Geomorphic Equations and Methods for Natural Channel Design

By

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List of Symbols

Q = Discharge
CDA = Contributing drainage area
MAP = Mean annual precipitation
L = Length of the longest flow path from the watershed divide to outlet
W = Channel top width
D = Mean depth
V = Mean velocity
λ = Meander wavelength
y_{pool} = Maximum depth at a pool
y_{riffle} = Maximum depth at the riffle
$\overline{y}_{riffle}$ = Mean depth at the riffle
η = Sediment transport efficiency
G = Bed material transport rate
ρ = Density of water
S = Channel slope
F = Total fall in channel thalweg elevation over a reach
L_v = Valley length
p = Sinuosity
b = Bottom channel width
Gs = Specific gravity
d_{50} = Sediment size for which 50% of the bed material is finer
P = Wetted perimeter
m = Side slopes, defined as horizontal/vertical
R = Hydraulic radius
γ_w = Specific weight of water
γ_s = Specific weight of sediment
g_s = Sediment transport rate per unit width
g = Gravitation acceleration
n = Manning roughness coefficient
s = Scaling factor
V = Valley slope

<u>Subscripts</u>

bf = Bankfull
b = Bed
d = Design channel
ref = reference reach
m = match reach

Abstract

Natural channel design in river engineering is the philosophy and practice of designing stream channels by copying or mimicking the geomorphology of stable, self-formed streams. This dissertation presents methods and equations for incorporating the principals of natural channel design into river and stream engineering in Kansas. Data from 123 reference reaches in Kansas are used to develop these methods and equations. An analysis of 46 gaged reference reaches indicates that the return period of bankfull flow (annual maximum series), ranges from 1.01 to 1.7 years, with an average of 1.2 years. This is significantly lower than the 2-year flow commonly used by engineers in naturalistic river designs. An equation is developed that predicts the 1.2-year flow as a function of watershed drainage area, mean annual precipitation, and the length of the longest flow path in the watershed. This equation is developed using data from 67 gaged streams with drainage areas less than 30 mi^2.

Geomorphic measurements from the reference reaches are used to verify previously published relationships between bankfull discharge and bankfull width for streams with sand and gravel beds. A new relationship is developed demonstrating the relationship between bankfull discharge and bankfull width for streams with beds of cohesive clay. Equations are provided to predict the average meander wavelength from the bankfull width, and the pool depth from the depth at the adjacent riffle.

Three stream design methods are presented: the Kansas Analytical Method (KAM), the Analytical Reference Reach Method (ARRM), and the Scaled Geomorphic Method (SGM). All three methods are based on natural stream processes and geomorphology. All three methods incorporate the Manning equation for flow resistance and the Meyer-Peter and Muller equation for sediment transport but differ in their use of geomorphic measurements from reference reaches. KAM uses a hydraulic geometry width equation which was developed from many reference reaches. ARRM uses the sinuosity, pool-depth ratio, and meander-width ratio from a single reference reach. SGM calculates a scaling factor that can be used to copy and scale additional cross-sections (pools, runs, and glides, as well as riffles) and planform features from the reference reach. The development of KAM and ARRM is presented in previously published reports. This dissertation presents the development of SGM in detail.

KAM, ARRM, and SGM make a common assumption that the median size of sediment in the channel bed is an adequate surrogate for the entire gradation of bed sediments. The reasonableness of this assumption is verified by calculating the bankfull sediment transport capacity for seven ARRM designs. It is found that a channel designed for equilibrium transport of the median sediment size is reasonably designed for transport of the entire gradation of sediment sizes. The exception is when the median sediment size found on the bed is among the largest that are mobile at bankfull flow.

These geomorphic relationships, equations, and design methods combine traditional hydraulic engineering and fluvial geomorphology in unique ways to provide practical tools to stream designers in Kansas.

1.0 Introduction

This dissertation presents methods and equations for incorporating the principals of natural channel design into river and stream engineering. In this dissertation, the term “natural channel design” is used to mean the philosophy and practice of copying or mimicking the geomorphology of self-formed streams for stream design. Natural channel design has two goals: channel stability and proper ecological functioning. Channel stability is defined as little change in the average bed elevation, cross-sectional dimensions, and sinuosity over time. Stability is achieved in a river reach when the quantity of incoming sediment equals the quantity of outgoing sediment over time. As long as there are no trends or dramatic changes in watershed conditions, channel dimensions tend to fluctuate around average values in what has been called “dynamic equilibrium” (Leopold and Maddock 1953). Dynamic equilibrium is an essential prerequisite to achieving proper ecological function. The natural channel design philosophy disfavors habitat design for a single, target species. Rather, the stream is designed with geomorphic characteristics that are typical of natural streams in similar settings—conveying the proper discharge and possessing features such as naturalistic cross-sections, meander patterns, bed profiles, and floodplain connectivity. While a properly designed channel is necessary for optimal ecological function (NRCS 2007), there may be other factors, such as water quality, invasive species, and connectivity to other habitat that must be addressed for full ecological functioning of a river. This dissertation only addresses the design of the channel geometry.

Chapter 1 provides three examples of situations in which a natural channel design may be appropriate and a description of the data sources used for the subsequent analyses. Chapter 2 determines the return period of bankfull flow in Kansas streams and provides a design equation for bankfull flow based on watershed characteristics. Chapter 3 presents analysis and design guidance for the bankfull width, meander wavelength, sinuosity, and pool depth. Chapter 4 describes two major approaches to channel design: the analytical approach and the reference-reach approach. Chapter 4 also presents the key steps to two original design methods: the Kansas Analytical Method (KAM) and the Analytical Reference Reach Method (ARRM). Chapter 5 provides the development of a third original design method, the Scaled Geomorphic Method (SGM). Chapter 6 discusses how sediment gradations are generalized for river engineering applications and tests the validity of using the sediment size for which fifty percent of the bed material is finer (d_{50}) as the basis for design. Chapter 7 concludes the dissertation.

1.1 Engineering Scenarios Suitable for Natural Channel Design

Situations in which a natural channel design may be appropriate are many and varied. This section provides three examples pertinent to Kansas and Missouri: stream relocation in conjunction with Kansas Department of Transportation (KDOT) projects, bank stabilization to decrease sedimentation in Kansas federal reservoirs, and habitat creation on the Missouri River for endangered species.

1.1.1 Stream Realignment

KDOT occasionally modifies natural streams near roadways, bridges and culverts in order to increase highway and bridge capacity, update safety features on existing roads and bridges, and protect highway infrastructure from scour or erosion damage. At times, these projects necessitate the realignment of short reaches of natural streams.

When modifying natural streams in conjunction with transportation projects, KDOT must secure a permit from the U.S. Army Corps of Engineers and the Division of Water Resources of the Kansas Department of Agriculture. Permit applications are forwarded to state and federal environmental agencies, including the Kansas Department of Wildlife and Parks and the U.S. Fish and Wildlife Service, for review and comment as to the environmental impact of the proposed stream modification and the sufficiency of the proposed mitigation measures. Negative comments from these agencies can significantly delay permitting. The following comment on a request for a permit to perform a stream modification demonstrates dissatisfaction in the environmental community with traditional stream design methods:

> "We can confidently say that this is not a properly designed stream channel nor was fluvial geomorphology taken into account. We can make this statement as bedload and discharge are not usually properly determined within the current hydraulic models..." (Kansas Department of Wildlife and Parks, 2006)

In the past, flood conveyance was the principal design goal for a realigned channel, i.e. the 100-year water surface elevation in the realigned channel would not exceed the 100-year water surface elevation in the existing channel. Mitigation for environmental impacts was provided by planting native vegetation or through other means, but did not explicitly address the design of the realigned channel—how wide, how deep, or how sinuous. The environmental commenting agencies were concerned that channels designed for flood conveyance would be unstable and would supply only inferior aquatic habitat. Such a view has justification, as straightened streams have caused channel instability and a loss of biodiversity in other locations (Simon and Hupp 1986, Possardt and Dodge 1978).

A solution to KDOT's channel realignment problems is to incorporate the principles of natural channel design into their channel realignment projects, so that the realigned channels are stable and possess the natural geomorphic properties that supply diverse habitat. The Kansas Analytical Method and the Analytical Reference Reach Method, described in Chapter 4, were developed to fill this need.

1.1.2 Sedimentation in Federal Reservoirs

Kansas reservoirs are filling in with sediment, some at rates far exceeding those anticipated. Table 1.1 shows the loss in multi-purpose pool storage for several Kansas reservoirs as of 2010. As seen, these reservoirs are already significantly impacted by sedimentation.

Table 1.1. Loss of multipurpose pool water-storage capacity in selected Kansas federal reservoirs (Data Source: KWO 2010)

Reservoir	Year Multi-purpose Pool Filled	Original Storage Capacity (ac-ft)	Estimated 2010 Storage Capacity (ac-ft)	Reduction in Storage
Kanopolis	1948	73,200	47,968	34.5%
Fall River	1949	30,401	18,869	37.9%
Toronto	1960	27,320	15,010	45.1%
Tuttle Creek	1963	425,312	241,747	43.2%
John Redmond	1964	82,230	48,010	41.6%
Pomona	1965	70,603	55,340	21.6%
Perry	1970	243,220	196,394	19.3%

In Kansas, channel banks have been found to be a significant, and often times predominant, source of sediment to the reservoirs (Juracek and Ziegler 2007). Similar conclusions have been found in other regions as well (Nagle et al. 2007, Brigham et al. 2001, Lefrançois et al. 2007). The annual cost of dredging the major Kansas reservoirs to offset sedimentation has been estimated at $75 million (Krug 2009), an enormous sum for a state such as Kansas. Stream instability following channelization, specifically channel incision and widening, increases the rate of sedimentation beyond the rates observed in stable streams (Simon 1989). Government water agencies have started looking at stream restoration as a cost-effective option to slow down the rate of storage loss due to sedimentation. This is another situation in which natural channel design may be warranted.

1.1.3 Habitat Creation on the Missouri River

In 1945, Congress charged the Army Corps of Engineers to construct the Bank Stabilization and Navigation Project (BSNP) on the Missouri River (Ferrell 1996). This project transformed the river from a wide, braided, constantly changing channel to a deep, narrow, high-velocity, "self-scouring" channel with a fixed location. This transformation made the river unsuitable for fish and bird species uniquely suited to the pre-modified Missouri River environment, including the federally endangered pallid sturgeon, least tern, and piping plover. In response, Congress authorized the Missouri River Recovery Program, an ongoing effort by the U.S. Army Corps of Engineers and other federal agencies to recover these endangered species. A critical component to the recovery program is the creation of 20-30 acres of shallow-water habitat per mile of river (USACE 2004). Because of the many competing uses for water in the main channel, habitat restoration is being accomplished in many places through the creation of side channels or "chutes". These chutes represent another opportunity for natural channel design.

Figure 1.1. A restored chute on the Missouri River in Saline, MO (Source: USACE 2004)

1.2 Additional Uses for Natural Channel Design

Transportation river relocations, sedimentation in reservoirs, and Missouri River habitat creation are just three local examples where the principles of natural channel design can aid engineers in solving real problems. Additional situations that could involve a natural channel design include protecting utility lines and other buried infrastructure, raising a water table that has been drawn down due to channel incision, improving fish populations for recreational fishing, improving water quality, and creating scenic river corridors in housing or retail developments. Natural channel design methods have been developed in other regions and are used extensively in these types of river engineering situations. However, natural channel design methods include a strong empirical component; they lead to the design of channels that mimic the natural channels in the region where the methods were developed. A definite need exists for methods to design streams typical in Kansas. Of necessity, these methods must be developed using data from Kansas natural channels.

1.3 Data Sources

The analyses in this dissertation are based on an extensive database of geomorphic and hydrologic data compiled for K-TRAN KU-09-4 (McEnroe et al. 2009). This database, known as the Kansas Reference Reach Dataset, includes data for 131 stable stream reaches in Kansas. These 131 streams were selected from two studies: *Geomorphic Assessment and Classification of Kansas Riparian Systems* (Emmert and Hase 2001) and *Assessment, Geomorphic Definition, and Documentation of Kansas Stream Corridor Reference Reaches* (KRTT 2006). These studies were funded by the Environmental Protection Agency and the State Conservation Commission, respectively. The central goal of these studies was to gain insight into proper stream functioning to aid in stream corridor management decisions. Figure 1.2 displays the location of these streams.

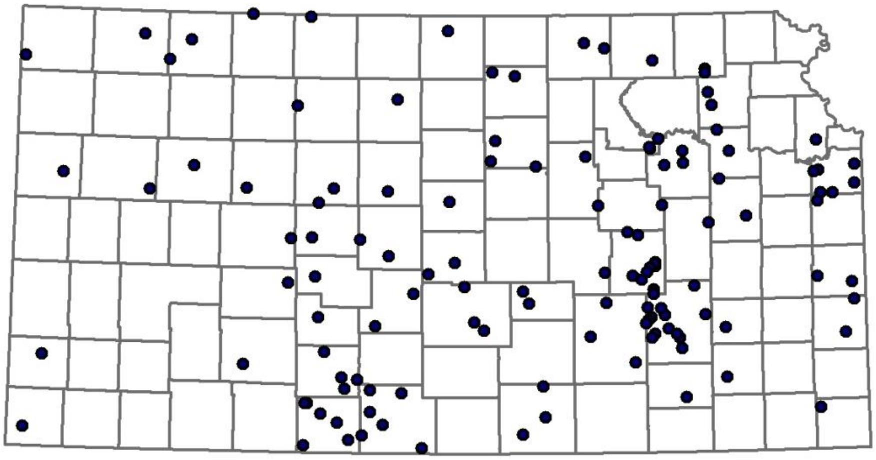

Figure 1.2. Locations of Stream Surveys

These stream data were collected according to the procedures established by David Rosgen (1996) with the intent that the streams included could be used as reference reaches in a Rosgen natural channel design. Useable information not normally reported in a Rosgen reference reach survey was extracted from the raw geomorphic survey data and additional watershed information is also included in the Kansas Reference Reach Dataset. Table 1.2 presents a summary of the stream data.

Table 1.2. Summary of data in the Kansas Reference Reach Dataset

	# of Reaches
Total	123
Gaged	74
Ungaged	49
Rosgen Stream Type	
B	14
C	67
E	42
Dominant Channel Material	
Bedrock	8
Cobble	2
Gravel	45
Sand	42
Silt/clay	26

Table 1.3 lists the information in the dataset. The complete dataset is provided in Appendix B. The following chapters make use of data from these natural streams to produce equations and methods for the design of naturalistic channels in Kansas.

Table 1.3. Data in the Kansas Reference Reach Dataset

ID
Stream name
County
Township
Range
Section
Latitude
Longitude
USGS quadrangle
USGS gage#
USEPA ecoregion
Predominant bed material
Rosgen level 2 stream type
Rosgen valley type
Sinuosity
Maximum depth (ft)
Area (ft^2)
Wetted perimeter (ft)
Mean depth (ft)
Width/depth ratio
Average adjacent pool depth
Flood-prone width (ft)
Entrenchment ratio
Sinuosity
Meander wavelength (ft)
Radius of of curvature (ft)
Belt width (ft)
Bankfull slope (ft/ft)
Drainage area (mi^2)
Mean annual precipitation (in)
Longest flow path (miles)
Excel file with original survey data

Chapter 1 References

Brigham, M, C. McCullough, and P. Wilkinson (2001). "Analysis of suspended sediment concentrations and radioisotope levels in the Wild Rice River basin, northwestern Minnesota, 1973-98." *Water Resources Investigation Report 01-4192,* U.S. Geological Survey.

deNoyelles, F. and M. Jakubauskas (2008). “Current state, trend, and spatial variability of sediment in Kansas reservoirs.” *Sedimentation in Our Reservoirs: Causes and Solutions*, Kansas State University.

Emmert, B.E. and K. Hase (2001). *Geomorphic Assessment and Classification of Kansas Riparian Systems*. Prepared for the Environmental Protection Agency under contract No. CD 997520-01.

Ferrell, John (1996). *Soundings: 100 years of the Missouri River navigation project.* U.S. Army Corps of Engineers, Kansas City, MO.

Juracek, K. E. and A. C. Ziegler (2007). “Estimation of sediment sources using selected chemical tracers in the Perry Lake and Lake Wabaunsee basins, northeast Kansas.” *Scientific Investigations Report 2007-5020,* U.S. Geological Survey.

KRTT (2006). *Assessment, Geomorphic Definition, and Documentation of Kansas Stream Corridor Reference Reaches,* Kansas Riparian Technical Team. Prepared for the Environmental Protection Agency and the Kansas State Conservation Service.

Krug, Nick (2009). Quote from Early Lewis, Director of the Kansas Water Office in "Sedimentation threatens sources of drinking water, flood control." *Lawrence Journal World,* Jan 27, 2009. Lawrence, KS.

Lefrançois, J., C. Grimaldi, et al. (2007). "Suspended sediment and discharge relationships to identify bank degradation as a main sediment source on small agricultural catchments." *Hydrological Processes* 21(21): 2923-2933.

Leopold, L. B. and T. J. Maddock (1953). "The hydraulic geometry of stream channels and some physiographic implications" *Professional Paper 252*, U.S. Geological Survey.

McEnroe, B. M., C. B. Young, and J. E. Shelley (2009). "Stream realignment design using a reference reach." *KTRAN: Report No. KU-09-4*, Kansas Department of Transportation.

Nagle, G. N., T. J. Fahey, et al. (2007). "Variations in sediment sources and yields in the Finger Lakes and Catskills regions of New York." *Hydrological Processes* 21(6): 828-838.

Kansas Department of Wildlife and Parks (2006). Comment on KDOT permit request.

Possardt, E. E. and W. E. Dodge (1978). "Stream channelization impacts on songbirds and small mammals in Vermont." *Wildlife Society Bulletin* 6(1).

Rosgen, D. (1996). *Applied River Morphology*. Pagosa Spring, Colorado, Wildland Hydrology.

Simon, A. (1989). "The discharge of sediment in channelized alluvial streams." *Journal of the American Water Resources Association* 25(6): 1177-1188.

Simon, A. and C. Hupp (1986). "Channel evolution in modified Tennessee channels." *Proceedings of the Fourth Federal Interagency Sedimentation Conference* : March 24-27, 1986, Las Vegas, Nevada.

USACE (2004). "Missouri River Mitigation Project." Retrieved August 4, 2009, from http://www.nwk.usace.army.mil/projects/mitigation/introduction.htm. U.S. Army Corps of Engineers.

2.0 Design Discharge

2.1 Bankfull Discharge

Stream discharge is the most significant driving factor in fluvial geomorphology. Natural streams experience a range of flows from drought flows to typical base flows to extreme floods. While low flows and rare floods are important design considerations, the bankfull discharge, defined here as “the discharge that fills a stable alluvial channel up to the elevation of the active floodplain” (FISRWG 2001), is the most important for natural channel design.

The term “bankfull discharge” has two distinct meanings, which creates considerable confusion (Stream Notes 1993, Shelley 2010). One use of the term implies the flow in a river at the level of the banks. Geomorphologists that study incising rivers may use this definition to say that a severely incised channel has a very large bankfull discharge corresponding to a rare flood. A second definition is the discharge capacity of a self-formed channel that is stable and well-connected to its floodplain. This is the definition used in natural channel design. A geomorphologist who says “the bankfull discharge is well below the banks in this incised channel” is using the second definition.

In a channel design, bankfull discharge by the first definition can be anything the designer specifies. However, by the second definition, bankfull discharge is something that nature specifies for a given location. A correctly designed channel conveys the natural bankfull discharge (definition 2) at the top of the banks.

On a gaged stream, the bankfull discharge at the gage location can be obtained using a stage-discharge rating curve, provided the bankfull stage can be determined. The bankfull flow for an ungaged stream reach can be calculated by hydraulic or hydrologic methods. If the project reach or an adjacent upstream or downstream reach is not incised, the bankfull flow can be estimated using hydraulic relationships such as Manning's equation. If adjacent reaches are incised or are otherwise unreliable for determining bankfull flow, a regional regression equation which correlates watershed characteristics to the bankfull discharge can be used.

Rosgen (1993) recommends that the bankfull discharge be found using a "regional curve"—a simple regression equation of the following form (FISRWG 2001):

$$Q_{bf} = a\ CDA^{b} \tag{2.1}$$

where Q_{bf} = bankfull flow

CDA= contributing drainage area

a and b are constants determined through regression

This form of equation implies that the bankfull flow is a function of drainage area only—an obvious simplification that ignores important watershed factors such as precipitation, land use, and soil types. To reduce the variation, and hence the importance, of these additional factors, streams are often grouped together in areas with similar climate, geology, and topography known as hydrophysiographic regions. This method can be used successfully, provided that the following conditions are met: 1) precipitation and geology are similar over the hydrophysiographic region, and 2) sufficient stream data are available to allow for statistical significance after available stream data are divided into regions. Regional curves have been developed by various organizations for many hydrophysiographic regions (Cinotto 2003, Chaplin 2005, Sweet and Geratz 2007, Emmert and Hase 2001, and others).

Where hydrologic and geologic conditions are not similar over large regions, regional curves may not be appropriate. Separate regional curves for distinct geologic conditions or multivariate regression equations that include additional terms may be more useful (Keaton et al. 2005).

A second approach to determining the design bankfull discharge is to use the discharge with a specific return period, based on the annual maximum series. Simon et al. (2004) recommends this approach for geomorphic analysis because it removes the ambiguity and subjectivity inherent in selecting the bankfull stage. Using a flow with a specific return period as the design discharge is attractive because flood-frequency regression equations for ungaged streams have already been developed by the USGS in most states and are familiar to engineers.

Pioneering work by Wolman and Leopold (1957) finds the annual maximum series return period for bankfull flow to be less than 5 years where the floodplain level is easily discernible. They report that where a geomorphic floodplain is absent or difficult to locate, the bankfull flows have higher return periods, such as 11 or 20 years, indicating that the geometries of those channels may be remnants of a large flood rather than the normal bankfull flows. Twenty-two of the 37 rivers they analyze have a bankfull flow with a return period less than 1.5 years.

