7	0.41
32	16.5	11.9	72.1	4	10	0.12
33	29.0	4.2	14.6	2	11.3	0.4
34	45.7	25.4	55.7	3	10.7	0.4
35	53.5	16.3	30.4	2	26.3	0.52
36	58.2	9.0	15.4	3	30.9	0.45

Appendix D

Uniform Sediment Data

Site #	D10 (cm)	D50 (cm)	D84 (cm)	Mean Max. Clast Size (cm)	Mean (cm)	Std. Dev. (cm)	CV%	Range (cm)	Min. (cm)	Max. (cm)
1	0.1	0.1	3.0	23.3	2.2	4.8	216.6	31.9	0.1	32.0
2	5.0	8.8	13.0	26.3	9.5	3.9	40.6	17.0	3.0	20.0
3	2.0	5.6	9.0	22.3	5.9	3.8	65.0	16.8	0.2	17.0
4	2.0	5.0	6.0	25.0	5.4	3.4	63.6	16.0	1.0	17.0
5	1.0	2.6	4.0	7.5	2.7	1.5	56.8	6.8	0.2	7.0
6	1.0	3.0	6.0	39.5	4.0	2.8	68.6	27.5	1.0	14.0
7	0.1	4.5	10.0	21.0	5.1	5.2	100.9	16.9	0.1	17.0
8	0.2	2.0	8.0	20.0	5.2	5.2	130.4	26.9	0.1	27.0
9	0.2	4.0	11.0	43.6	6.6	6.2	93.7	26.8	0.2	27.0
10	0.1	1.0	5.0	14.9	2.5	3.3	128.9	13.9	0.1	14.0
11	0.2	0.6	5.0	30.0	2.7	4.1	152.7	19.8	0.2	20.0
12	2.2	3.8	7.0	25.3	4.7	3.3	69.8	14.7	1.3	16.0
13	0.2	1.3	3.0	20.2	1.5	1.4	92.7	5.4	0.1	5.5
14	0.2	1.9	4.7	14.7	3.1	4.8	154.4	31.8	0.2	32.0
15	0.2	0.2	0.2	0.2	0.2	7.4	3.7	0.0	0.2	0.2
16	1.5	2.7	4.2	14.2	3.1	1.7	55.0	6.8	0.2	7.0
17	0.2	2.7	5.7	14.6	3.2	3.1	96.8	11.6	0.2	11.8
18	3.1	6.6	10.5	26.1	7.4	4.3	57.7	20.3	1.7	22.0
19	0.1	0.1	0.1	31.6	0.6	1.7	269.7	8.4	0.1	8.5
20	0.2	2.3	6.5	24.3	4.0	4.8	122.2	22.8	0.2	23.0
21	0.1	2.0	5.0	28.6	4.0	5.6	154.5	26.9	0.1	27.0
22	0.1	0.1	5.5	17.3	2.2	3.8	173.4	15.9	0.1	16.0
23	3.0	5.1	8.0	20.9	6.0	4.1	68.5	28.0	1.0	29.0
24	0.1	0.1	0.1	26.5	0.1	3.7	3.7	0.0	0.1	0.1
25	2.2	4.6	8.8	20.9	5.5	3.1	56.9	11.0	1.6	12.6
26	3.0	6.6	12.0	23.6	7.3	3.9	54.4	13.8	2.2	16.0
27	1.0	2.5	4.5	27.7	6.5	1.9	61.0	9.0	1.0	10.0
28	2.0	4.7	7.0	23.1	4.7	3.6	75.8	19.8	0.2	20.0
29	0.2	0.2	1.4	14.1	0.7	1.0	144.0	3.3	0.2	3.5
30	1.0	2.5	3.8	11.3	2.6	1.3	51.2	6.0	0.2	6.2
31	1.5	4.7	16.0	27.8	8.1	8.3	103.3	35.7	1.3	37.0
32	0.2	1.2	2.7	42.0	2.1	4.6	224.2	32.8	0.2	33.0
33	1.0	2.5	5.0	10.5	3.2	2.0	62.0	9.0	1.0	10.0
34	1.0	2.0	3.0	13.6	2.3	1.6	70.2	10.3	0.7	11.0
35	1.0	3.0	6.0	10.6	3.0	1.9	54.8	7.0	1.0	8.0
36	0.2	2.5	5.0		3.2	2.8	86.5	14.9	0.1	15.0