Numerous additional studies show similar results. Most of the bankfull flows are smaller than the two-year flow, although outliers have been reported (Williams 1978). Bankfull flows with extremely high return periods may actually correspond to abandoned terraces above incised channels. The general consensus is that on the average, the bankfull flows for perennial rivers have return periods less than two years (Soar and Thorne 2001). Because of inherent variability, approximations for bankfull flow based on a return period should be calibrated with local data if they are to be used (Castro and Jackson 2001).

Many engineers favor using the two-year discharge because this is the smallest return period discharge for which regional regression equations are available in most states. However, the two-year discharge is much larger than the bankfull discharge in many natural streams. Engineers accustomed to flood mitigation designs may think using the two-year flow is a conservative design practice. This is not the case for stream stability. A channel designed for too large a flow is oversized, not over-designed. A channel that is deepened to accommodate a larger discharge will experience higher maximum velocities, which can induce channel incision and bank failures. A channel that is over-widened to accommodate a larger discharge may experience deposition and undesirable planform changes. For stable stream design, designing for a larger-than-natural flow is not a conservative design practice.

2.2 Bankfull Discharge in Stable Kansas Streams

This section presents an analysis of bankfull flow in gaged Kansas streams and provides a multivariate regression equation that predicts bankfull flow based on watershed characteristics. This research has been published in McEnroe et al. (2008) and Shelley et al. (2009). The analysis followed these steps:

(1) The bankfull flow was determined for 46 gaged Kansas streams.

(2) The return periods of bankfull flows in those streams were calculated.

(3) Based on step (2), the average return period for bankfull flow was determined.

(4) A multivariate regression equation was developed to predict the flow with the return period determined in step (3) as a function of watershed characteristics.

2.2.1 Determining Bankfull Flow

The 46 gaged streams used in this analysis were surveyed and the bankfull stage was determined by Emmert and Hase (2001) using Rosgen's (1996) stream assessment protocols. USGS stage-discharge rating curve information was used to calculate a flow for each bankfull elevation.

The return period of each bankfull flow was determined using USGS (Rasmussen and Perry 2000) estimates for the 2-year, 5-year, and 10-year flows. Extrapolation below the 2-year discharge was accomplished assuming a log-Pearson type 3 distribution. (All return periods referenced in this section are based on the annual maximum series and represent the reciprocal of the annual probability of exceedance). These flows are provided in Appendix A. A histogram of the return periods for bankfull flow is shown in Figure 2.1.

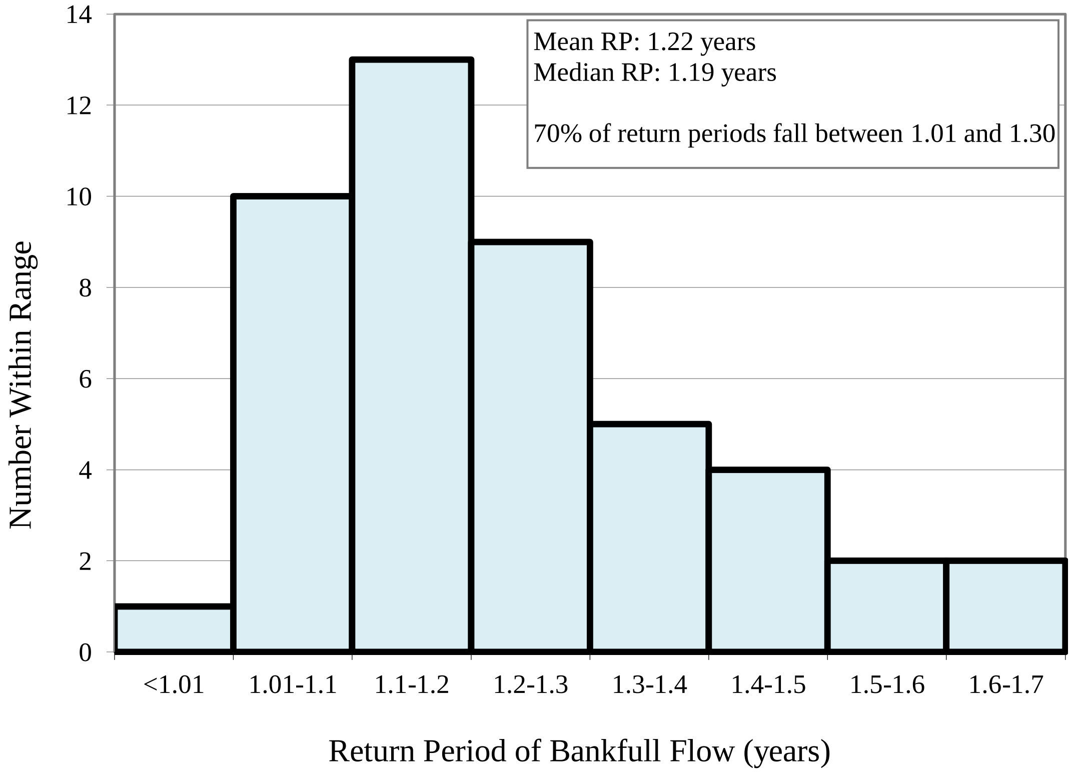

Figure 2.1. Histogram of return periods of bankfull flow for 46 Kansas reference reaches

The return periods range from less than 1.01 years to 1.7 years, with both a median and a mean return period of 1.2 years. The return period of bankfull flow appears to be independent of geographic location and of channel material, as shown in Figure 2.2. In addition, the return period of bankfull flow is independent of drainage area (see Figure 2.3). This suggests that the 1.2-year discharge is an appropriate approximation for bankfull flow for design purposes in Kansas.

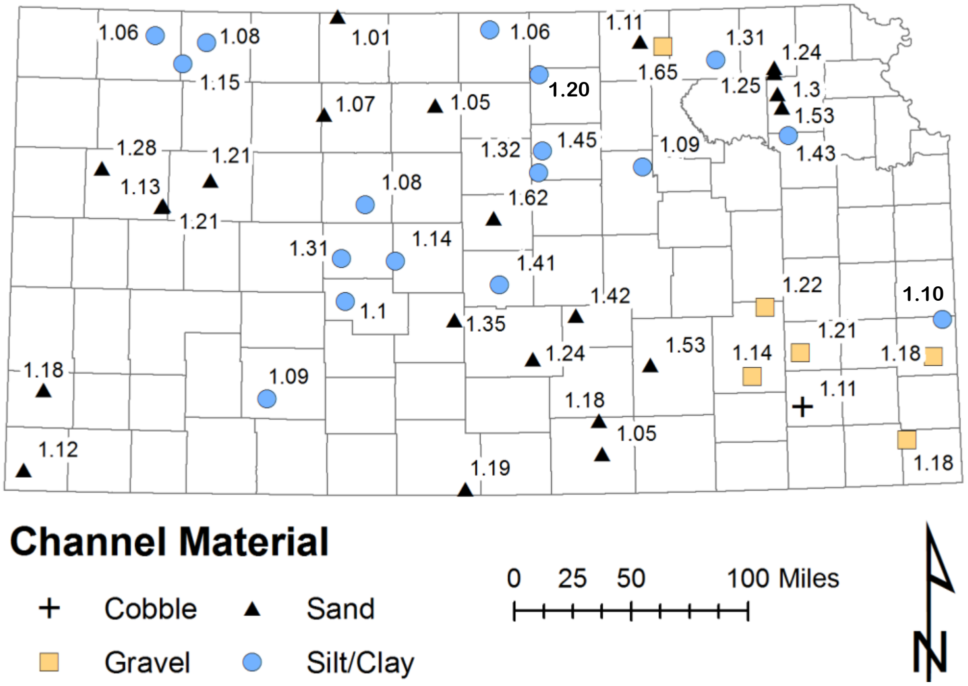

Figure 2.2. Return period (in years) of bankfull flow at selected USGS stream gages

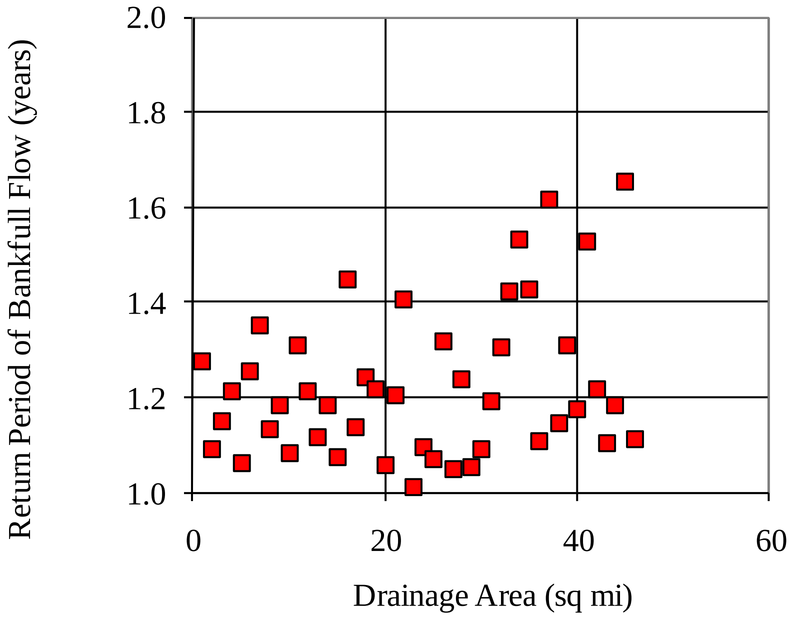

Figure 2.3. Non-dependence of return period on drainage area

2.2.3 Regression Equation for the 1.2-year Discharge

As seen in Figure 2.3, the majority of the streams in this data set are far larger than streams that are typically candidates for realignment or restoration. Only four of the 46 streams have drainage areas less than 30 square miles, whereas 34 of the 46 streams have drainage areas of over 500 square miles. In order to create a valid equation for the 1.2-year discharge, data from small streams were required.

A data set with extensive hydrologic and watershed data for 72 gaged Kansas streams with drainage areas less than 30 square miles was used to develop a regression equation for the 1.2-year discharge. These streams are similar in size to streams likely to be considered for realignment and restoration. McEnroe and Young (2007) use this data set to derive flood frequency estimates for rural, ungaged streams in Kansas. The methodology for stepwise linear regression used by McEnroe and Young (2007) was employed here to develop a predictive equation for the 1.2-year discharge. Five stations from the dataset were removed because they have $Q_{1.2}$ values equal to zero.

Table 2.1 lists the five excluded stations. Four of these stations are located in western Kansas, where low precipitation and quick-draining soils cause occasional zero-flow years. The fifth station excluded from the analysis is a small watershed (1.62 mi^2) located in Washington County, Kansas. Appendix A lists the stations used in the regression analysis.

Table 2.1. Stations with $Q_{1.2}$ equal to zero

Site #	Station name	County	CDA (mi^2)	MAP (in)
6884100	Mulberry Creek tributary near Haddam	Washington	1.62	30.1
6846200	Beaver Creek tributary near Ludell	Rawlins	10.55	20.5
6873300	Ash Creek tributary near Stockton	Rooks	0.88	23
7141600	Long Branch Creek near Ness City	Ness	29.58	21.4
7141800	Otter Creek near Rush Center	Rush	17.2	22.9

Table 2.2 lists the predictors that were considered in the regression analysis. Details on the determination of these watershed characteristics can be found in McEnroe and Young (2007).

Table 2.2. Watershed characteristics used in the regression for $Q_{1.2}$

Symbol	Watershed Characteristic	Units
CDA	Contributing Drainage Area	mi^2
Sh	Basin Shape Factor	--
Sl	Average Slope of Main Channel	ft/mi
SP	Generalized Soil Permeability	in/hr
CN	NRCS Runoff Curve Number	--
i_2	2-year Rainfall Intensity for Duration t_c	in/hr
MAP	Mean Annual Precipitation	in
MAE	Mean Annual Lake Evaporation	in
MAD	Mean Annual Precipitation Deficit	in
L	Length of the Longest Flow Path	mi

Forward stepwise linear regression analysis found that contributing drainage area, mean annual precipitation, and the length of the longest flow path were the most significant predictors of the $Q_{1.2}$. This led to Equation 2.2:

$$Q_{1.2} = 0.00258\,\mathrm{CDA}^{1.26}\,\mathrm{MAP}^{3.17}\,\mathrm{L}^{-1.10} \qquad (2.2)$$

where $Q_{1.2}$ is in cfs. The mean annual precipitation, MAP, is determined from Figure 2.4. The length of the longest flow path, L, is measured in miles along the channel from the watershed outlet to the drainage divide. The standard error of estimate is 0.217 log units (-39%, +65%) and the coefficient of determination, R^2, is 0.827. This standard error and coefficient of determination are similar to previously published equations for 2, 5, 10, 20, 50, and 100-year discharges (McEnroe and Young 2007).

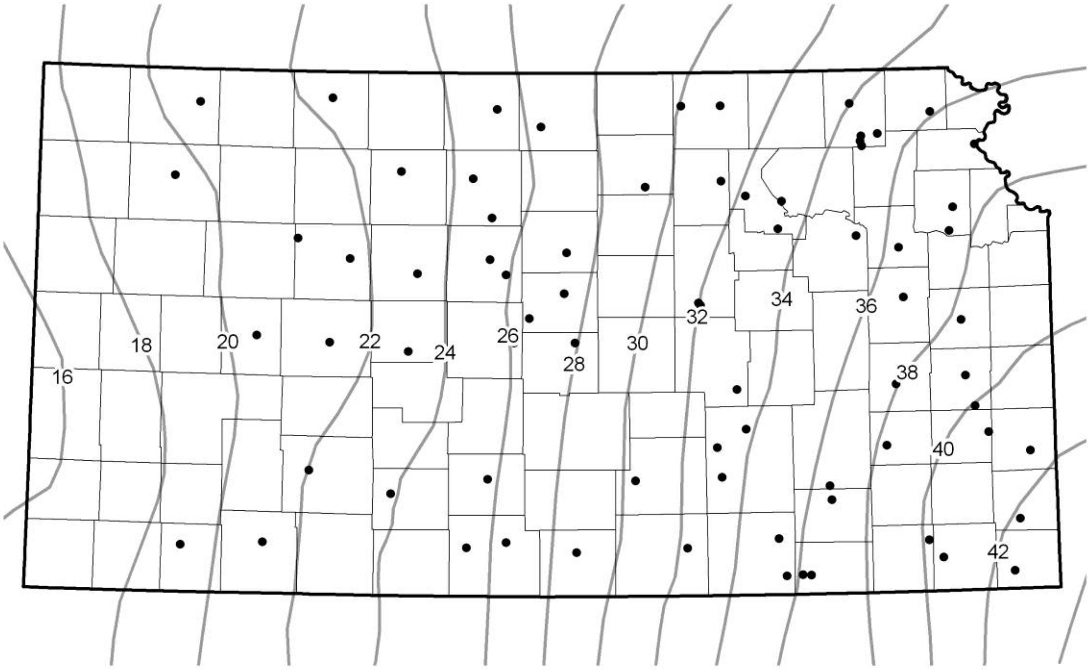

Figure 2.4. Mean annual precipitation (inches) in Kansas along with gages used in regression analysis (Source: McEnroe et al. 2007)

The bankfull discharge for small rural streams in Kansas can be approximated by the 1.2-year discharge, estimated from Eq. 2.2. This equation can be used to determine the discharge capacity for a natural channel design. However, three limitations should be kept in mind. First, the use of local data to derive Eq. 2.2 makes it applicable to Kansas streams only. Second, this equation may not be applicable in stream systems that regularly experience zero-flow years, as is the case for some streams in western Kansas. Finally, Eq. 2.2 should not be applied to urban or regulated streams because the return period analysis and the regression analysis used only rural, unregulated streams.

2.2.3 Hydraulic Calculation of Bankfull Flow

A second way to calculate bankfull flow is to use a flow-resistance equation such as Manning's equation. Flow-resistance equations require cross-section dimensions up to the bankfull stage, the longitudinal slope of the bankfull channel, and additional data to estimate channel roughness. Hydraulic equations are potentially more accurate than hydrologic methods because they calculate bankfull flow at the restoration site based on site-specific geomorphology. However, the accuracy of the hydraulic calculations hinges on the correct determination of the bankfull stage, which can be difficult and unreliable in incised streams—the types of streams most in need of restoration (Johnson and Heil 1996). Furthermore, the accuracy of the flow calculation depends on the accuracy of the estimate of the channel roughness coefficient, such as the Manning 'n' value. Discussion of flow-resistance equations suitable for natural streams is not provided here, but can be found in NRCS (2007).

2.3 Effective Discharge

Bankfull discharge is the most common, but not the only discharge pertinent to river restoration design. The effective discharge, defined as "the mean of the discharge increment that transports the largest fraction of the annual sediment load over a period of years" (Andrews 1980) is also common. This value could be described as the flow that produces the maximum probability-weighted sediment transport rate. It is derived by multiplying each rate of sediment transport by the probability that the flow required to induce the transport occurs. Soar and Thorne (2001) describe multiple methods for calculating the effective discharge. Calculation of effective discharge requires a measured or simulated flow-duration curve and measured sediment transport data or the use of a bedload sediment transport equation.

Bankfull discharge is sometimes assumed equivalent to effective discharge (Rosgen 1996). Emmett and Wolman (2001), using measured bedload data, find that the ratio of effective discharge to bankfull discharge ranges from 0.98 to 1.3 in five snowmelt-dominated, gravel-bed rivers. However, this equivalence is not general to all rivers. Soar and Thorne (2001) find that for 58 sand-bed streams in the United States, the effective discharge was less than the bankfull discharge in all cases. Doyle, et al. (2007) confirms that bankfull discharge approximates effective discharge in coarse-bed streams (gravel and cobble) dominated by snow-melt hydrology, but find that bankfull and effective discharges are not equivalent for other types of streams. The effective discharge and the bankfull discharge are found to be different in many studies and in diverse regions (Lichvar et al. 2009, Ma et al. 2010). Because the effective discharge is not typically conveyed at the bankfull stage in natural streams, it is not an appropriate bankfull design discharge for natural channel design.

2.4 Conclusions

Water discharge is the most significant driving factor in fluvial geomorphology. The design discharge for a natural channel design should be similar to the bankfull discharge of natural, self-formed streams in the region. The analysis presented in this section shows that the average return period for bankfull discharge in natural Kansas streams is 1.2 years. A multi-variate regression equation is derived that relates the 1.2-year discharge to watershed factors. This equation can be used to determine an appropriate bankfull flow for design of stream realignments and restorations in Kansas.

Chapter 2 References

Castro, J. M. and P. L. Jackson (2001). "Bankfull discharge recurrence intervals and regional hydraulic geometry relationships: patterns in the Pacific Northwest, USA." *Journal of the American Water Resources Association* 37: 1249-1262.

Chaplin, J. J. (2005). “Development of regional curves relating bankfull-channel geometry and discharge to drainage area for streams in Pennsylvania and selected areas of Maryland.” *Scientific Investigations Report 2005-5147*, U.S. Geological Survey.

Cinotto, P. J. (2003). “Development of regional curves of bankfull-channel geometry and discharge for streams in the non-urban, Piedmont Physiographic Province, Pennsylvania and Maryland.” *Water-Resources Investigations Report 03-4014*, U.S. Geological Survey.

Emmert, B.E. and K. Hase (2001). *Geomorphic assessment and classification of Kansas riparian systems*. Prepared for the Environmental Protection Agency under contract No. CD 997520-01.

Emmett, W. W. and M. G. Wolman (2001). "Effective discharge and gravel-bed rivers." *Earth Surface Processes and Landforms* 26: 1369–1380.

FISRWG (2001). *Stream corridor restoration: principles, processes, and practices*, NEH-653, Federal Interagency Stream Restoration Working Group.

Johnson, P. A., and T.M. Heil (1996). “Uncertainty in estimating bankfull conditions.” *Journal of the American Water Resources Association* 32(6):1283-1292.

Keaton, J. N., T. Messinger, et al. (2005). “Development and analysis of regional curves for streams in the non-urban valley and ridge physiographic province, Maryland, Virginia, and West Virginia." *Scientific Investigations Report 2005-5076*, United States Geological Survey.

McEnroe, B. M., C. B. Young, and J. E. Shelley (2008). "Guidelines for stream realignment design." *Report No. K-TRAN KU-08-2,* Kansas Department of Transportation.

McEnroe, B. M. and C. B. Young (2007). "Flood frequency relationships for small watersheds in Kansas." *Report No. K-TRAN: KU-06-4,* Kansas Department of Transportation.

Rasmussen, P., C. Perry, et al. (2000). "Estimation of peak streamflows for unregulated rural streams in Kansas." *Water Resources Investigations Report 00-4079*, United States Geological Survey.

Rosgen, D. (1996). *Applied river morphology*. Pagosa Spring, Colorado, Wildland Hydrology.

Rosgen, D. L. (1993). *Applied fluvial geomorphology training manual*. Pagosa Springs, CO, Wildland Hydrology.

Shelley, J. E., C. B. Young, and B. M. McEnroe. (2009). "Bankfull discharge for Kansas natural alluvial channel design." *Proceedings of the World Environmental and Water Resources Congress 2009: Great Rivers*, Kansas City, MO.

Shelley, J. E., C. B. Young, and B. M. McEnroe. (2010). "The Rosgen Rosetta stone: translating Rosgen terminology." *Proceedings of the World Environmental and Water Resources Congress 2010: Challenges of Change*, Providence, RI, American Society of Civil Engineers.

Simon, A., W. Dickerson, et al. (2004). "Suspended-sediment transport rates at the 1.5-year recurrence interval for ecoregions of the United States: Transport conditions at the bankfull and effective discharge?" *Geomorphology* 58: 243-246.

Soar, P. J. and C. R. Thorne (2001). *Channel restoration design for meandering rivers*, ERDC/CHL CR-01-1, U.S. Army Engineer Research and Development Center, Flood Damage Reduction Research Program, Vicksburg, MS.

Stream Systems Technology Center (SSTC) (1993). "Would the real bankfull please stand up?" *Stream Notes*, April 1993, U.S. Department of Agriculture United States Forest Service.

Sweet, W. V. and J. W. Geratz (2003). "Bankfull hydraulic geometry relationships and recurrence intervals for North Carolina's coastal plain." *Journal of the American Water Resources Association* (39): 861-871.

Williams, G. P. (1978). "Bankfull discharge of rivers." *Water Resources Research* 14(6): 1141-1154.

Wolman, M. G. and L. B. Leopold (1957). "River flood plains: some observations on their formation." *Professional Paper 282-C*, U.S. Geological Survey.

3.0 Design of Geomorphic Features

This chapter discusses how to design individual geomorphic features: the bankfull width, the meander wavelength, the sinuosity, and the pool depth. These features can be used to supplement other channel design methods or to create artificial channels with a natural appearance. A reasonably natural bankfull width can be determined through hydraulic geometry equations which relate channel dimensions to the bankfull discharge. Other geomorphic features can be designed using form relationships that describe how one aspect of channel form (such as meander wavelength) varies with another aspect of channel form (such as bankfull width) in self-formed channels. These relationships are correlative, not causal, in nature. However, relationships of this kind can be used to “fill in the gaps” in our ability to define all aspects of a river channel analytically. Although geomorphic relationships yield “average” values for individual aspects of channel form, they do not yield coupled combinations of channel dimensions (cross-sectional shape, meander pattern, and bed profile). If a complete combination is desired, a reference-reach approach with all the channel dimensions scaled from a single stream reach must be used.

3.1 Hydraulic Geometry

In recent decades, attempts have been made to develop equations to predict channel width, mean depth, and velocity from the bankfull discharge. These equations, known as hydraulic geometry equations, take the following form:

$$W_{bf} = a\, Q_{bf}^{\,d} \tag{3.1}$$

$$D_{bf} = b\, Q_{bf}^{\,e} \tag{3.2}$$

$$V_{bf} = c\, Q_{bf}^{\ f} \qquad (3.3)$$

where

W_{bf} = bankfull width

D_{bf} = bankfull mean depth (area divided by width)

V = average velocity at bankfull flow

Q_{bf} = bankfull flow

and a, b, c, d, e, and f are constants determined through regression

Numerous studies report the exponent *d* to be close to 0.5. The sum of *d*, *e*, and *f* must be 1 to satisfy flow continuity. Studies show some regional variation in the exponents, particularly for *e* and *f*.

Soar and Thorne (2001) develop hydraulic geometry equations for the width of natural meandering channels in the United States. They find statistically significant differences in the coefficient *a* depending on the type of bed material. Their equation for sand-bed streams is developed from data for 58 rivers. Soar and Thorne find the density of bank vegetation to be a statistically significant parameter in sand-bed streams. Consequentially, they develop three sand-bed stream equations, one for streams with less than 50% tree cover, one for streams with more than 50% tree cover, and one that includes all sand-bed streams together. The equation for gravel-bed streams is derived from measurements on 94 streams in North America. They find that tree cover is not statistically significant in predicting the channel width of gravel-bed streams. The Soar and Thorne hydraulic geometry width equations are included in the NRCS National Engineering Handbook (NRCS 2007) and are presented in Table 3.1.

Table 3.1. Soar and Thorne (2001) hydraulic geometry equations

Bed Material	Tree Cover	Equation	R^2	Eq. Number
Gravel	All Streams	$W_{bf} = 2.03\sqrt{Q_{bf}}$	0.80	(3.4)
Sand	< 50%	$W_{bf} = 2.86\sqrt{Q_{bf}}$	0.87	(3.5)
Sand	> 50%	$W_{bf} = 1.83\sqrt{Q_{bf}}$	0.85	(3.6)
Sand	All Streams	$W_{bf} = 2.34\sqrt{Q_{bf}}$	0.76	(3.7)

3.2 Bankfull Width of Stable Kansas Streams in Kansas

The hydrologic and geologic forces that shape natural channels vary considerably from region to region. In addition, the streams used to develop the equations given in Table 3.1 are larger than streams that would be typical candidates for relocation/restoration in Kansas. Accordingly, these general hydraulic geometry equations merit validation with local data. This analysis is originally presented in McEnroe, et al. (2008). Figure 3.1 shows how measurements from Kansas gravel-bed streams from the Kansas Reference Reach Dataset (KRRDS) compare to Equation 3.4 and its 90% confidence limits. As seen in Figure 3.1, the data from Kansas gravel-bed streams fall within the 90% confidence limits of Equation 3.4.

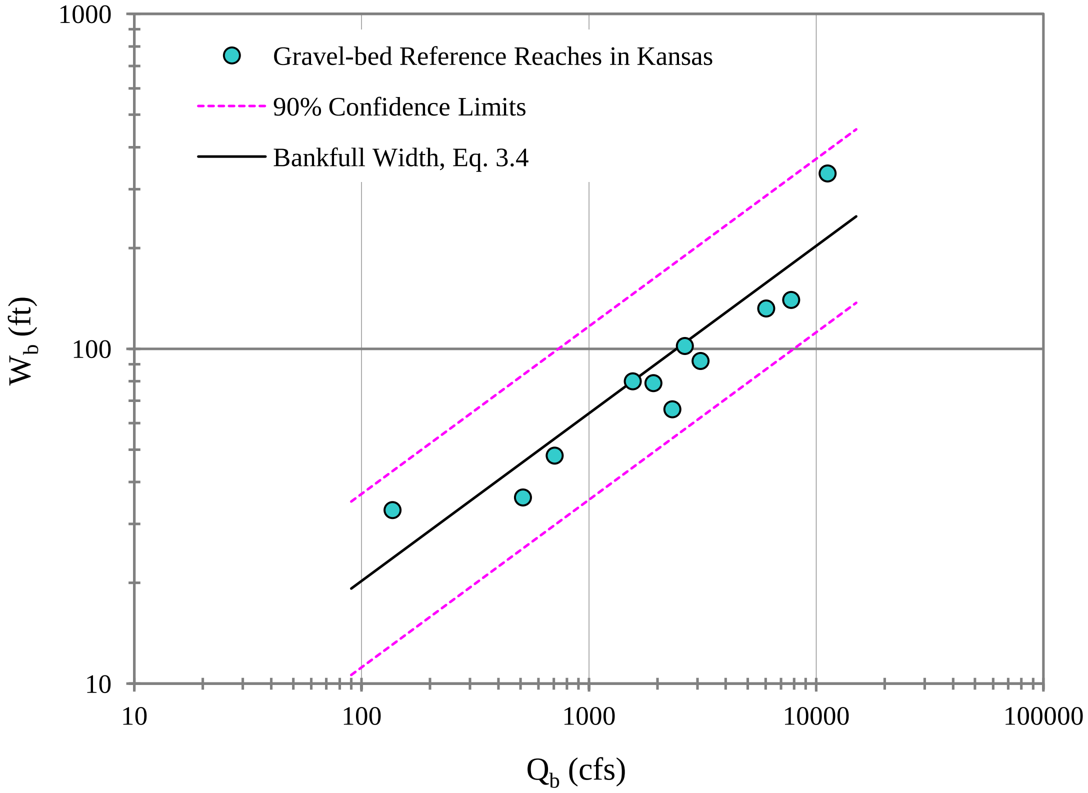

Figure 3.1. Comparison of Soar and Thorne (2001) sand-bed stream hydraulic geometry equation to Kansas stream data

Figure 3.2 shows how measurements from Kansas sand-bed streams from KRRDS compare to Equation 3.7 and its 90% confidence limits. Most of the sand-bed streams fall within the 90% confidence limits, suggesting that Equation 3.7 is generally adequate for use in Kansas. However, four streams do not fall within the 90% confidence limits. These are streams in western Kansas with width-to-depth ratios over 100. Rosgen (2009) does not consider these streams to be stable reference reaches because of the abnormally high width-to-depth ratios. However, Emmert (2009) respectfully disagrees with Rosgen's assessment, stating that these streams are indeed stable reference reaches. Equation 3.7 applies to most, but not all, Kansas streams.

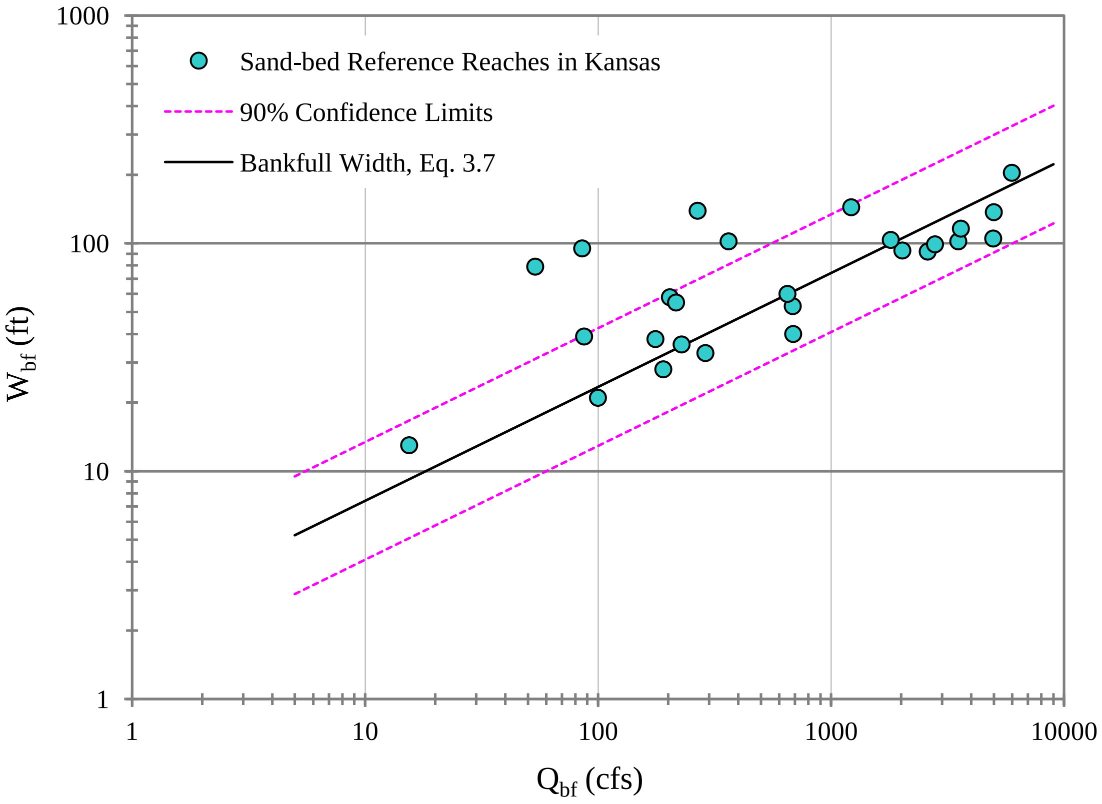

Figure 3.2. Comparison of Soar and Thorne (2001) sand-bed stream hydraulic geometry equation to Kansas stream data

Kansas has a significant number of channels with beds of cohesive silt and clay. No national equation for the hydraulic geometry of cohesive-bed streams has been developed. Equation 3.8 was developed using data from 21 gaged, cohesive-bed streams in KRRDS, starting from the common assumption that width is proportional to the square root of discharge. The coefficient 1.92 is the median value for $W_b/Q_b^{0.5}$. Equation 3.8 and the stream data used in its development are shown in Figure 3.3.

$$W_{bf} = 1.92\sqrt{Q_{bf}} \tag{3.8}$$

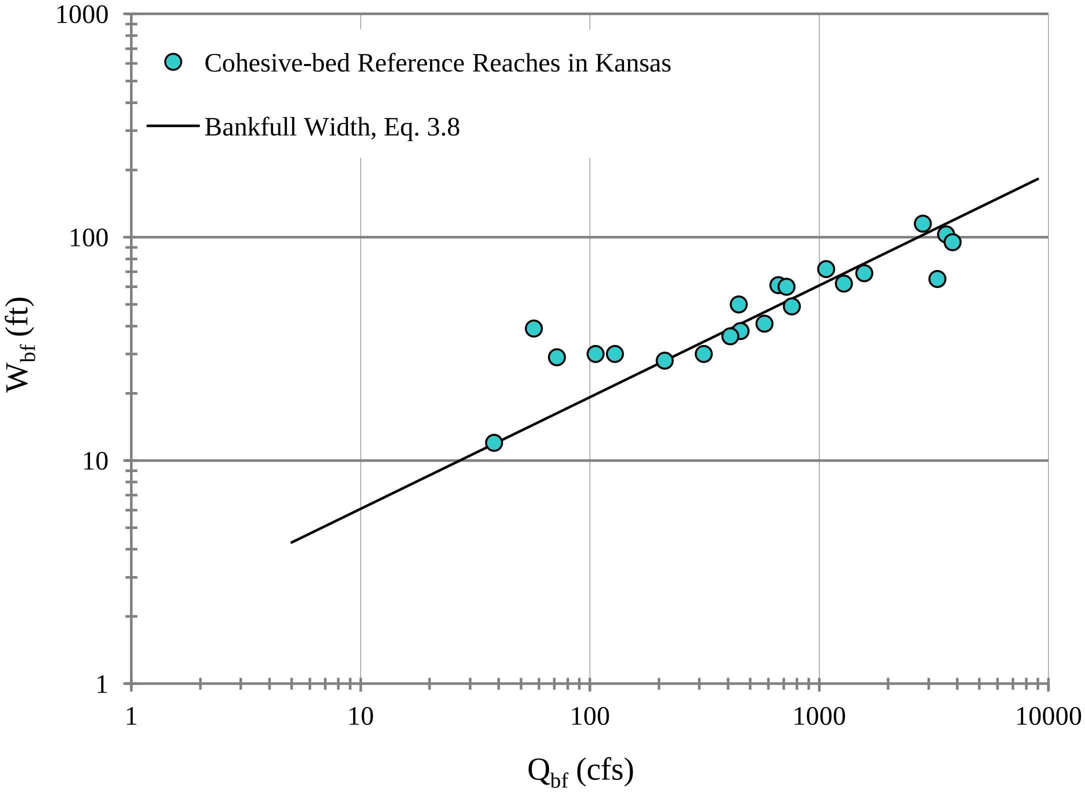

Figure 3.3. Hydraulic geometry relationship for cohesive-bed streams in Kansas

Table 3.2 summarizes values of the ratio $W_{bf}/Q_{bf}^{0.5}$ for reference reaches on gaged Kansas streams. The variability is especially high in sand-bed streams.

Table 3.2. Ratio of $W_{bf}/Q_{bf}^{0.5}$ for reference reaches on gaged streams in Kansas

	Dominant Bed Material		
Statistic	Gravel	Sand	Silt/Clay
Number	11	26	21
Min	1.37	1.49	1.14
Max	3.15	10.77	5.17
Mean	1.95	3.44	2.19
Median	1.80	2.37	1.92
Standard Deviation	0.55	2.57	0.85

3.3 Meander Wavelength

The linear relationship between meander wavelength, λ, and channel width was first documented by Jefferson (1902) and has been confirmed in numerous studies since. Figure 3.4 shows the linear relationship found between λ and W_{bf} for 438 natural alluvial channels (Soar and Thorne 2001). The equation shown in Figure 3.4 yields an equation that predicts the geometric mean of meander wavelengths for a given bankfull width. Soar and Thorne present Equation 3.9 as an "unbiased" equation, meaning that Equation 3.9 predicts the arithmetic mean of meander wavelengths for a given bankfull width.

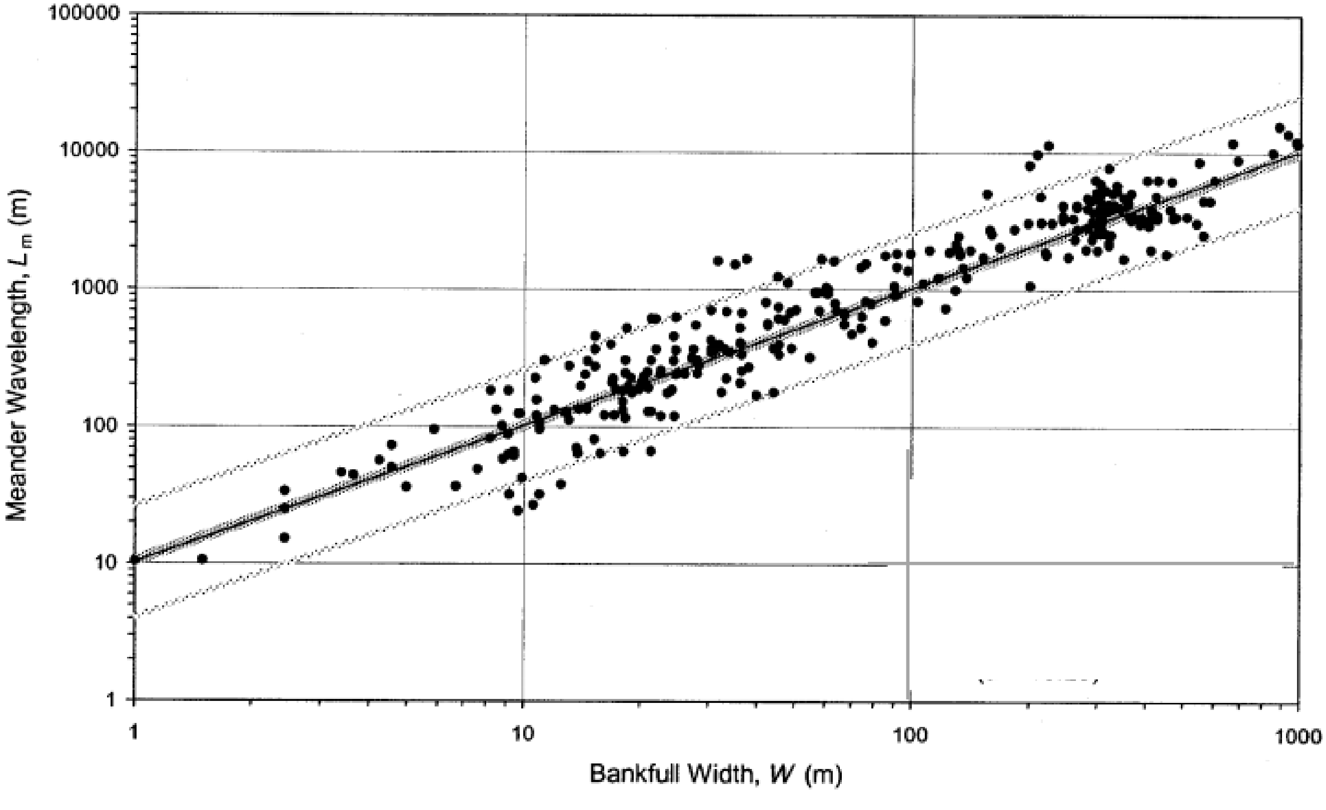

Figure 3.4. Relationship between meander wavelength and bankfull width. The 90% confidence limits are also shown. (Source: Soar and Thorne, 2001)

$$\lambda = 11.85\ W_{bf} \tag{3.9}$$

The relationship is clear, but the scatter is considerable. According to Figure 3.4, for a bankfull width of 10 meters nature could plausibly create a meander wavelength ranging anywhere from 40 m to 261 m. Meander wavelength varies on any given stream due to heterogeneity in soil properties, vegetation, and geology. The ratio of meander wavelength to bankfull width for streams in different watersheds derives additional variability from differences in hydrologic, geologic, and land-use conditions and history.

Figure 3.5 shows the linear relationship between meander wavelength and bankfull width in the Kansas Reference Reach Dataset. As seen, the relationship is linear with the best-fit line very similar to the line defined by Equation 3.9, which indicates that Equation 3.9 is valid for Kansas streams. Figure 3.6 presents a relative frequency histogram of λ/W_{bf}, and Table 3.3 presents the minimum, maximum, mean, median, and standard deviation of λ/W_{bf}.

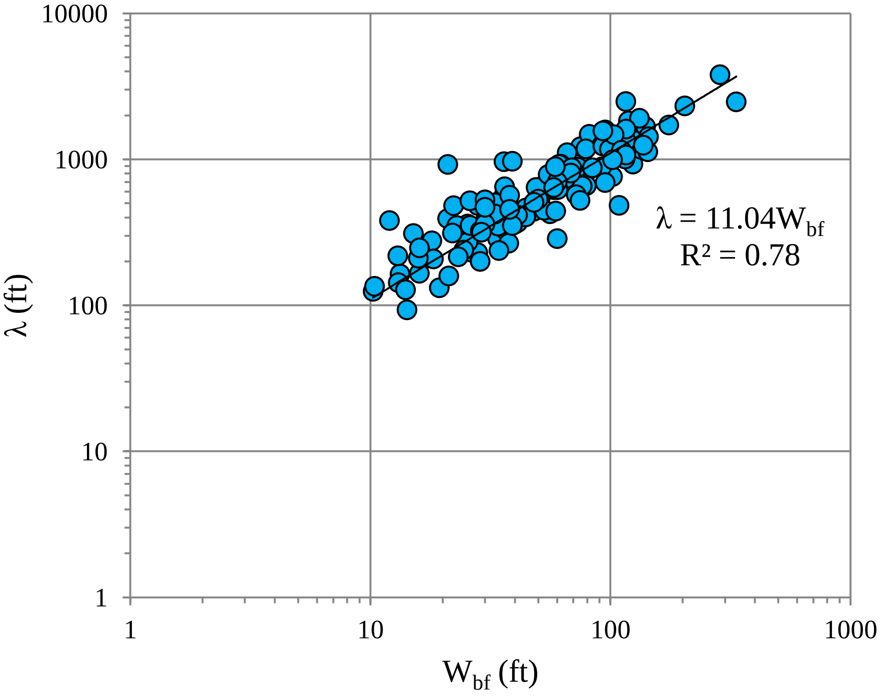

Figure 3.5. Relationship between meander wavelength and bankfull width in Kansas streams

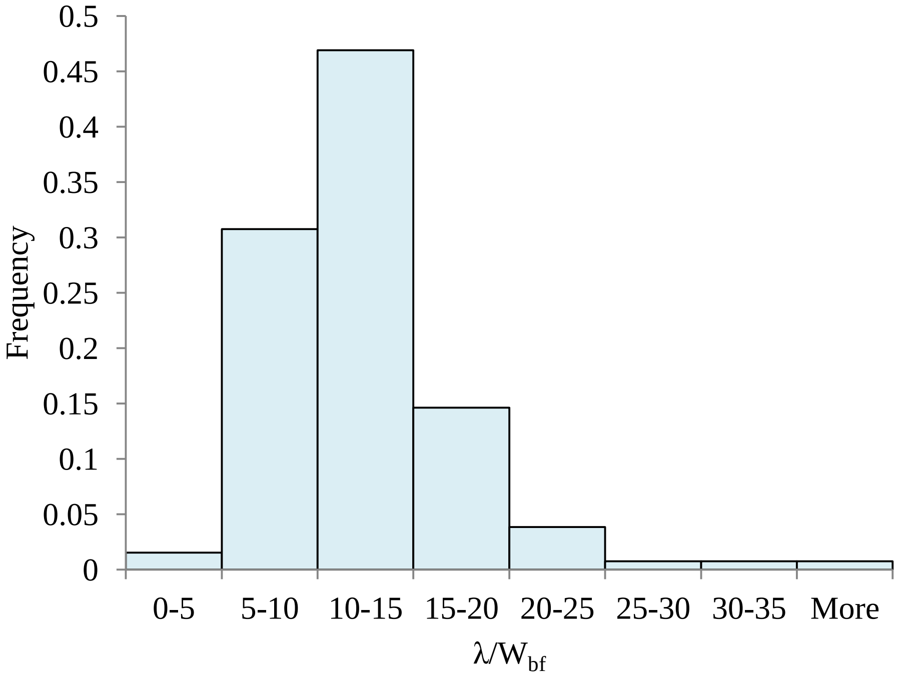

Figure 3.6. Histogram of meander wavelength / bankfull width (λ/W_{bf})

Table 3.3. Statistics for λ/W_{bf} in KRRDS

Min	4.5
Max	44.0
Mean	12.4
Median	11.3
Standard Deviation	5.0

3.4 Sinuosity

Sinuosity, defined as the ratio of valley slope to channel slope (or alternatively channel length to valley length) is an important geomorphic ratio. Sinuosity depends on the same inputs that determine the channel slope: the flow and sediment inputs, the bed material, and the bank strength. In flume experiments looking at stable channel configurations, Ackers (1972) finds that slope varies with sediment concentration but not with discharge. Similarly, Schumm (1963) does not find a correlation between sinuosity and discharge on 50 rivers in the Great Plains. Schumm does note that sinuous streams tend to have lower channel slopes than straight streams carrying the same discharge. Rosgen (2001) demonstrates that streams with steeper slopes tend to have lower sinuosities, as shown in Figure 3.7. The same relationship is evident in the KRRDS by plotting sinuosity versus valley slope instead of channel slope. As seen in Figure 3.8, reference reaches in Kansas with sinuosities above 2.0 only exist when the valley slope is less than 0.002.

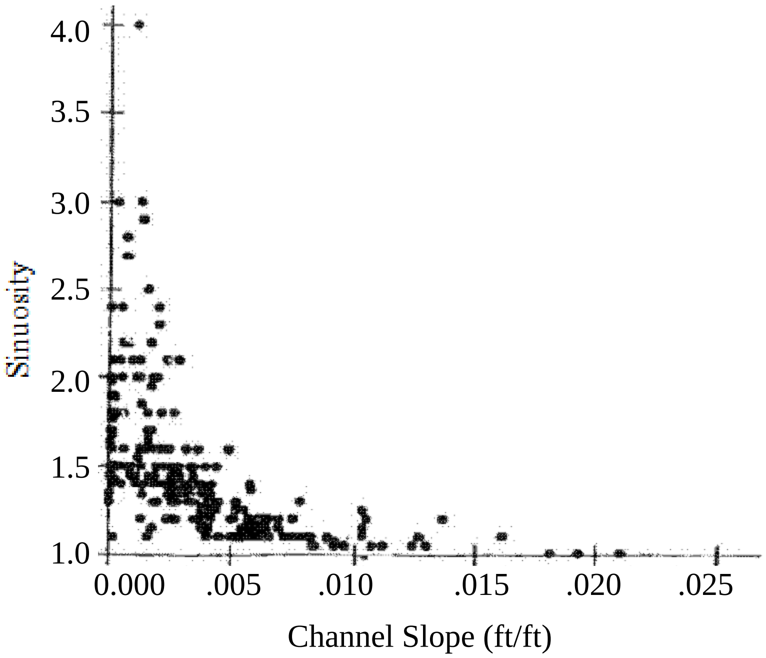

Figure 3.7. The relationship between channel slope and sinuosity at different streams

(Source: Rosgen 2001. The incorrectly labeled x-axis has been corrected.)

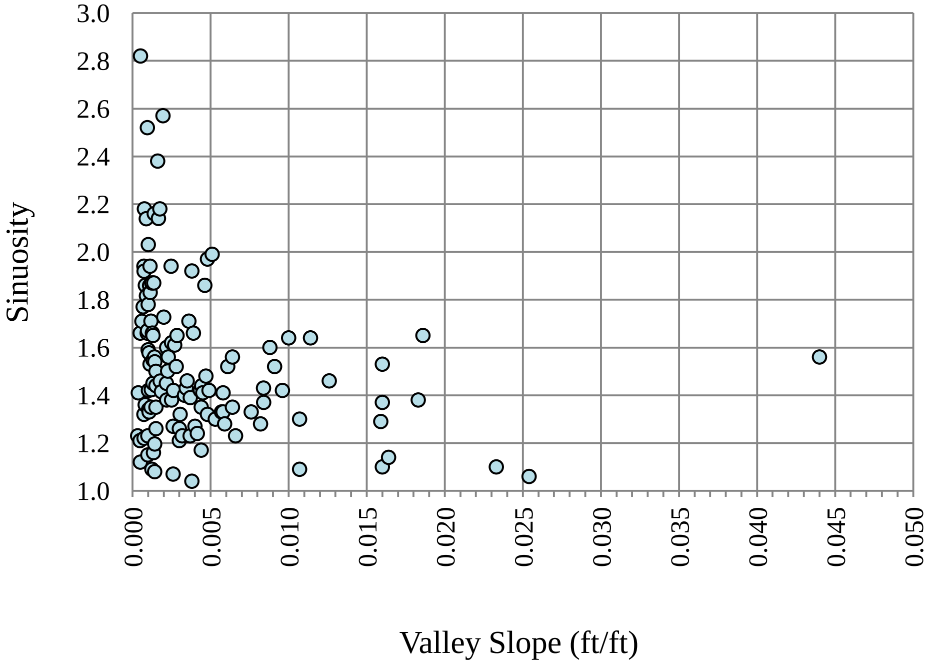

Figure 3.8. The relationship between sinuosity and valley slope for Kansas reference reaches

Table 3.4 reports the minimum, maximum, mean, median, and standard deviation of sinuosity for the streams in the Kansas Reference Reach Dataset. The values are reported for two ranges of valley slopes and all together, up to the maximum reported valley slope of 0.045. Stable streams with low sinuosities occur on any valley slope. However, the streams with the highest sinuosities are found only in valleys with very gentle slopes.

Table 3.4. Statistics for sinuosity in KRRDS

	$V_{Slp} < 0.002$	$0.002 < V_{Slp} < 0.045$	$V_{Slp} > 0.045$
Min	1.08	1.04	1.04
Max	2.82	1.99	2.82
Mean	1.65	1.43	1.53
Median	1.58	1.41	1.44
Standard Deviation	0.39	0.22	0.33

A comparison of the sinuosity values in Table 3.4 and the values for $W_{bf}/Q_{bf}^{0.5}$ in Table 3.2 reveals that there is considerably less variation in the range of naturally occurring sinuosities than in naturally occurring channel widths. This finding has important implications for channel design which are discussed in Chapter 4.

3.5 Riffles and Pools

Most natural channels exhibit significant, spatially repeating variations in cross-section and bottom slope known as riffles (or cross-overs) and pools. These features coincide with important locations on the channel, as seen in Figure 3.9.

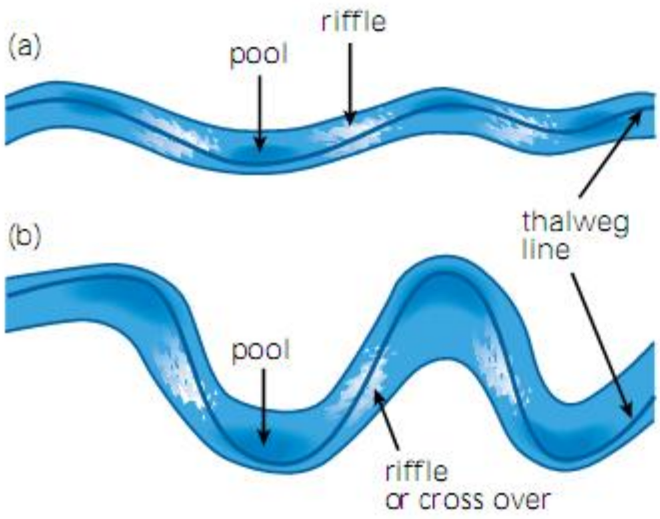

Figure 3.9. Riffle and pool planform (Source: FISRWG, 2001)

Riffles are shallow areas with fast-moving water that usually form "between two bends at the point where the thalweg crosses over from one side of the channel to the other" (FISRWG 2001). In gravel and cobble rivers, the bed material at a riffle may be coarser than at other locations in the stream. This is usually not the case in sand streams, although a sequence of shallow areas and pools is still present. Most geomorphic analyses are performed on riffle (cross-over) sections. These analyses include stream classification; form measurements for bankfull width, depth, and area; and the calculation of bankfull flow and sediment transport capacity.

Pools are deep areas that typically form near the outside bank of a meander bend. Pools dissipate energy and provide important aquatic habitat, especially during periods of little to no flow. Pool features are common in sand, gravel, and cobble streams. Many clay-bed streams have beds with constant slopes without differences in bed elevation typical to riffles and pools. Analytical channel design equations apply to the riffle cross-section. The pools must be designed using separate methods or left to form on their own.

3.6 Pool Depth

An analysis by Soar and Thorne (2001) of 295 meander bends from field and flume studies indicates that the ratio of the maximum depth at the pool to the mean depth at the riffle varies from about 1.5 to the maximum given by Equation (3.10).

$$\frac{y_{\text{pool}}}{\overline{y}_{\text{riffle}}} = 1.5 + 4.5\left(\frac{W_{\text{riffle}}}{R_c}\right) \tag{3.10}$$

where

y_{pool} = the maximum depth in the pool

$\overline{y}_{\text{riffle}}$ = the mean depth in the riffle

W_{riffle} = the bankfull width at the riffle

R_c = the radius of curvature for the meander bend

Soar and Thorne present Equation (3.10) as a “safe design curve” because it presents the maximum depth that can be expected to form naturally. This depth can guide the design of bank protection measures.

Emmert and Hase (2001) and KRTT (2006) provide a ratio of pool depth to mean depth which Rosgen (1996) names the “pool-depth ratio.” Unfortunately, the “pool-depth ratio” as defined by Rosgen is not a valid representation of stream geomorphology. According to Rosgen’s reference-reach survey protocols, the riffle that best represents what a riffle should look like is chosen as the “representative riffle,” and the pool that best represents what a pool should look like is chosen as the “representative pool.” The representative pool need not be adjacent to the representative riffle. This selection preference yields especially shallow riffles, especially deep pools, and an unnaturally high ratio of pool depth to riffle depth. For this reason, the “pool-riffle depth ratios” reported in Emmert and Hase (2001) and KRTT (2006) are not valid representations of Kansas stream geomorphology. Comparisons of pool depth to riffle depth should be made at pools adjacent to the riffle.

The following procedure was followed to extract meaningful information about riffles and adjacent pools for Kansas reference reaches. First, the elevations of the channel thalweg and bankfull indicators were plotted on the y-axis with distance along the channel on the x-axis. Second, a best-fit linear trend-line was drawn through the bankfull indicators. Third, the representative riffle selected in the field was located on the profile. Fourth, the maximum depth was measured from the thalweg to the bankfull trend-line at the representative riffle and at pools located immediately upstream and downstream of the riffle. The pool depth used in subsequent analysis is the average of the depths of the pools directly upstream and downstream of the riffle. This process is illustrated in Figure 3.10 for Norton Creek near Bazaar, Kansas.

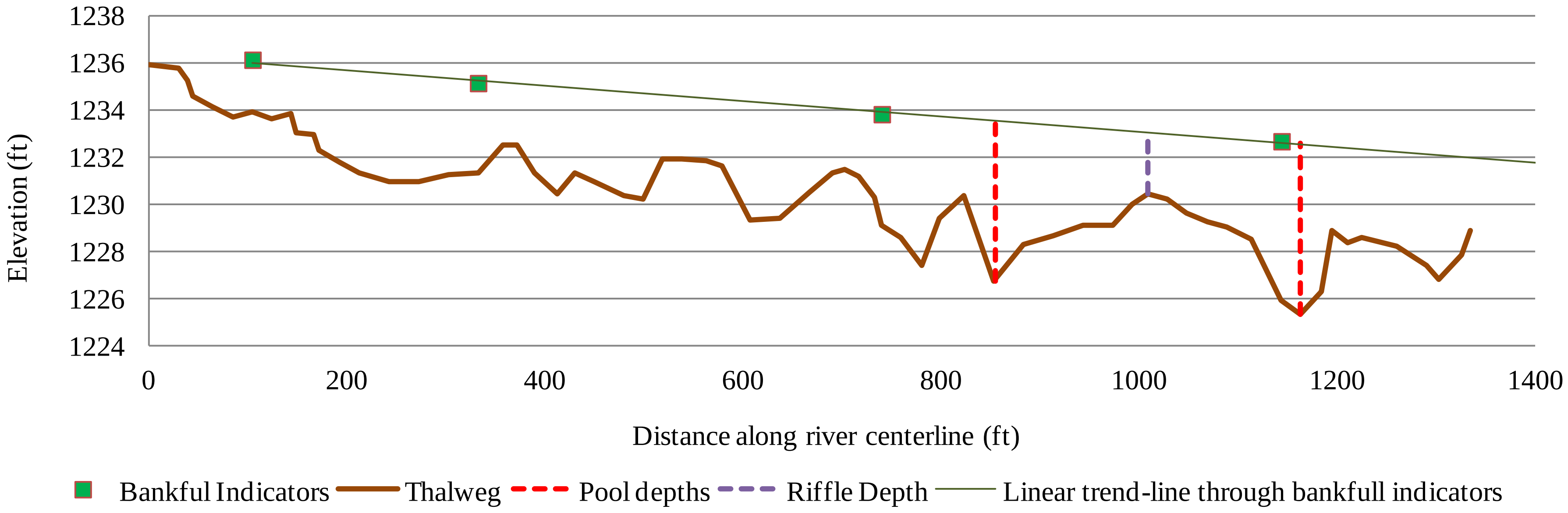

Figure 3.10. Extraction of riffle and pool depths from reference-reach profile data

Figure 3.11 shows the distribution of the ratio of pool depth to riffle depth, y_{pool}/y_{riffle}, for the KRRDS streams.

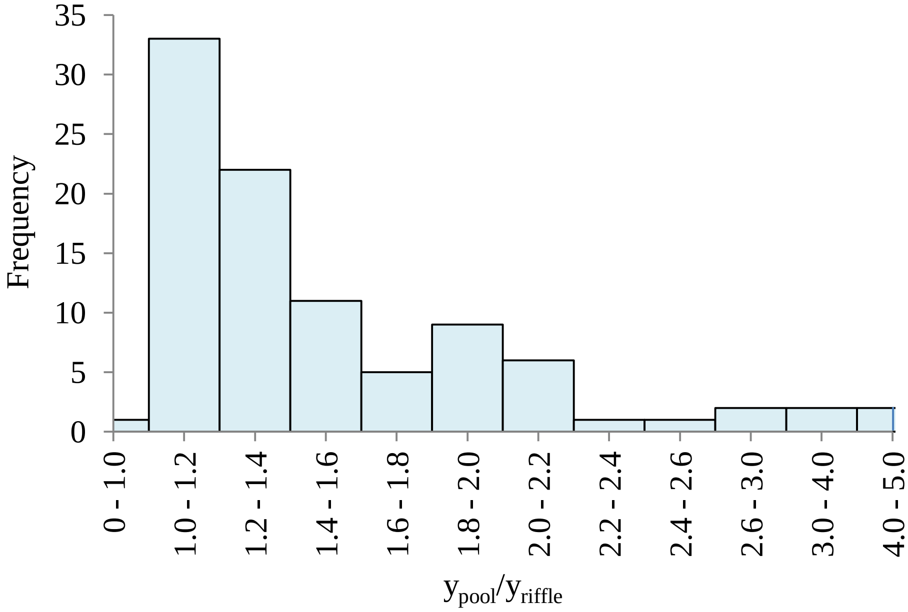

Figure 3.11. Histogram of the ratio of pool depth to riffle depth, y_{pool}/y_{riffle}

Figure 3.12 shows that pool depth is a linear function of riffle depth and that there is remarkably little scatter. The two outliers shown on Figure 3.12 were removed for the calculation of the best-fit regression line (Equation 3.10) and the confidence limits.

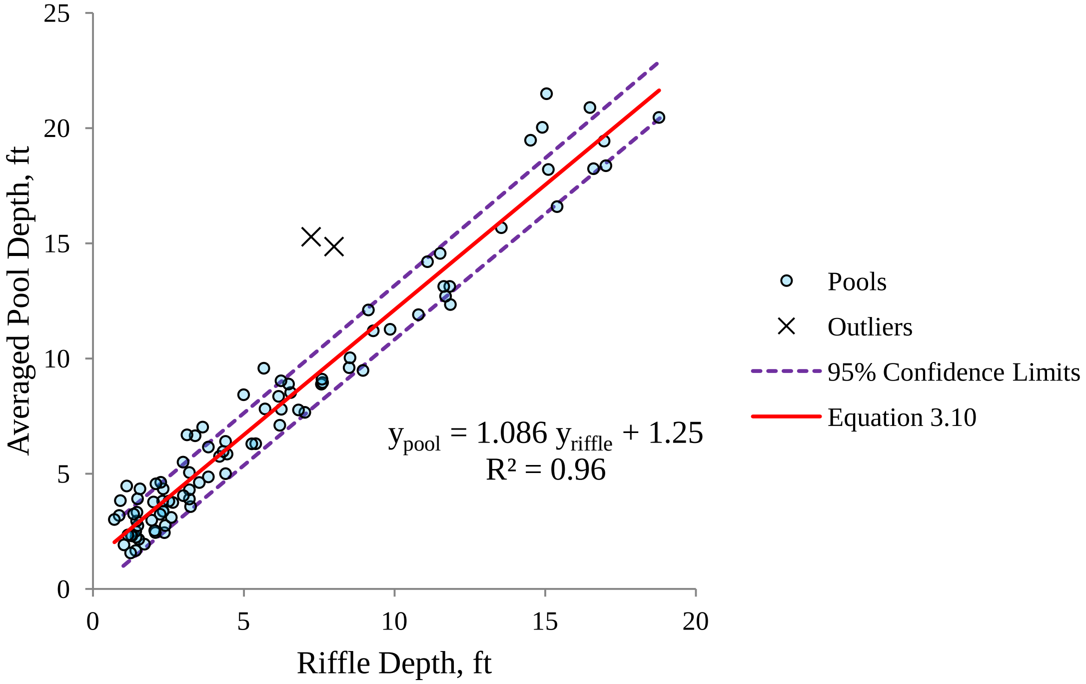

Figure 3.12. Pool depth as a function of riffle depth

$$y_{pool} = 1.086\ y_{riffle} + 1.249 \qquad (3.10)$$

where y_{riffle} = the maximum depth (thalweg to bankfull stage) in the riffle (ft)

y_{pool} = the maximum depth in the pools adjacent to the riffle (ft)

3.7 Sample Uses of Geomorphic Relationships

This section presents three hypothetical scenarios that demonstrate the use of geomorphic ratios.

Scenario #1

A local developer wishes to restore a channelized stream to a more natural configuration as mitigation for an adverse stream impact in a nearby project. Because the mitigation credits are assessed based on the channel length, the developer wants to create a channel with a high sinuosity. A stream with a sinuosity of 2.2 would provide enough mitigation credits to offset the developer's other project. The valley slope of the straightened reach is 0.006 ft/ft.

Figure 3.8 shows that a sinuosity of 2.2 would be unnaturally high for a valley slope of 0.006. Figure 3.8 suggests that the highest value of sinuosity that remains in the range of naturally occurring sinuosities for a valley slope of 0.006 is 1.6.

Scenario #2

A department of transportation needs to realign a small stream in conjunction with a highway improvement project. The realigned stream has been designed to pass the incoming bankfull flow and sediment load. However, in order to receive a permit, the realigned stream must be built with a natural bed profile containing riffles and pools. The design depth of the channel is 3 ft.

Taking the design depth to be the riffle depth, Equation 3.10 predicts a pool depth of 4.5 ft. This value is suitable for design, with the understanding that small adjustments will likely occur post-construction. A procedure for designing a channel to pass the incoming bankfull flow and sediment load is presented in Chapter 4.

Scenario #3

A logging operation carelessly removes a significant number of trees from the riparian corridor. An engineer is asked to provide a back-of-the-envelope estimate of how the tree removal may impact the stream channel to see if further study is warranted. The river flows into a reservoir with a sedimentation problem.

The ratio of Equation 3.5 to Equation 3.6 suggests that with a much less dense riparian zone, the channel might widen to 1.6 times its current width (2.86/1.83 = 1.6). The possibility of so much additional bank sediment entering the reservoir convinces state officials that further study and possible intervention is warranted.

3.7 Conclusions

This section demonstrates that the Soar and Thorne (2001) width-prediction equations are applicable to Kansas sand and gravel channels. However, the scatter in each relationship is significant. A hydraulic geometry equation for cohesive-bed streams is presented. Soar and Thorne's (2001) equation for meander wavelength as a function of channel width is shown to be appropriate for Kansas streams, but again, the scatter is significant. The maximum sinuosity of Kansas streams is found to depend on the valley slope, with sinuosities above 2 only present where the valley slope is less than 0.002 ft/ft. An equation for pool depth is presented that has a high correlation coefficient and much less variation than the other geomorphic relationships presented. These geomorphic relationships were derived from reference reaches in Kansas and are recommended for use in Kansas over other published equations. Their applicability most likely extends to alluvial, meandering rivers in other Midwestern states, as well.

The equations presented in this section can be used to design a channel with an average channel width, an average meander wavelength, an average sinuosity, and an average pool depth. However, the resulting combination of "average" dimensions may not resemble a typical natural stream, may not convey the desired discharge, and may not be stable. The mechanisms of three-dimensional flow and sediment transport carve out the complete channel configuration and are heavily influenced by site-specific climate, geology, vegetation, land use and geomorphic history. While the equations presented in this chapter can be used for a variety of purposes, they should be used as design tools in conjunction with analytical channel design methods that consider site-specific flow and sediment inputs.

Chapter 3 References

Ackers, P. (1970). "Meander geometry arising from varying flows." *Journal of Hydrology*, 11: 230-252.

Ackers, P. (1972). "River regime: research and application." *Journal of the Institution of Water Engineers*, 26(5): 257-281.

Emmert, B.E. and K. Hase (2001). *Geomorphic Assessment and Classification of Kansas Riparian Systems*, Prepared for the Environmental Protection Agency under contract No. CD 997520-01.

Emmert, B. (2009). Personal Communication. J. Shelley.

FISRWG (2001). *Stream corridor restoration: principles, processes, and practices*, NEH-653, Federal Interagency Stream Restoration Working Group.

Jefferson, M. S. W. (1902). "Limiting width of meander belts." *National Geographic Magazine*, 13: 373-384.

KRTT (2006). *Assessment, Geomorphic Definition, and Documentation of Kansas Stream Corridor Reference Reaches*, Kansas Riparian Technical Team. Prepared for the Environmental Protection Agency and the Kansas State Conservation Service.

McEnroe, B. M., C. B. Young, and J. E. Shelley (2008). "Guidelines for stream realignment design." *Report No. K-TRAN KU-08-2*, Kansas Department of Transportation.

NRCS (2007). "Stream restoration design." *National Engineering Handbook--Part 654*, Natural Resources Conservation Service.

Rosgen, D. (1996). *Applied River Morphology*, Pagosa Spring, Colorado, Wildland Hydrology.

Rosgen, D. (2009). Personal communication. J. Shelley.

Rosgen, D. L. (2001). “The cross-vane, W-weir and J-hook vane structures: their description, design and application for stream stabilization and river restoration.” *Proceedings of ASCE 2001 Wetland and River Restoration Conference*, Reno, Nevada. American Society of Civil Engineers.

Schumm, S. A. (1963). "Sinuosity of alluvial rivers on the great plains." *Geological Society of America Bulletin*, 74(9): 1089-1100.

Soar, P. J. and C. R. Thorne (2001). *Channel restoration design for meandering rivers*, ERDC/CHL CR-01-1, U.S. Army Engineer Research and Development Center, Flood Damage Reduction Research Program, Vicksburg, MS.

4.0 Channel Design Methods

Channel design methods typically fall into three categories: regime equations, analytical approaches, and reference-reach approaches. This chapter addresses the strengths and weaknesses of the latter two approaches. In addition, two original channel design methods are presented: the Kansas Analytical Method and the Analytical Reference Reach Method.

4.1 Analytical Approaches

Analytical approaches to natural channel design specify channel dimensions by employing equations that describe flow resistance and sediment transport. Analytical descriptions of all the processes involved in river formation would include descriptions of complex 3-dimensional hydraulics and sediment transport, erosion transport and deposition of cohesive materials, geotechnical failure mechanisms for channel banks, groundwater interactions, and the influence of riparian vegetation. Such descriptions are beyond the state of the science and the practice. While complex models including many of these processes have been developed for specific projects, they typically contain multiple parameters that require field calibration and are of limited scope and usefulness for general design purposes.

Although analytical approaches cannot be used to design the complete river with all its variability, they can provide an appropriate combination of average width, depth, and slope (or wetted perimeter, hydraulic radius, and slope) of a channel using a sediment transport equation and a flow-resistance equation. Often, a trapezoidal cross-section with fixed side-slopes is chosen for design. The channel is designed to have a sediment transport capacity equal to the incoming sediment load, thus conveying sediment through the reach with no net change in bed elevation over time. The channel is also designed to convey a characteristic bankfull flow at the top of the banks. Solving the flow-resistance and sediment-transport equations simultaneously yields a family of solutions for the three unknowns. Figure 4.1 shows the typical forms of the slope-width and depth-width relationships that result from the solution of these equations.

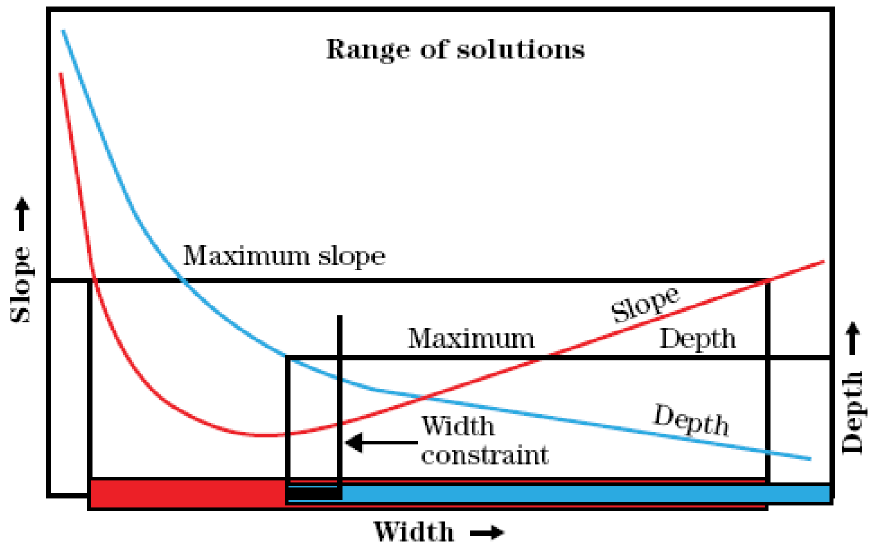

Figure 4.1. Curves representing possible combinations of width, depth, and slope generated by analytical methods (Source: NRCS 2007)

For a given width, a combination of depth and slope can be found that will pass the required discharge and sediment load at the bankfull level. This would suggest that any value for width can be chosen. However, the width of naturally formed channels for a given discharge varies within a predictable range and depends on additional factors such as bed material, bank material, and bank vegetation (see Chapter 3).

Many researchers suggest imposing the assumption that the stream will reach an optimum configuration that maximizes the sediment transport efficiency, a dimensionless quantity defined by Equation (4.1) (Millar 2005; an extensive list of researchers proposing this optimum solution is provided in Soar and Thorne 2001).

$$\eta = \frac{G_b}{\rho Q_b S} \tag{4.1}$$

where η = sediment transport efficiency

G_b = bed-material transport rate at the bankfull discharge (mass/time)

Q_b = the bankfull discharge (vol/time)

ρ = the density of water (mass/vol)

S = channel slope (length/length)

The sediment transport efficiency is not truly an “efficiency” with a value that ranges from 0 to 1, but rather it is a ratio of the sediment transport rate, G_b, to stream power required for transport, ρQS. The optimum channel configuration is one that maximizes the sediment transported per unit of stream power. (Note that the gravitational acceleration term included in the typical definition for stream power, ρgQS, has been omitted in Millar’s formulation to make η a dimensionless ratio.)

For a transport rate equal to the rate of incoming sediment load and a bankfull flow determined by watershed conditions (i.e. G_b and Q_b are fixed), the optimum solution to Equation 4.1 is the solution with the smallest slope. This is depicted as the minimum of the slope curve shown in Figure 4.1. The presence of an optimum solution is known as optimality theory (Millar 2005) or the extremal hypothesis (NRCS 2007). Evidence for an optimum solution dates back to Gilbert (1914). However, stable channels can be found with width, depth, and slope combinations other than the optimum or extremal solution (NRCS 2007). Millar (2005) defends the extremal solution but proposes that additional information on bank strength relative to bed strength be used and that an additional degree of freedom (the side slopes) be added.

Another approach to obtaining a unique solution is to use a geomorphic relationship as a third equation. USACE's *Hydraulic Design of Meandering Channels* (Copeland et al. 2001) and the NRCS's *Stream Restoration Design* (2007) recommend the use of a regional hydraulic geometry equation to guide the selection of the bankfull width (see Section 3.1). Once the bankfull width has been chosen, the flow-resistance and sediment transport equations yield a unique combination of depth and slope. This basic approach is followed in the Kansas Analytical Method (McEnroe et al. 2008), described in Section 4.3. The Analytical Reference Reach Method (McEnroe et al. 2009) uses the channel sinuosity of a reference reach to determine the design channel slope, and calculates the wetted perimeter and hydraulic radius. The Analytical Reference Reach Method is described in Section 4.4. The Scaled Geomorphic Method, described in Chapter 5, uses the relationship between bankfull area and wetted perimeter from a reference reach, then calculates the channel slope and a scaling factor to apply to the reference reach cross-sections.

The main strength of analytical methods is that channels are designed for stability using site-specific flow and sediment boundary conditions. Additionally, the design is physically-based, repeatable, and programmable. Analytical methods also provide a good framework for including additional degrees of freedom as equations that describe additional processes are developed.

Analytical approaches have limitations. The main drawback of current analytical approaches is that too few channel dimensions are derived for a complete channel design. Analytical design methods do not specify the planform geometry, the profile variations at riffles and pools, or the cross-sectional variations around meander bends. In practice, these features are either left to develop on their own or are designed using geomorphic relationships. Designing channel variability after the fact is problematic. In nature, channel cross-sections, profiles, and meander patterns are formed by the same flow and sediment inputs as an interrelated set. Designing the meanders independent of the pool depths, for example, may lead to unnatural combinations. Additional limitations are imposed by the resistance and sediment transport formulas used in a particular analytical method. Another potential drawback is that the computational nature of the procedures may give overconfidence to engineers who use them for design without understanding the limitations and assumptions of the methods or the geomorphic tendencies of the stream.

4.2 Reference-Reach Methods

Reference-reach approaches to river design obtain the slope, cross-sectional dimensions and planform geometry of the design reach by scaling from a reach of a similar stream, termed the reference reach.

Reference-reach approaches rely on correlations among dependent variables instead of relating dependent variables to independent variables. This approach draws criticism from engineers and geomorphologists who claim reference-reach methods are “form-based” instead of “process-based” (Simon et al. 2007). Rosgen (2008) defends the reference-reach approach by saying that form and process are “critically linked.”

This point merits clarification. Geomorphic processes are affected by the channel form in the short term (i.e. a steeper slope increases erosion) but create channel form in the medium to long term (i.e. increased erosion lessens channel slope). In a stable channel, the opposing processes have reached dynamic equilibrium, which allows water and sediment to pass through the reach without significant alterations to average channel dimensions. However, if the channel configuration is transferred to a new location where the flow and sediment inputs are different, the constructed form may not represent the stable form that would be created by geomorphic processes achieving equilibrium. One process will be favored over the other (such as erosion favored over deposition), and the constructed "natural channel" will not be stable. Instability is especially probable when the flow and sediment inputs at the reference reach site are drastically different than at the project site, as is the case in the redesign of urban streams using rural reference reaches (Moses and Morris 1998). Thus, the correct form for a channel should be determined by considering the site-specific flow and sediment inputs.

NRCS (2007) uses the term "analogy method" to mean a reference-reach method that copies channel dimensions or features directly from an upstream, downstream, or nearby channel without scaling. If watershed conditions remain unchanged and sufficient information is available, the configuration of the pre-disturbance channel can be used as the reference-reach.

Using the analogy method (no scaling) is clearly appropriate in some situations. For example, if a reach to be realigned is in a reasonably natural state and is stable on its current alignment, it can serve as a reference reach and its characteristics can be copied directly to the realigned reach.

A stable reach a short distance upstream or downstream of the project reach can also serve as a reference reach in many cases.

Often, a suitable reference reach on the same stream is not available. An appropriate reference reach is one that, when scaled, not only possesses the geomorphic features that foster a healthy riparian ecosystem, but conveys the proper bankfull flow and incoming sediment load without bed degradation or aggradation. Using any other stream as a reference reach—or even the historic configuration of the current reach if watershed conditions have changed—may not be appropriate.

The most popular reference-reach method is the Rosgen natural channel design method (Rosgen 1996). In this method, a reference reach is chosen based on similarity in the valley type and professional judgment as to which of five stable stream types is required. The chosen reference reach can be scaled up or down to the correct size based on a ratio of the bankfull area in the reference reach to a design value for bankfull area. The design bankfull area is selected from a "regional curve" which relates the bankfull areas of nearby stable channels to their drainage areas.

This use of the bankfull area to scale the reference reach is flawed. Bankfull area is insufficient to describe the flow and sediment transport, and a design based on a ratio of bankfull areas cannot assure stability. Despite ardent criticism from river engineering and geomorphology researchers in both academia and at government research facilities (Simon et al. 2007, Doyle and Harbor 2000, Kondolf 1995, Miller and Ritter 1996) the Rosgen method continues to be a very popular river restoration method, especially among government environmental agencies. Lave (2008) suggests that most river restoration design firms that use the Rosgen method use it in conjunction with other methods.

In Kansas, state environmental agencies strongly prefer that all work performed on streams utilize Rosgen's design methods. Engineers at the Kansas Department of Transportation (KDOT) were concerned that the Rosgen method was not applicable to streams in Kansas and would not lead to the design of stable channels. KDOT funded research into alternative stream design methods that led to the development of two river design methods: the Kansas Analytical Method (KAM) and the Analytical Reference Reach Method (ARRM). KAM is described briefly in Section 4.3. ARRM is presented in Section 4.4.

4.3 The Kansas Analytical Method

The Kansas Analytical Method (KAM) is an analytical channel design method that follows the basic procedure recommended by Copeland, et al. (2001) and NRCS (2007). KAM is a complete design method that specifies each step of the design from data collection to laying out the planform. The bankfull discharge is determined using either Manning's equation on a match reach (a stable upstream or downstream reach of the same stream) or by using a regional hydrologic equation (see Section 2). A hydraulic geometry equation provides the channel width (see Section 3), and Manning's equation and a simplified version of the Meyer-Peter and Muller (MPM) sediment transport equation define the depth and slope of a stable trapezoidal channel. The channel planform is defined as a practical arc-and-line approximation of the sine-generated curve planform suggested by Langbein and Leopold (1966). The pool depth is set to 1.5 times the mean riffle depth, the minimum ratio suggested by Soar and Thorne (2001). KAM can be considered a natural channel design method because the flow, bankfull width, meander wavelength, and pool depth are designed using equations based on measurements from natural channels.

KAM makes the unrealistic assumption that bed-load transport occurs over the entire cross-section, instead of just over the channel bed. Error in the design introduced by this assumption is minor, however, because the same assumption is applied to both the match reach and the design reach. The KAM cross-section is trapezoidal with user-specified side slopes. The KAM bed profile assumes the riffles and pools are points with no length, which results in a saw-tooth pattern. This would be a starting point from which the channel would carve out more natural transitions. Further details are available in McEnroe, et al. (2008).

4.4 The Analytical Reference Reach Method

The Analytical Reference Reach Method (ARRM) incorporates both analytical and reference-reach concepts. ARRM is an analytical method because it solves for width, depth, and slope using flow, sediment transport, and a third relationship. In contrast to KAM, which uses a hydraulic geometry relationship to yield the design bankfull width, ARRM uses the sinuosity of a reference reach to yield the design channel slope. ARRM is a reference-reach method because the channel slope, meander wavelength, and pool depth are derived from geomorphic ratios taken from a reference reach.

The steps to an ARRM alluvial channel design are provided in this section. Additional information, background, and explicit instructions for both alluvial (mobile bed) and threshold (immobile bed) channel design are published in McEnroe, et al. (2009, 2010).

Steps to an alluvial channel design by the Analytical Reference Reach Method

1. Determine bankfull discharge, Q_d, using a hydraulic method or regional relationship (see Chapter 2).

2. Compute the average channel slope through the design reach with Equation (4.2).

$$S_d = \frac{F_d}{p_d \cdot L_{v,d}} \tag{4.2}$$

where

S_d = average channel slope through the design reach (ft/ft)

F_d = total fall in channel thalweg elevation through design reach (ft)

$L_{v,d}$ = valley length through design reach (ft)

p_d = sinuosity of design reach (same as sinuosity of reference reach)

3. Select a trial value for the depth of the design channel, y_d.

4. Compute the bottom width of the design channel, b_d, using Equation (4.3).

$$b_d = b_m \left[\frac{\bar{y}_m S_m - 0.047\left(G_s - 1\right) d_{50}}{y_d S_d - 0.047\left(G_s - 1\right) d_{50}} \right]^{3/2} \tag{4.3}$$

where

b_m = bed width at representative riffle section in match reach (ft)

$\bar{y}_m$ = average depth over bed at representative riffle section in match reach (ft)

G_s = specific gravity of sediment

d_{50} = sediment size for which 50% of the bed material is finer (ft)

S_m = channel slope in the match reach (ft/ft)

S_d = channel slope in the design reach (ft/ft)

The match reach is a reasonably stable reach located upstream or downstream of the project reach. It is an equivalent concept to the “upstream supply reach” mentioned in Copeland, et al. (2001).

5. Compute the wetted perimeter and top width using Equations (4.4) and (4.5).

$$P_d = b_d + 2\, y_d \sqrt{1 + m_d^{\,2}} \qquad (4.4)$$

$$W_d = b_d + 2\, m_d\, y_d \qquad (4.5)$$

where m_d = side slope for design reach, defined as run/rise (ft/ft)

6. Compute the discharge capacity of the trial design with Equation (4.6). Adjust y_d until Q_d from Equation (4-6) equals Q_d calculated in Step 1.

$$Q_d = \frac{1.49A_d^{5/3}}{n_d P_d^{2/3}} \sqrt{S_d} \tag{4.6}$$

7. Compute the channel length (fall in thalweg elevation divided by average channel slope, or valley length divided by sinuosity).

8. Compute the average meander wavelength with Equation (4.7).

$$\lambda_d = \frac{W_d}{W_r} \lambda_r \tag{4.7}$$

where

λ_d = the meander wavelength of the design channel, ft

W_d = the bankfull width of the design channel, ft

W_r = the bankfull width of the reference reach, ft

λ_r = the meander wavelength of the reference reach, ft

9. Lay out a planform with the correct length and an average meander wavelength approximately equal to the value obtained from Equation (4.7). McEnroe, et al. (2008) provides instructions for laying out a planform with regular meanders that approximates the sine-generated curve planform suggested by Langbein and Leopold (1966).

10. Compute the pool depth with Equation (4.8).

$$(\text{pool depth})_d = \frac{(\text{riffle depth})_d}{(\text{riffle depth})_r} \cdot (\text{pool depth})_r \tag{4-8}$$

where subscripts d and r refer to the design reach and reference reach, respectively.

11. Locate the riffles, pools, and transitions following the guidelines in Figure 4.2.

12. Design the bottom profile according to Figure 4.3.

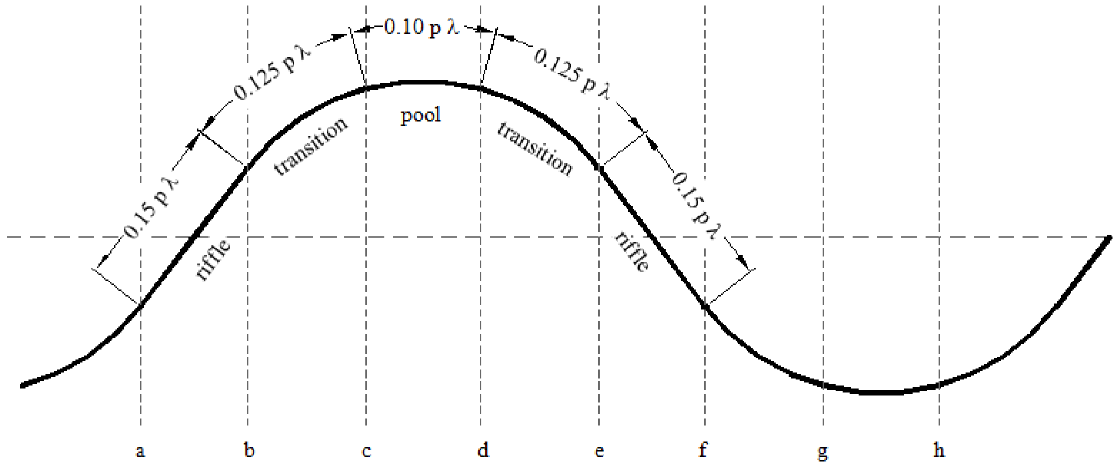

Figure 4.2. Location of riffles and pools

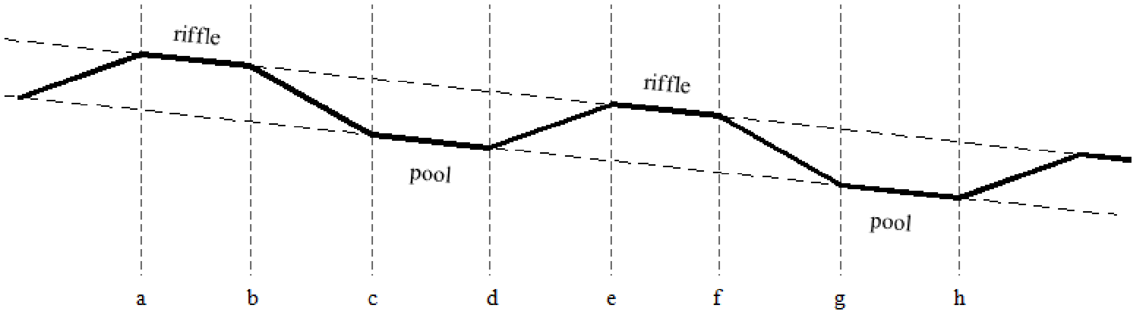

Figure 4.3. Bottom profile with riffles and pools

ARRM is a significant step forward for analytical channel design methods because it incorporates geomorphic relationships from a single reference reach, which should improve the chances of those features working together as a set. ARRM is also a significant step forward for reference-reach design methods because it incorporates site-specific flow and sediment transport. In ARRM, the bed-load transport is assumed to occur only over the bed portion. In addition, the ARRM bed profile is more realistic than the KAM bed profile.

ARRM designs a channel that has the same sediment transport capacity as the match reach for a single sediment size, the d_{50}. This sediment size is assumed to be an adequate surrogate for the entire sediment gradation. Chapter 6 tests this assumption with an analysis of the transport of the complete sediment gradation in seven ARRM designs.

As indicated in Figure 4.1, for a given slope, there are two, one, or no solutions. A solution gives a combination of slope, width and depth that pass the flow and sediment in equilibrium with the match reach. When a desired slope yields no solution, it means the sinuosity of the reference reach is too high. A reference reach with a lower sinuosity should be chosen. Often, the specified slope will yield two solutions. Project constraints or site-specific geomorphic information may dictate that one or the other solution is preferred. When either solution is feasible for the project and reasonable from a geomorphic perspective, the solution most similar to the match reach is usually the most appropriate.

ARRM is an excellent channel design methodology for small channel realignment and restoration projects. However, the channel cross-section is constrained to be trapezoidal with uniform side-slopes everywhere. Depending on project goals, a method that incorporates the cross-sectional shape and variability of the reference reach may be desired. The Scaled Geomorphic Method, presented in Chapter 5, provides this additional flexibility.

Chapter 4 References

Copeland, R. R., D. N. McComas, et al. (2001). *Hydraulic Design of Stream Restoration Projects*, Engineering Research and Development Center Vicksburg Coastal and Hydraulics Lab.

Doyle, M. and J. M. Harbor (2000). "Discussion of 'Evaluation of Rosgen's streambank erosion potential assessment in Northeast Oklahoma' by R. Daren Harmel, C. T. Haan, and Russell C. Dutnell." *The Journal of the American Water Resources Association,* 36(5): 1191-1192.

Kondolf, G. M. (1995). "Geomorphological stream channel classification in aquatic habitat restoration: Uses and limitations." *Aquatic Conservation: Marine and Freshwater Ecosystems,* 5(2): 127-141.

Langbein, W. B., and Leopold, Luna B. (1966). "River meanders- theory of minimum variance." *Professional Paper 422-H,* U.S. Geological Survey.

Lave, R. (2008). *The Rosgen Wars,* Doctoral Dissertation, University of California, Berkeley.

McEnroe, B. M., C. B. Young, and J. E. Shelley (2008). "Guidelines for stream realignment design." *Report No. K-TRAN KU-08-2,* Kansas Department of Transportation.

McEnroe, B. M., C. B. Young, and J. E. Shelley (2009). "Stream realignment design using a reference reach." *Report No. KTRAN KU-09-4,* Kansas Department of Transportation.

Millar, R. G. (2005). "Theoretical regime equations for mobile gravel-bed rivers with stable banks." *Geomorphology,* 64(3-4): 207-220.

Miller, J. and J. Ritter (1996). "An examination of the Rosgen classification of natural rivers." *Catena,* 27(3-4): 295-299.

Moses, T. and S. Morris (1998). "Environmental constraints to urban stream restoration, part 1." *Public Works*, 129(45).

NRCS (2007). "Stream restoration design." *National Engineering Handbook--Part 654*, Natural Resources Conservation Service.

Rosgen, D. (1996). *Applied River Morphology*, Pagosa Spring, Colorado, Wildland Hydrology.

Rosgen, D. L. (2008). "Discussion." *Journal of the American Water Resources Association*, 44(3): 782-792.

Simon, A., M. Doyle, et al. (2007). "Critical evaluation of how the Rosgen classification and associated natural channel design methods fail to integrate and quantify fluvial processes and channel response." *Journal of the American Water Resources Association*, 43: 1117-1131.

Soar, P. J. and C. R. Thorne (2001). *Channel restoration design for meandering rivers*, ERDC/CHL CR-01-1, U.S. Army Engineer Research and Development Center, Flood Damage Reduction Research Program, Vicksburg, MS.

5.0 Scaled Geomorphic Method

5.1 Components of SGM

This chapter presents the Scaled Geomorphic Method (SGM), an original reference-reach scaling mechanism that accounts for both flow and sediment transport. The strengths of other reference-reach approaches, including naturalistic cross-sections, bed profiles, and meander patterns, are retained in this method. The key improvement is that the stability criteria (conveyance of the proper bankfull discharge and sediment load) are provided for in the scaling mechanism. As with other analytical stable-channel design methods, SGM solves the three basic channel dimensions of slope, hydraulic radius, and wetted perimeter by using a flow resistance equation, a sediment transport equation, and a geomorphic relationship. In this case, the geomorphic relationship is derived from a cross-section of the reference reach.

SGM uses the Manning equation for flow resistance (see Equation 4.6). In this scaling method, as in many analytical river-restoration design methods, flow is assumed to be uniform at the bankfull discharge. This assumption allows the slope of the energy grade line to be approximated as the channel slope from the top of one riffle to the top of the next riffle.

This method assumes that a reasonably stable section of stream exists either upstream or downstream of the design reach. This stable section is called the “match reach” because flow and sediment transport in the design reach are set to match this reach. The match reach need not be a reference reach that possesses desirable geomorphic and ecologic features. Bankfull flow in the design reach is set equal to the bankfull flow in the match reach, as expressed by Equation (5.1).

$$\frac{1.49}{n_m} A_m R_m^{2/3} \sqrt{S_m} = \frac{1.49}{n_d} A_d R_d^{2/3} \sqrt{S_d} \tag{5.1}$$

where the subscript *m* denotes the match reach and *d* denotes the design reach.

A simplified form of the Meyer-Peter and Muller (MPM) equation is used to set the sediment transport in the design reach equal to the sediment transport in the match reach. The original MPM equation is shown in Equation (5.2) (ASCE 1975, from Meyer-Peter and Muller 1948). The k values in Equation (5.2) represent the reciprocal of the Manning 'n' coefficient and should not be confused with grain roughness values which are often denoted as k_s.

$$\left(\frac{k}{k'}\right)^{3/2} \gamma_w R_b S = 0.047(\gamma_s - \gamma_w)d_{50} + 0.25\left(\frac{\gamma_w}{g}\right)^{1/3}\left(\frac{\gamma_s - \gamma_w}{\gamma_w}\right)^{2/3} g_s^{2/3} \tag{5.2}$$

where

k = $1/n_b$, n_b = Manning n coefficient accounting for all bed roughness

k' = $1/n'_b$, n'_b = Manning n coefficient accounting only for particle roughness

γ_w = specific weight of water

γ_s = specific weight of sediment

d_{50} = sediment size for which 50% is finer by weight

g_s = sediment transport in actual weight per unit time per unit width

R_b = bed hydraulic radius

g = gravitation acceleration

Substituting $\rho = \gamma_w / g$, $G_s = \gamma_s / \gamma_w$, and using n-values rather than k-values, Equation (5.3) can be re-written as Equation (5.4) in the following steps:

$$\left(\frac{n_b'}{n_b}\right)^{3/2} \gamma_w R_b S = 0.047\left(\gamma_s - \gamma_w\right) d_{50} + \left(\frac{1}{4}\right)\left(\rho_w\right)^{1/3}\left(\frac{\gamma_s - \gamma_w}{\gamma_s}\right)^{2/3} g_s^{2/3}$$

$$g_s^{2/3} = \frac{4}{\left(\rho_w\right)^{1/3}}\left(\frac{\gamma_s}{\gamma_s - \gamma_w}\right)^{2/3}\left[\left(\frac{n_b'}{n_b}\right)^{3/2} \gamma_w R_b S - 0.047\left(\gamma_s - \gamma_w\right) d_{50}\right]$$

$$g_s = \left[\frac{4}{\left(\rho_w\right)^{1/3}}\left(\frac{G_s \gamma_w}{(G_s - 1)\gamma_w}\right)^{2/3}\right]^{3/2}\left[\left(\frac{n_b'}{n_b}\right)^{3/2} \gamma_w R_b S - 0.047\left(G_s - 1\right) d_{50}\right]^{3/2}$$

$$g_s = \frac{8}{\sqrt{\rho_w}}\left(\frac{G_s}{G_s - 1}\right)\left[\left(\frac{n_b'}{n_b}\right)^{3/2} \gamma_w R_b S - 0.047\left(G_s - 1\right) d_{50}\right]^{3/2}$$

$$Q_s = \frac{8P_b}{\sqrt{\rho_w}}\left(\frac{G_s}{G_s - 1}\right)\left[\left(\frac{n_b'}{n_b}\right)^{3/2} \gamma_w R_b S - 0.047\left(G_s - 1\right) d_{50}\right]^{3/2} \qquad (5.3)$$

where Q_s = sediment transport in weight/time (lbs/sec or N/sec)

For a planar bed, n_b' / n_b equals 1 and Equation (5.3) can be re-written as Equation (5.4). This is a simplifying assumption that may not strictly be valid for sand-bed streams at bankfull flow. However, as the same assumption is used on both the match reach and the design reach, any biases it introduces are expected to be minimal.

$$Q_s = \frac{8P_b}{\sqrt{\rho_w}}\left(\frac{G_s}{G_s - 1}\right)\left[R_b S - 0.047\left(G_s - 1\right) d_{50}\right]^{3/2} \qquad (5.4)$$

The specific gravity of natural river sediment, G_s, is approximated as 2.65. Stability in alluvial channels is achieved when the total sediment transported out of the reach equals the sediment input to the reach. The match reach is stable, which means its sediment transport capacity is roughly equal to the sediment input from the watershed, including upstream and overland sources. The design reach should have the same sediment transport capacity as the match reach so that it, too, is in equilibrium with the watershed. Assuming that no significant additions of sediment occur between the match reach and the design reach, this sediment transport condition can be described by Equation (5.5).

$$\frac{8P_m}{\sqrt{\rho}}\left(\frac{G_s}{G_s-1}\right)\left[R_mS_m-0.047(G_s-1)d_{50}\right]^{3/2}=\frac{8P_d}{\sqrt{\rho}}\left(\frac{G_s}{G_s-1}\right)\left[R_dS_d-0.047(G_s-1)d_{50}\right]^{3/2} \qquad (5.5)$$

All quantities that pertain to the match reach are measurable. The sediment properties d_{50} and G_s in the design reach are assumed to be the same as in the match reach. After substitution of A/P for R, the three unknowns in Equations (5.1) and (5.5) are A_d, P_d, and S_d.

At this point, the shape of the reference reach can be used to determine a unique solution. A linear scaling factor, s, is applied to the cross-sectional properties of the reference reach:

$$A_d = s^2A_r \qquad (5.6)$$

$$P_d = sP_r \qquad (5.7)$$

where the subscript *r* indicates the reference reach.

The use of the cross-sectional area and wetted perimeter of the reference reach with a scaling factor introduces two new equations and one new unknown, which results in a unique solution for A_d, P_d, and S_d. The slope of the design reach, S_d, determines its sinuosity. For the design reach to be a scaled version of the reference reach, the design sinuosity should closely match the sinuosity of the reference reach.

An exact match is unlikely, given the wide range of natural variability that exists in natural streams. Schumm (1963) reports variations in sinuosity of up to 16% from reach to reach of the stream due to the effects of meander cutoffs and migration. For design, I propose that the design sinuosity be allowed to vary from the sinuosity of the reference reach by a maximum of 15%. The planform configuration for the design reach may be designed using the practical line-and-arc planform given by McEnroe, et al. (2009) which approximates the sine-generated planform advocated by Langbein and Leopold (1966). Alternately, the scaling factor used to scale the cross-sections may be applied to the planform of the reference reach to yield the design planform. However, some distortion of this scaled planform may be necessary to assure that the correct sinuosity is achieved.

Not every stream can be scaled in a way that yields a sinuosity that is within 15% of the reference-reach sinuosity while still satisfying flow and sediment continuity. Streams with unacceptable design sinuosities are not appropriate, even if they are derived from reference reaches that are stable in their own watersheds. Thus, SGM is both a scaling method and a selection method. It can easily be employed to guide the selection of a reference reach from a database of potential reference reaches.

The scaling factor, s, can be applied to all linear measurements of the channel cross-section, profile, and planform. This allows much more of the natural variability and many more habitat features to be scaled from the reference reach than in other methods for natural channel design. The shapes of the riffle and pool cross-sections can be scaled. Any transitional cross-sections representing glides or runs can be scaled, as can features such as low-flow channels, slack-water areas, etc. The same scaling factor can be applied to the planform geometry or to average planform descriptors such as the meander wavelength. Project goals, cost, and constructability will guide the level of detail scaled from the reference reach.

5.2 Derivation of SGM Equations

Equal flow conveyance in the design channel and the match reach can be written using Manning's equation, as provided in Equation (5.1). Equation (5.1) can be re-written as Equation (5.8):

$$\frac{n_d}{n_m} A_m R_m^{2/3} \sqrt{S_m} = A_d R_d^{2/3} \sqrt{S_d} \qquad (5.8)$$

The sediment transport at bankfull flow in the downstream design reach should equal the transport in the upstream reach, approximated by the simplified Meyer-Peter and Muller equation. Equation (5.5) can be simplified by canceling terms that appear on both sides of the equation to yield the following:

$$P_{b,m}\left[R_{b,m}S_m - 0.047(G_s - 1)d_{50}\right]^{3/2} = P_{b,d}\left[R_{b,d}S_d - 0.047(G_s - 1)d_{50}\right]^{3/2} \quad (5.9)$$

The subscript *b* has been added to indicate that the hydraulic radius and wetted perimeter refer to the bed portion of the channel only. The hydraulic radius and wetted perimeter in Equation (5.9) pertain to the entire bankfull channel. This differentiation is illustrated in Figure 5.1.

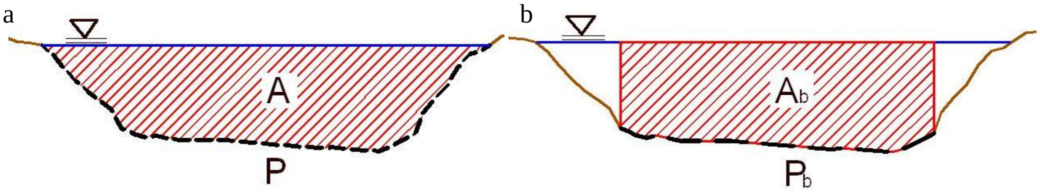

Figure 5.1. Area and wetted perimeter of the (a) bankfull channel and (b) bed

If we assume that the bed sediment composition in the design reach will equilibrate over time with the sediment in the match reach, then the term $0.047(G_s - 1)d_{50}$ is constant for a given problem. For simplicity, this term will be replaced by α in subsequent manipulations. In addition, for a given problem, the left-hand side of Equation (5.9) is a constant because it depends only on measurements from the match reach. The left-hand side of the equation is replaced with β in subsequent equations.

$$\alpha = 0.047\,(G_s - 1)\,d_{50} \quad (5.10)$$

$$\beta = P_{b,m}\left[R_{b,m}S_m - 0.047\,(G_s - 1)\,d_{50}\right]^{3/2} \quad (5.11)$$

Equations (5.10) and (5.11) can be substituted into Equation (5.9) to yield the following:

$$\beta = P_{b,d}\left[R_{b,d}S_d - \alpha\right]^{3/2} \tag{5.12}$$

Equation (5.12) can be rewritten to solve for the design slope in the downstream reach, S_d, in the following steps:

$$\left(\frac{\beta}{P_{b,d}}\right)^{2/3} + \alpha = R_{b,d}S_d \tag{5.13}$$

$$S_d = \left[\left(\frac{\beta}{P_{b,d}}\right)^{2/3} + \alpha\right] \Big/ R_{b,d} \tag{5.14}$$

Substituting Equation (5.14) into Equation (5.8) yields the following:

$$\frac{n_d}{n_m} A_m R_m^{2/3}\sqrt{S_m} = A_d R_d^{2/3}\sqrt{\left[\left(\frac{\beta}{P_{b,d}}\right)^{2/3} + \alpha\right] \Big/ R_{b,d}} \tag{5.15}$$

Let s be the linear scaling factor that will be applied to the reference reach, such that:

$$A_d = s^2 A_{ref} \tag{5.16}$$

$$R_d = s\, R_{ref} \tag{5.17}$$

$$P_{b,d} = s\, P_{b,ref} \tag{5.18}$$

$$R_{b,d} = s\, R_{b,ref} \tag{5.19}$$

Equations (5.16) to (5.19) are substituted into Equation (5.15) to yield Equation (5.20):

$$\frac{n_d}{n_m} A_m R_m^{2/3} \sqrt{S_m} = \left(s^2 A_{ref}\right)\left(s\ R_{ref}\right)^{2/3} \sqrt{\left[\left(\frac{\beta}{s\ P_{b,ref}}\right)^{2/3} + \alpha\right] \Big/ s\ R_{b,ref}} \tag{5.20}$$

If the upstream and downstream Manning ‘n’ values are assumed equal, Equation (5.20) simplifies to Equation (5.21):

$$A_m R_m^{2/3} \sqrt{S_m} = \left(s^2 A_{ref}\right)\left(s\ R_{ref}\right)^{2/3} \sqrt{\left[\left(\frac{\beta}{s\ P_{b,ref}}\right)^{2/3} + \alpha\right] \Big/ s\ R_{b,ref}} \tag{5.21}$$

The scaling factor, s, is the only unknown in Equation (5.21). Its value can be found by trial. After s is found, channel dimensions can be determined by Equations (5.16) to (5.19). Substituting Equations (5.18) and (5.19) into Equation (5.14) yields an explicit equation for channel slope:

$$S_d = \left[\left(\frac{\beta}{s\ P_{b,ref}}\right)^{2/3} + \alpha\right] \Big/ s\ R_{b,ref} \tag{5.22}$$

The resultant combination of cross-sectional measurements and channel slope should be checked for appropriateness. The sinuosity (p) of the design reach should fall reasonably close to the sinuosity of the reference reach. An appropriate tolerance may be ±15%.

If the sinuosity does not fall within an acceptable range, the reference reach is not appropriate. This means there is no way to scale the reference reach that will satisfy flow and sediment transport constraints and yield an acceptable design sinuosity. A new reference reach should be chosen and the previous steps repeated.

This process can be easily automated using a spreadsheet program and a database of stream data. A scaling factor, design slope, and design sinuosity can be calculated using each stream in the data base as the reference reach. The design sinuosity can then be compared with the sinuosity of the reference reach. Additional considerations such as proximity of the reference reach to the project site, stream type, similarities in watershed conditions, project goals and constraints, etc., can guide the engineer in selecting from among potential stream designs with acceptable sinuosities.

5.3 Procedures for SGM

This section provides a step-by-step procedure for performing the Scaled Geomorphic Method. The equations are repeated here.

1. Gather project reach location data: V_d (valley slope at design site)
2. Gather upstream reach data: A_m, P_m, R_m, $A_{b,m}$, $R_{b,m}$, $P_{b,m,}$, S_m, d_{50}, G_s
3. Gather reference reach data: A_{ref}, P_{ref}, R_{ref}, $A_{b,ref}$, $R_{b,ref}$, $P_{b,ref}$, and p_{ref} (sinuosity)
4. Calculate α and β with Equations (5.10) and (5.11).

$$\alpha = 0.047(G_s - 1)d_{50}$$

$$\beta = P_{b,m}\left[R_{b,m}S_m - 0.047(G_s - 1)d_{50}\right]^{3/2}$$

5. Substitute all values into Equation (5.21) and solve for the scaling factor, s, by iteration.

$$A_m R_m^{2/3}\sqrt{S_m} = \left(s^2 A_{ref}\right)\left(s\,R_{ref}\right)^{2/3}\sqrt{\left[\left(\frac{\beta}{s\,P_{b,ref}}\right)^{2/3} + \alpha\right] \Big/ s\,R_{b,ref}}$$

6. Solve for the design slope with Equation (5.22):

$$S_d = \left[\left(\frac{\beta}{s\,P_{b,ref}}\right)^{2/3} + \alpha\right] \Big/ s\,R_{b,ref}$$

7. Check the sinuosity of the design reach. If it is sufficiently close to the sinuosity of the reference reach, the reference reach can be used.

8. Repeat steps 3 through 7 for additional reference reaches. Choose the reference reach from among designs with appropriate sinuosities by considering project goals and constraints.

9. Scale the linear dimensions of the chosen reference-reach cross-sections by s to create the channel cross-sections. The scaling is accomplished by multiplying each cross-sectional transverse station and elevation point by s, as shown in Figure 5.2:

Reference Reach			Design Reach	
Sta	Elev		Sta	Elev
x1	y1	➡	s*x1	s*y1
x2	y2		s*x2	s*y2
x3	y3		s*x3	s*y3

Figure 5.2. Scaling the station-elevation points from the reference-reach cross-section

For simplicity in scaling, the transverse station and elevation points should be relative to the cross-section, not to an outside datum. For example, the station numbering can be measured from the left-most point on the cross-section and the elevation can be measured from the elevation of the thalweg.

10. The planform can be designed in one of two ways:
    a. Use the ratio of meander wavelength to bankfull width from the reference reach and the design sinuosity to create a planform configuration according to K-TRAN Report KU-09-04 (McEnroe, et al. 2009).

    b. Scale the reference-reach planform. This option is only appropriate if the design sinuosity is very close to the reference-reach sinuosity. Some distortion of the planform may be required.

11. Place the scaled cross-sections in the correct locations, using the reference reach as a guide.

5.4 Comparison of SGM to Other Methods

SGM shares key components with the Kansas Analytical Method (KAM) and the Analytical Reference Reach Method (ARRM). All three methods satisfy the stability criteria that the design reach conveys the bankfull flow and has the sediment transport capacity of the match reach. All three methods use Manning's equation and a simplified Meyer-Peter and Muller sediment-transport equation. However, each method also possesses unique features. Table 5.1 summarizes the similarities and differences among the three methods.

A channel designed using the KAM has trapezoidal cross-sections, a reasonable bankfull width, a reasonable meandering planform, and zero-length riffles and pools. Bed-load transport is assumed to occur over the entire wetted perimeter. The same assumption is applied in the match reach as well as the design reach. A channel designed using the ARRM also has trapezoidal cross-sections. Its sinuosity, meander wavelength, and pool depth are copied or scaled from a local reference reach, and riffles and pools have reasonable lengths. Bed-load transport is assumed to occur over the bed only, a more realistic assumption. However, neither KAM nor ARRM provide guidance on how to scale additional features from the reference reach.

SGM is similar to ARRM in that it incorporates both analytical and reference-reach concepts. The reference-reach riffle cross-section provides the geomorphic relationship that is used with the flow resistance and sediment transport equations to yield a unique design. The key benefit of SGM is that it provides a scaling factor that can be used to scale actual cross-sections from the reference reach. These cross-sections need not be trapezoidal or limited to riffles only. This feature of SGM is especially advantageous for capturing a realistic pool shape and additional channel variability present in intermediate cross-sections. The key weakness in SGM is that the sinuosity in the design reach is not forced to match the sinuosity of the reference reach. This distortion can be avoided by choosing a reference reach that scales to yield a design sinuosity that closely matches the reference reach. Multiple reference reaches may need to be scaled to find one that yields an appropriate sinuosity. This can be accomplished efficiently with a database of reference reaches, such as the Kansas Reference Reach Dataset (McEnroe, et al. 2009).

Table 5.1 Comparison of KAM, ARRM, and SGM design methods

Feature	KAM	ARRM	SGM
Riffle X-Section	Trapezoidal	Trapezoidal	Scaled from the reference reach
Pool X-Section	Trapezoidal with same bottom width and side slopes as riffle	Trapezoidal with same bottom width and side slopes as riffle	Scaled from the reference reach
Bankfull Width	Hydraulic geometry equation	Calculated analytically	Implicit in the natural cross-section
Riffle Depth	Calculated analytically	Calculated analytically	Implicit in the natural cross-section
Slope	Calculated analytically	From the sinuosity of the reference reach	Calculated analytically
Pool depth	Average geomorphic relationship	Scaled from the reference reach	Implicit in the natural cross-section
Meander wavelength	Average geomorphic relationship	Scaled from the reference reach	Scaled from the reference reach
Sinuosity	Calculated from channel slope	Copied from the reference reach	Reasonably similar to the reference reach
Planform	Approximates a sine-generated curve	Approximates a sine-generated curve	Approximates a sine-generated curve or scaled from the reference reach
Profile	Saw-tooth	Reasonable riffle and pool lengths with transitions (glides and pools)	Can approximate the natural profile to as much detail as desired
Additional X-Sections	None	None	As many as desired--scaled from the reference reach

5.5 Applicability and Limitations

SGM is an alluvial channel design method applicable to channels with beds that are mobile at the bankfull discharge. It is not applicable to streams with beds of cohesive clay, bedrock, or large cobbles or boulders that are not mobilized by bankfull flow events. In addition, it only applies to streams with adequate sediment inputs to replace sediment transported out of the reach. Streams in urban settings may have storm drain systems for headwaters and relatively little sediment contribution from overland sources. In these cases threshold channel design methods that design the channel boundary to remain immobile are more appropriate.

SGM allows additional variability in the constructed channel which equates to additional difficulty in construction. This unavoidable trade-off will limit the number of cross-sections actually scaled from the reference reach. This method gives the river designer the power to choose how many cross-sections to scale from the reference reach and whether or not to generalize cross-sectional characteristics based on project goals and constraints.

5.6 Example

Fall Creek is a hypothetical small stream in North-Central Kansas. The stream was widened, straightened, and moved to the edge of the property thirty years ago. The first twenty years following the modifications, the stream regained a little sinuosity and decreased its width slightly. There have not been significant changes over the past decade. Fisheries biologists have noted that Fall Creek still lacks the habitat diversity that can be found on nearby streams in the region. Ivanpah Creek, a nearby reference reach from the Kansas Reference Reach Database, has abundant habitat diversity: high sinuosity, riffles, pools, glides, runs, and an in-channel bench with important habitat value. The land owner has received a federal grant to restore the ecological function of Fall Creek. This example follows the steps given in Section 5.3.

Steps 1-3: Collect geomorphic data.

Two geomorphic surveys were performed: one on a stable, downstream section of Fall Creek, which will be used as the match reach, and one on Ivanpah Creek, the reference reach. Table 5.2 and Table 5.3 present key measurements taken on these reaches. Table 5.4 presents the station/elevation coordinates for the riffle cross-section surveyed on Ivanpah Creek. The reference-reach survey on Ivanpah Creek also included cross-sectional surveys of the pool directly after the riffle, a run located between the riffle and the pool, and a glide located after the pool before the next riffle. The locations of the cross-sections and the distances between them are shown on Figure 5.3. Note that the Deepest Pool is located 55% of the distance between the Center of Bend and the next Start of Riffle.

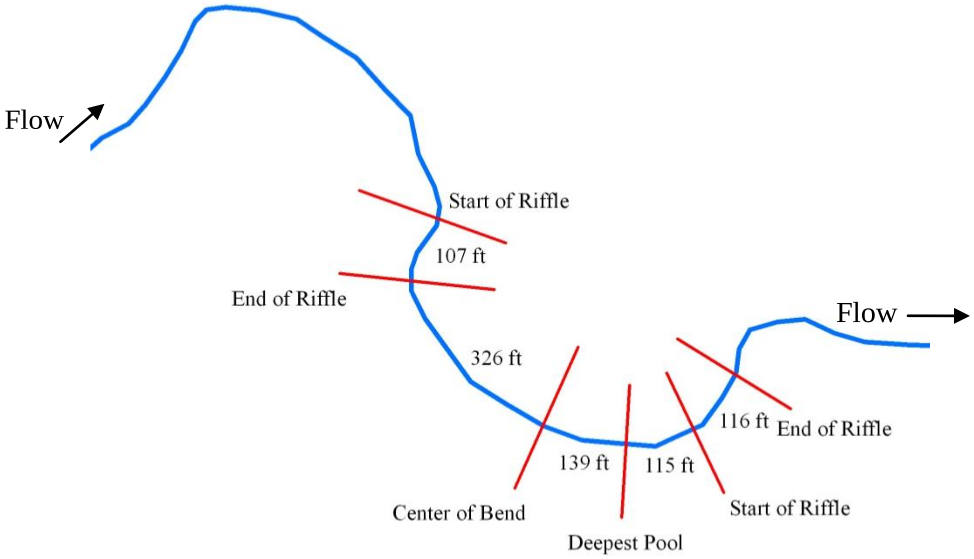

Figure 5.3. Location of cross-sections on Ivanpah Creek (reference reach) and the distances between them

Table 5.2. Measurements for Fall Creek (match reach)

A_m (ft)^2	27.39
P_m (ft)^2	26.50
R_m (ft)	1.03
$A_{b,m}$ (ft)^2	26.18
$P_{b,m}$ (ft)^2	23.17
$R_{b,m}$ (ft)	1.13
S_m	0.01438
d_{50} (ft)	0.1476
G_s	2.65
V_d	0.0164

Table 5.3. Measurements for Ivanpah Creek (reference reach)

A_{ref} (ft^2)	41.63
P_{ref} (ft^2)	34.31
R_{ref} (ft)	1.21
$A_{b,ref}$ (ft^2)	19.78
$P_{b,ref}$ (ft^2)	11.02
$R_{b,ref}$ (ft)	1.79
p_{ref}	1.26

Symbols are defined as stated in Sections 5.2 and 5.3.

Step 4. Calculate α and β by Equations (5.10) and (5.11).

$\alpha = 0.01145$

$\beta = 0.007694$

Step 5. Substitute all values into Equation (5.21) and solve for s by iteration.

$s = 0.829$

Step 6. Solve for the slope of the design reach with Equation (5.22):

$S_d = 0.0137$

Step 7. Check the sinuosity. If the sinuosity is appropriate, the reference reach can be used.

$p_d = V_d/S_d = 1.20$

$p_d/p_{ref} = 0.95$

Sinuosity is within 15%. Set the channel slope to S_d.

Step 8. Scale the chosen reference-reach cross-sections by the scaling factor, s, to create the channel cross-sections. The transverse stations and elevations are specified relative to the left-most station and the channel thalweg.

Table 5.4. Riffle cross-section scaling

Reference Reach		**Design Reach**	
Sta (ft)	**Elev (ft)**	**Sta (ft)**	**Elev (ft)**
0	3.03	0	2.51
2	2.95	1.66	2.45
4	2.89	3.32	2.4
6	2.8	4.97	2.32
8	2.62	6.63	2.17
10	2.67	8.29	2.21
10.5	1.94	8.7	1.61
11	1.53	9.12	1.27

Table 5.4. Riffle cross-section scaling (cont)

Reference Reach		**Design Reach**	
Sta (ft)	**Elev (ft)**	**Sta (ft)**	**Elev (ft)**
12	1.23	9.95	1.02
13	0.38	10.78	0.32
14	0.13	11.61	0.11
15	0.2	12.44	0.17
16	0.22	13.26	0.18
17	0.23	14.09	0.19
18	0.2	14.92	0.17
19	0.09	15.75	0.07
20	0.12	16.58	0.1
21	0.18	17.41	0.15
22	0.15	18.24	0.12
23	0.07	19.07	0.06
24	0.04	19.9	0.03
25	0	20.73	0
26	0.11	21.55	0.09
27	0.33	22.38	0.27
28	0.5	23.21	0.41
30	1.01	24.87	0.84
32	1.04	26.53	0.86
34	1.15	28.19	0.95
36	1.18	29.84	0.98
38	0.92	31.5	0.76
40	1.12	33.16	0.93
42	1.26	34.82	1.04
44	1.94	36.48	1.61
46	1.91	38.13	1.58
48	1.95	39.79	1.62
50	1.9	41.45	1.58
52	1.73	43.11	1.43

The same scaling factor is also applied to the pool, glide, and run cross-sections in a similar manner. Using the planform design guidance provided in K-TRAN Report KU-09-4 (McEnroe, et al. 2009), the plan view looks as shown in Figure 5.4.

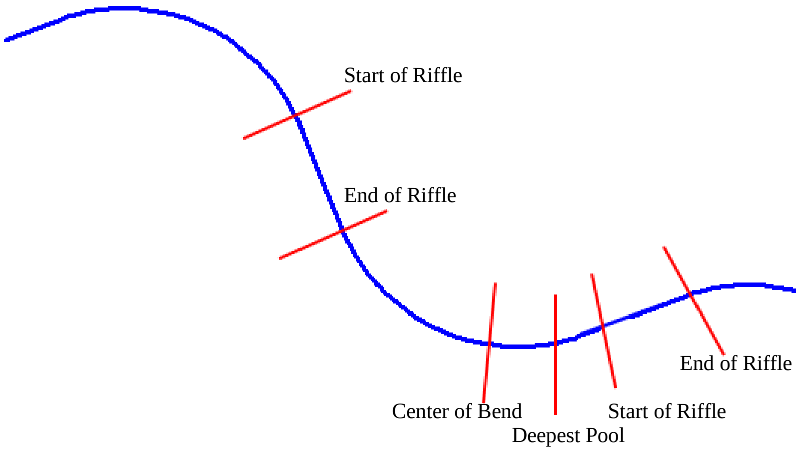

Figure 5.4. Plan view of the redesigned reach of Fall Creek

The relative locations of the Start of Riffle, End of Riffle, and Center of Bend are specified in KTRAN KU-09-4 (McEnroe et al. 2009). The placement of additional cross-sections is accomplished using the reference reach as a guide. To mimic the reference reach, the deepest pool is placed 55% of the distance between the Center of Bend and the next Start of Riffle.

5.6 Conclusions

Analytical and reference-reach approaches possess complementary strengths for natural channel design. The Scaled Geomorphic Method is a straight-forward natural channel design method that incorporates the strengths of both approaches. It includes analytical stability criteria and site-specific flow and sediment inputs. It also allows for the design of ecological features present in natural cross-sections, profiles, and planforms by scaling these features from a reference reach.

Chapter 5 References

ASCE (1975). *Sedimentation Engineering*, American Society of Civil Engineers, New York, NY.

Langbein, W. B., and Leopold, Luna B. (1966). "River meanders – theory of minimum variance." *Professional Paper 422-H*, U.S. Geological Survey.

McEnroe, B. M., C. B. Young, and J. E. Shelley (2009). "Stream realignment design using a reference reach." *Report No. KTRAN KU-09-4*, Kansas Department of Transportation.

Meyer-Peter, E. and R. Müller (1948). “Formulas for bed-load transport.” *Proceedings of the 2nd Meeting of the International Association for Hydraulic Structures Research*, Delft, Netherlands.

Schumm, S. A. (1963). "Sinuosity of alluvial rivers on the Great Plains." *Geological Society of America Bulletin*, 74(9): 1089-1100.

6.0 Sediment Generalization

The Kansas Analytical Method (KAM), Analytical Reference Reach Method (ARRM), and Scaled Geomorphic Method (SGM) share a simplifying assumption with regard to sediment transport. They assume that a channel designed for equilibrium transport of the d_{50} will likewise have equilibrium transport over the natural range of sediment sizes in the channel bed. For design purposes, the d_{50} is assumed an adequate surrogate for the entire sediment gradation. This chapter discusses how sediment gradations are generalized for river engineering applications and tests the validity of using the d_{50} as the basis for ARRM designs.

6.1 Sediment Generalization

Engineering and geomorphic equations often simplify sediment gradations. Commonly, a statistical distribution of sediment sizes is assumed and the mean and standard deviation of sediment sizes is calculated. Most often, bed sediment is assumed to be log-normally distributed (ASCE 2008), though other distributions have been suggested (Hajek, et al. 2010). The Brownlie (1981) resistance formula, which is incorporated into the HEC-RAS Stable Channel Design method, assumes a log-normal distribution of sediment sizes.

Many engineering methods simplify the sediment gradation further by using a single sediment size to represent the complete gradation of sediment sizes. Einstein and Barbarossa (1952) require the d_{65} for their sand-bed resistance equation. Hey (1979) presents a resistance equation based on the d_{84}. Rosgen (1996) classifies streams by the d_{50}. KAM, ARRM, and SGM calculate sediment transport based on the d_{50}.

Many sediment gradations exhibit a bi-modal or multi-modal distribution of sediment. This is evident in the sediment size distribution for the Verdigris River, collected approximately 470 feet downstream from the Kansas Highway 57 bridge (Emmert and Hase 2001). The pebble-count gradation is provided in Table 6.1 and plotted in Figure 6.1. In this sample, the d_{50} of 22.6 mm is only present in small amounts and is clearly not the dominant bed material.

Table 6.1. Verdigris River Sediment Gradation

d (mm)	% Finer
0.125	19
0.25	21
0.5	23
1	27
2	30
4	42
5.7	44
8	47
16	48
22.6	50
32	55
45	62
64	68
90	74
128	80
180	86
256	91
362	92

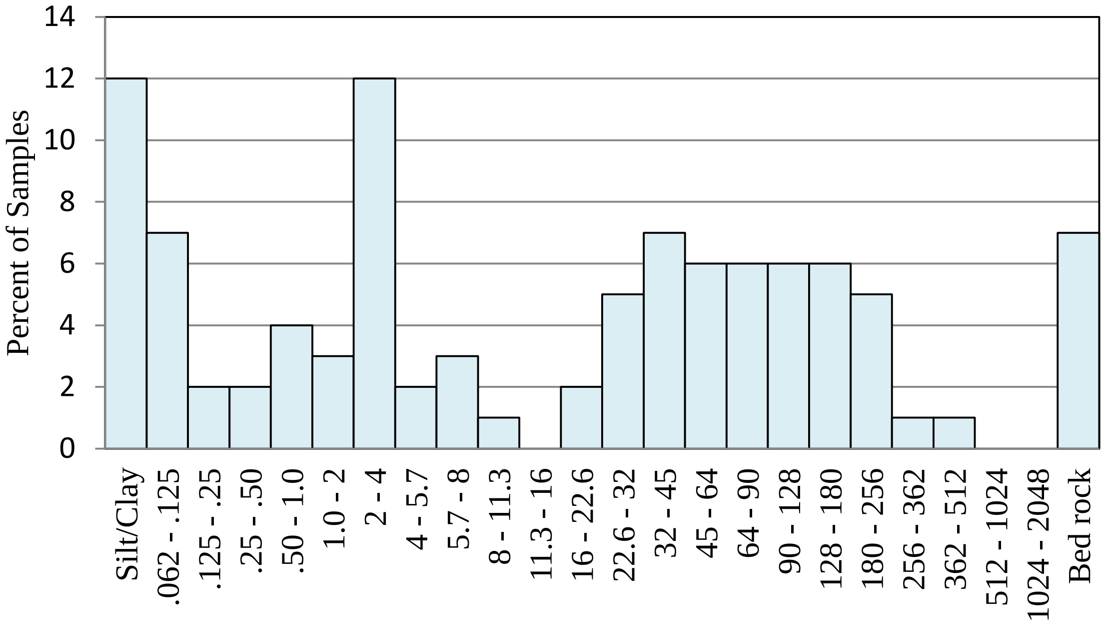

Figure 6.1. Verdigris River sediment gradation

Computer sediment transport models such as HEC-RAS (US Army Corps of Engineers), SRH-1D (Bureau of Reclamation), and CONCEPTS (US Department of Agriculture) calculate sediment transport capacity without assuming a statistical distribution or representative sediment size for the entire gradation. These computational tools divide the sediment gradation into standard sieve sizes, analyze each fraction of the sediment separately and weight the results based on the prevalence of that size of sediment in the bed. This approach was developed by Einstein (1950) and is still used by virtually all sediment transport models, including two- and three-dimensional models. This approach can be used on streams with bi-modal or multi-modal distributions of sediment gradations, as no assumption about the statistical distribution of grain sizes is required. Adjustment factors can be included to model the effects that large sediment can have on small sediment transport (Proffitt and Sutherland 1983) or that high concentrations of fines can have on coarse sediment transport (Colby 1964).

The gradation of sizes is not constant across a stream cross-section or along its profile. Disparate locations on a stream with different velocities, such as riffles versus pools or the inside versus the outside of a bend, can have different sediment gradations (Milne 1982). Downstream fining, a decrease in sediment size in the downstream direction, has been observed in field and flume studies (Furguson, et al. 1996; Paola, et al. 1992). The Kansas River, on the other hand, has a remarkably constant sediment gradation over its 178-mile length (SLA 1984). A sediment sample from a single location may not be representative of the average sediment gradation for a reach.

Channels designed according to KAM, ARRM, and SGM have similar sediment transport capacity for the d_{50} as the match reach. However, equal transport of the d_{50} does not necessarily assure equal transport of the other sizes of sediment. This chapter compares the total sediment transport capacity in seven match reaches to seven reaches designed for equal conveyance of the d_{50}. These are ARRM designs, but the results should be representative of SGM designs as well. This section is divided into three parts. First, the sediment transport capacity ratio and the HEC-RAS sediment capacity tool are introduced. Second, the analysis is described. Third, the results of the analysis comparing the sediment transport capacity in the match reaches and the design reaches are presented.

6.2 Sediment Transport Capacity Analysis

The sediment transport capacity indicates how much of a specific size of sediment a given flow can transport. Soar and Thorne (2001) present a concept they call the “sediment capacity ratio” (SCR). The SCR is the ratio of the sediment transport capacity of the design reach to the sediment transport capacity in an “upstream supply reach” which is equivalent to the match reach used in KAM, ARRM, and SGM. Soar and Thorne (2001) calculate the sediment transport capacity based on several years worth of daily flow values. They recommend that the SCR fall within 0.9 and 1.1. The SCR presented in this section differs from the SCR in Soar and Thorne (2001) because it evaluates the sediment transport capacity at a single bankfull flow, not over a series of daily flows. Accordingly, it will be referred to as the bankfull sediment capacity ratio (BSCR). A BSCR close to 1 indicates that the design reach can convey an equal quantity of sediment as the match reach at the bankfull flow.

For this analysis, the sediment transport capacity tool in HEC-RAS 4.0 was used to calculate the bankfull sediment transport capacity in the match reaches and design reaches. HEC-RAS calculates the sediment transport capacity of each sediment size separately, as if the bed were composed only of that sediment size. Then, each calculated capacity is multiplied by the fraction of that size present on the channel bed. The total sediment transport capacity is the sum of the weighted sediment transport capacities for the individual sizes. HEC-RAS extracts the required hydraulic parameters from the output of the hydraulic model. The parameters are calculated for three regions: the main channel and the left and right overbanks. The overbanks represent regions with different sediment properties, which do not necessarily coincide with the bank stations used in the hydraulic model. For this analysis the channel side slopes were modeled as overbanks in order to isolate the sediment transport capacity for the bed.

In this analysis, only the Meyer-Peter and Muller bed-load transport function was used. By default, HEC-RAS only applies the function to the sediment sizes documented in the function's development, which for the Meyer-Peter and Muller function are 0.4 to 29 mm. The default can be changed, however, to allow the function to calculate outside its normal range of applicability. Both options were assessed.

The seven reference reaches from the Kansas Reference Reach Dataset used as match reaches are listed in Table 6.2. Geomorphic information for these reaches is provided in Appendix B. The first two match reaches have a d_{50} in the sand range. The next five reaches have a d_{50} in the gravel range. Additional gravel streams are included because sediment transport is more sensitive to sediment size in the gravel range. The sediment gradations for these reaches are shown in Figure 6.2.

Table 6.2. Match Reaches

Match Reaches	d_{50} (mm)
Cimarron River Near Elkhart	0.34
Soldier Creek near Belvidere	0.79
Verdigris River near Madison	22.6
Tributary to West Bound Fall River near Eureka	34.3
Tributary to Rock Creek near Council Grove	21.2
Tributary to Antelope Creek near Zeandale	6.38
Oleson Creek Near Eureka	12.6

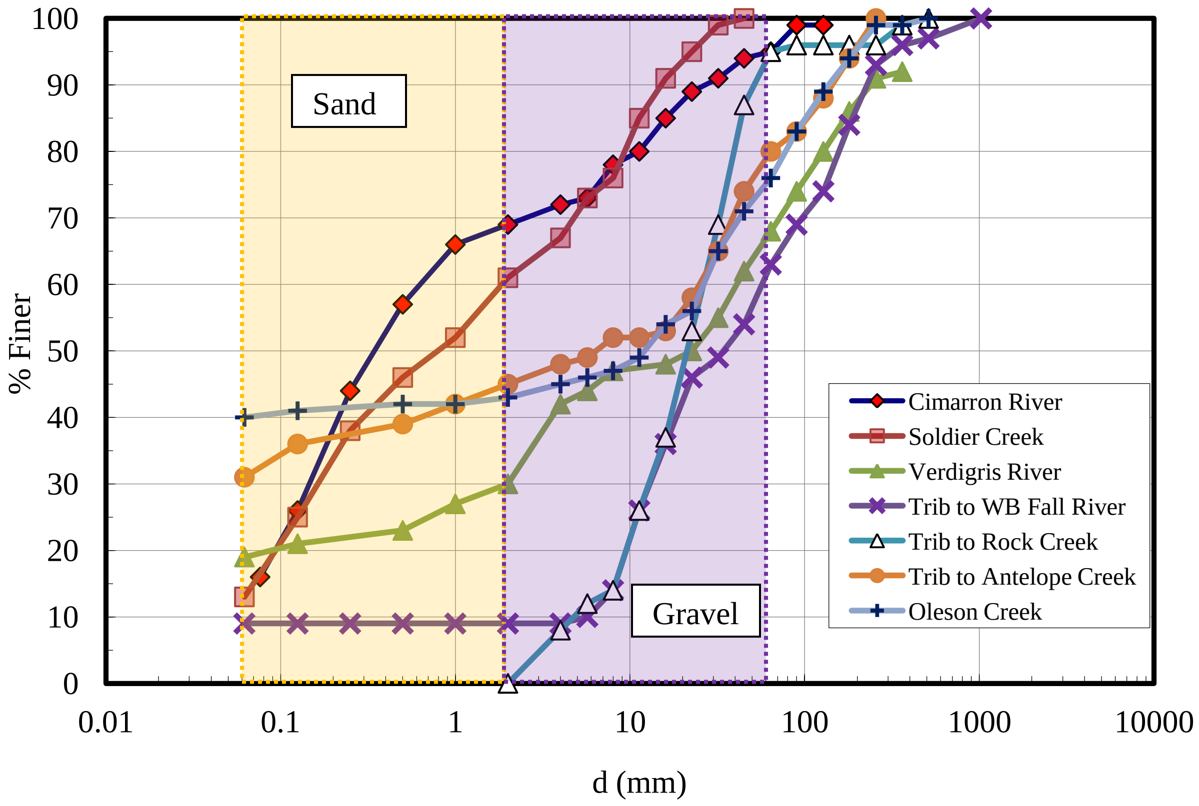

Figure 6.2. Sediment gradations. Dotted regions illustrate sand and gravel size ranges.

ARRM procedures were used to design seven stable channels, one for each match reach. As discussed in Chapter 4, no solution, one solution, or two solutions may be possible for a given slope. For this analysis, when two solutions were present, the solution with a W/D ratio closer to the W/D ratio of the match reach was chosen. When possible, a design sinuosity that exceeded the match reach sinuosity is specified. Trial designs with channel slopes that were significantly smaller than the slopes of the match reaches yielded no solution. This is because the match reaches had slopes close to the minimum slope solution (see Figure 4.1). Therefore, only less dramatic increases in sinuosity were possible for most of the design reaches. No increase in sinuosity was possible for the design using the Verdigris River as the match reach. In this case, the sinuosity was decreased.

The sediment transport capacity for the match reaches was assessed by performing the basic steps outlined in Parr and Shelley (2009). These steps included the following:

1. A HEC-RAS project for the match reach was created. The geometry consisted of a single riffle cross-section repeated three times. The elevations of the second and third cross-sections were increased to produce a channel bottom slope equivalent to the bankfull channel slope for the match reach. The downstream boundary condition was set to normal depth.

2. The HEC-RAS sediment transport capacity tool was used to quantify the sediment transport capacity of this prismatic match reach using the full sediment gradation.

3. A HEC-RAS project for the design reach was created. The geometry consisted of three identical trapezoidal cross-sections designed according to ARRM guidelines. The elevations of the second and third cross-sections were increased to produce the correct design slope. The downstream boundary condition was set to normal depth.

4. The HEC-RAS sediment transport capacity tool was used to quantify the sediment transport capacity of this prismatic match reach using the same full sediment gradation as the match reach.

5. The sediment capacity ratio was calculated. This ratio was defined as the sediment transport capacity of the design reach divided by the sediment transport capacity of the match reach. This ratio was calculated for each size class separately and for the weighted average sediment transport capacity.

Table 6.3 presents the d_{50} for each design, the chosen design sinuosity, and the match reach sinuosity.

Table 6.3. Parameters used in ARRM designs

	Cimarron River	Soldier Creek	Verdigris River	Trib to WB Fall River	Trib to Rock Creek	Trib to Antelope Creek	Oleson Creek
d_{50} (mm)	0.34	0.79	22.6	34.3	21.2	6.38	12.6
design sinuosity	2.1	1.4	1.7	1.2	1.42	1.6	1.45
match sinuosity	1.87	1.2	1.86	1.14	1.37	1.53	1.23

6.3 Results and Discussion

Table 6.4 presents the results for each design. Five out of seven streams (both of the sand-bed streams and three of the gravel-bed streams) have a BSCR that falls between 0.97 and 1.05. These values are within the 0.9 to 1.1 range suggested by Soar and Thorne (2001). This suggests that designing for equilibrium transport of the d_{50} sediment size in many cases leads to a channel in equilibrium for the entire sediment gradation.

However, the BSCR for two gravel-bed streams, Verdigris River and Tributary to Rock Creek, are 1.27 and 1.21, respectively. An analysis of the BSCR values for each individual size class demonstrates that in both of these cases the d_{50} is near the largest size of sediment that a bankfull flow event can transport. A significant fraction of the bed sediment larger than d_{50} is not mobile at bankfull flow and must have been deposited by larger flow events or through non-fluvial processes. In these cases, an alluvial channel design may not be appropriate, or it may be more appropriate to design a channel for equal transport of the median *transportable* sediment size at bankfull flow.

Table 6.4. BSCR by Grain Size

Sediment Size Range (mm)	Cimarron River	Soldier Creek	Verdigris River	Trib to WB Fall River	Trib to Rock Creek	Trib to Antelope Creek	Oleson Creek
0.0625 - 0.125	0.99	1.06	1.29	-	-	1.22	0.96
0.125 - 0.25	0.99	1.06	1.29	-	-	1.22	0.96
0.25 - 0.5	1.00	1.05	1.29	-	-	1.21	0.96
0.5 - 1	1.03	1.04	1.28	-	-	1.21	-
1 - 2	1.21	1.02	1.27	-	-	1.20	0.97
2 - 4	-	0.91	1.25	-	1.00	1.17	0.99
4 - 8	-	-	1.19	0.95	1.00	1.09	1.04
8 - 16	-	-	0.98	0.95	1.00	0.72	1.36
16 - 32	-	-	-	0.97	0.99	-	-
full gradation	1.00	1.05	1.27	0.96	1.00	1.21	0.97

Table 6.4 indicates that for many design situations, the d_{50} is an appropriate surrogate for the entire sediment gradation. However, the d_{50} may not be an appropriate surrogate where the d_{50} in the bed is near the largest size a bankfull flow can transport. The bankfull sediment capacity ratio is an appropriate and relatively simple back-check for designs using KAM, ARRM, and SGM.

6.4 Conclusions

This chapter assesses the validity of using the d_{50} to represent the range of sediment sizes found in the river bed. The bankfull sediment capacity ratio (BSCR) for seven streams designed for equilibrium transport of the d_{50} is calculated using the HEC-RAS sediment transport capacity tool. In five out of seven of the streams analyzed (two out of two sand-bed streams and three out of five gravel-bed streams), the sediment capacity ratios for the design streams fall within 0.9 to 1.1, indicating that the sediment transport capacity for the complete sediment gradation is within 10% of the sediment transport capacity in the match reaches. However, two gravel-bed reaches have BSCR values of 1.27 and 1.21, respectively. These reaches are unique, in that the bankfull flow is only barely competent to transport the d_{50}. A design based on the d_{50} cannot assure adequate equilibrium transport for the entire sediment gradation in all situations. River designers may want to calculate the BSCR for their designs using the full sediment gradation.

Chapter 6 References

Brownlie, W. R. (1981). “Prediction of flow depth and sediment discharge in open channels” *Report No. KH-R-43A*. Pasadena, CA, California Institute of technology, W.M. Keck Laboratory of Hydraulics and Water Resources.

Einstein, H. A. (1950). “The bed load function for sediment transportation in open channels.” *Technical Bulletin No. 1026*. Soil Conservation Service.

Einstein, H. A. and N. L. Barbarossa (1952). "River channel roughness." *Transactions of the American Society of Civil Engineers* 117: 1121-1132.

Emmert, B.E. and K. Hase (2001). *Geomorphic Assessment and Classification of Kansas Riparian Systems*. Prepared for the Environmental Protection Agency under contract No. CD 997520-01.

Ferguson R., T. Hoey, et al. (1996). "Field evidence for rapid downstream fining of river gravels through selective transport." *Geology* 24(2): 179-182.

Hajek, E., S. Huzurbazar, et al. (2010). "Statistical characterization of grain-size distributions in sandy fluvial systems." *Journal of Sedimentary Research* 80(2): 184-192.

Hey, R. (1979). "Flow resistance in gravel-bed rivers." *Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers* 109(6): 842-851.

Parr, A. D. and J. E. Shelley (2009). "A study of fluvial geomorphology aspects of hydraulic design." *Report No. K-TRAN KU-08-5*. Kansas Department of Transportation.

Proffitt, G. T. and A. J. Sutherland (1983). "Transport of non-uniform sediments." *Journal of Hydraulic Research* 21(1).

Rosgen, D. (1996). *Applied River Morphology*. Pagosa Spring, Colorado, Wildland Hydrology.

SLA (1984). “Analysis of channel degradation and bank erosion in the lower Kansas River.” *MRD Sediment Series 35*. Prepared by Simons Li and Associates for the U.S. Army Corps of Engineers, Kansas City District.

Soar, P. J. and C. R. Thorne (2001). *Channel restoration design for meandering rivers*, ERDC/CHL CR-01-1, U.S. Army Engineer Research and Development Center, Flood Damage Reduction Research Program, Vicksburg, MS.

7.0 Conclusion

Natural channel design is an important and emerging field of river engineering. There are many uses for methods to engineer channels to mimic natural stream channels. This dissertation presents methods and equations for incorporating the principles of natural channel design into river and stream engineering in the state of Kansas.

The average return period of bankfull flow in Kansas reference reaches is found to be 1.2 years (see Chapter 2). A regression equation is developed that predicts the 1.2-year discharge based on three watershed parameters: the contributing drainage area, the mean annual precipitation, and the length of the longest flow path. This equation is suitable to determine the design discharge for natural channel design for streams in small, unregulated watersheds in Kansas.

The Soar and Thorne (2001) hydraulic geometry equations, which relate the channel width to the square root of bankfull discharge, are found to be appropriate for sand- and gravel-bed streams in eastern and central Kansas (see Chapter 3). The Soar and Thorne equations may under-predict the width of streams in arid regions of western Kansas. An equation similar to the Soar and Thorne equations is developed for cohesive-bed streams. The meander wavelength of Kansas streams is found, on average, to be eleven times the bankfull width, though considerable variability exists. The upper bound on sinuosity is shown to be a function of the valley slope. Streams in less steep valleys have sinuosities as high as 2.8, while streams in steeper valleys have sinuosities no higher than 1.7. Streams with lower sinuosity are present on all valley slopes. The pool depth is found to be a linear function of the depth of the adjacent riffle. A design equation for pool depth is presented.

Three original design methods are presented: the Kansas Analytical Method (KAM) (see Chapter 4), the Analytical Reference Reach Method (ARRM) (see Chapter 4), and the Scaled Geomorphic Method (SGM) (see Chapter 5). These methods allow the design of channel width, depth, slope, riffles, pools, and meanders. All three use Manning's equation, the Meyer-Peter and Muller transport equation, and a third geomorphic equation to solve for channel wetted perimeter, hydraulic radius, and slope. KAM uses the Soar and Thorne hydraulic geometry equations as the geomorphic relationship. ARRM uses the sinuosity of a reference reach as the geomorphic relationship. SGM uses the relationship between bankfull area and wetted perimeter in a reference-reach cross-section. ARRM and SGM derive additional geomorphic information from the reference reach that is used to design meanders and pools.

KAM, ARRM, and SGM produce a channel that has equal sediment transport capacity of a single sediment size, the d_{50}. Designing for equal transport of the d_{50} is shown to yield a channel in approximate equilibrium with the total sediment load in five out of seven stream designs. Two out of seven stream designs, however, have bankfull sediment transport capacities that differ by 21 and 27%, respectively, from their match reaches. Imbalances of this magnitude are more likely when a significant portion of the bed sediment remains immobilized at bankfull flow. An analysis of the sediment transport continuity over the entire range of sediment sizes is recommended as a design check.

The geomorphic relationships were developed using data from Kansas streams and are suitable for use in Kansas or other nearby areas with similar watershed conditions. The design methods presented in this dissertation can be used in other regions to design meandering channels

(Rosgen stream type C or E), provided the equation used to calculate the bankfull flow is applicable to the local area and an appropriate, local reference reach is used.

Research into the complex field of river hydraulics, sedimentation, and geomorphology will continue to better define geomorphic processes and create more robust models. This dissertation presents practical geomorphic equations based on Kansas stream data. In addition, it presents stream design methods that combine traditional hydraulic engineering and fluvial geomorphology in unique ways to further the practice of natural channel design.

Chapter 7 References

Soar, P. J. and C. R. Thorne (2001). *Channel restoration design for meandering rivers*, ERDC/CHL CR-01-1, U.S. Army Engineer Research and Development Center, Flood Damage Reduction Research Program, Vicksburg, MS.

Appendix A- Data used in flow regression

Appendix B- Kansas Reference Reach Data Set

A1- Bankfull flow in streams in the Kansas Reference Reach Data Set

Stream Gage #	Stream Name	Drainage Area (sq mi)	Bankfull Flow (cfs)	Return Period* (years)
6858500	North Fork Smoky Hill River near McAllaster	650	53.77	1.28
7139800	Mulberry Creek near Dodge City	73.8	38.2	1.09
6844900	South Fork Sappa Creek near Achilles	378	56.97	1.15
6860500	Hackberry Creek at Gove	421	87.16	1.21
6846000	Beaver Creek at Ludell	1120	71.83	1.06
6889100	Soldier Creek near Goff	2.06	190.7	1.25
7142575	Rattlesnake Creek near Zenith	519	216.3	1.35
6859500	Ladder Creek Below Chalk Creek near Scott City	1330	85.53	1.13
7156220	Bear Creek near Johnson	835	99.94	1.18
6845000	Sappa Creek near Oberlin	923	105.9	1.08
7141780	Walnut Creek at Nekoma	1150	454.1	1.31
6860000	Smoky Hill River near Elkader	3390	267.6	1.21
7155590	Cimarron River near Elkhart	2420	203.5	1.12
6917400	Marmaton River Tributary near Fort Scott	2.8	512.8	1.18
6863500	Big Creek near Hays	594	212.1	1.08
6876700	Salt Creek near Ada	384	760.2	1.45
7141900	Walnut Creek at Albert	1310	409.8	1.14
6889120	Soldier Creek near Bancroft	10.5	688.2	1.24
7166200	Sandy Creek near Yates Center	6.8	707	1.21
6853800	White Rock Creek near Burr Oak	227	446	1.06
6855800	Buffalo Creek near Jamestown	330	664	1.20
7143300	Cow Creek near Lyons	499	1073	1.41
6848500	Prairie Dog Creek near Woodruff	1000	289	1.01
7141200	Pawnee River near Rozel	2010	720.4	1.10
6873000	South Fork Solomon River Above Webster Reservoir	1040	363.4	1.07
6869500	Saline River at Tescott	2820	1574	1.32
6874000	South Fork Solomon River at Osborne	2010	650.3	1.05
7144780	North Fork Ninnescah River Above Cheney Reservoir	550	1221	1.24
7145700	Slate Creek at Wellington	154	685.2	1.05
6878000	Chapman Creek near Chapman	300	1282	1.09
7149000	Medicine Lodge River near Kiowa	903	1805	1.19
6889160	Soldier Creek near Circleville	49.3	2600	1.30
7143665	Little Arkansas River at Alta Mills	681	2795	1.42
6889180	Soldier Creek near St. Clere	80	3518	1.53
6889200	Soldier Creek near Delia	157	3279	1.43
6884200	Mill Creek at Washington	344	2024	1.11
6864500	Smoky Hill River at Ellsworth	7580	4997	1.62
7167500	Otter Creek at Climax	129	1923	1.14
6885500	Black Vermillion River near Frankfort	410	3578	1.31

Stream Gage #	Stream Name	Drainage Area (sq mi)	Bankfull Flow (cfs)	Return Period* (years)
7184000	Lightning Creek near McCune	197	2644	1.18
7147070	Whitewater River at Towanda	426	4968	1.53
7165700	Verdigris River near Madison	181	3100	1.22
6917000	Little Osage River at Fulton	295	3820	1.10
7145500	Ninnescah River near Peck	1790	5972	1.18
6884400	Little Blue River near Barnes	3320	11230	1.65
7169500	Fall River at Fredonia	827	7763	1.11

* Annual maximum series.

A2- Flow estimates for small streams used in the $Q_{1.2}$ regression

Site #	Station Name	CDA (sq mi)	Latitude	Longitude	$Q_{1.2}$ (cfs)	Q_2 (cfs)	Q_5 (cfs)
6813700	Tennessee C Tr Nr Seneca	0.9	39.8128	-96.0458	69.5	201.3	497.3
6815700	Buttermilk C Nr Willis	3.74	39.7544	-95.4508	643	1360	2604
6818260	White Clay C At Atchison	13.1	39.5592	-95.1275	384	920.2	1979
6844800	Sf Sappa C Tr Nr Goodland	4.98	39.3206	-101.6329	4.3	54.1	389.1
6847600	Prairie Dog C Tr At Colby	7.53	39.3911	-101.0457	64.6	215.7	560.3
6848200	Prairie Dog C Tr Nr Norton	1.02	39.8542	-99.8885	78.3	184.1	365.6
6856800	Moll C Nr Green	3.6	39.3800	-97.0081	125	348	820.6
6863400	Big C Tr Nr Ogallah	4.81	38.9333	-99.7429	37.2	196.1	735
6863700	Big C Tr Nr Hays	6.19	38.8522	-99.2470	17.7	72.1	222
6864300	Smoky Hill R Tr At Dorrance	5.39	38.8478	-98.5959	79.2	246.7	617.3
6864700	Spring C Nr Kanopolis	9.84	38.7397	-98.1689	106	414.3	1255
6866800	Saline R Tr At Collyer	3.13	39.0461	-100.1271	33.0	161.6	565.8
6867800	Cedar C Tr Nr Bunker Hill	0.99	38.9342	-98.7129	67.1	130.9	223
6868300	Coon C Tr Nr Luray	6.53	39.1750	-98.7009	90.5	353.4	1073
6868900	Bullfoot C Tr Nr Lincoln	2.64	38.9742	-98.1512	37.3	103.9	238.6
6872600	Oak C At Bellaire	4.75	39.7983	-98.6670	26.3	93.5	267.1
6873800	Kill C Tr Nr Bloomington	1.45	39.3995	-98.8409	76.9	228	548.6
6874500	E Limestone C Nr Ionia	25.6	39.6976	-98.3396	287	644.7	1274
6876200	M Pipe C Nr Miltonvale	10.2	39.3500	-97.5692	190	535	1274
6877200	W Turkey C Nr Elmo	26.6	38.6678	-97.1720	569	1194	2214
6877400	Turkey C Tr Nr Elmo	2.48	38.6825	-97.1847	80.1	292	839.8
6879650	Kings C Nr Manhattan	4.09	39.1019	-96.5952	87.2	481.9	2016
6879700	Wildcat C At Riley	14	39.2928	-96.8308	375	932.3	2017
6884300	Mill C Tr Nr Washington	3.2	39.8133	-97.0086	196	487.6	1056
6887200	Cedar C Nr Manhattan	13.4	39.2586	-96.5636	464	1361	3395
6887600	Kansas R Tr Nr Wamego	0.83	39.1744	-96.2628	120	242.8	436.8
6888600	Dry C Nr Maple Hill	15.6	39.0517	-96.0208	838	1784	3399
6888900	Blacksmith C Tr Nr Valencia	1.31	39.0222	-95.8353	133	347.3	776.1
6889100	Soldier C Nr Goff	2.06	39.6242	-95.9661	161	428	987.8
6889120	Soldier C Nr Bancroft	10.5	39.5948	-95.9739	616	1280	2407
6889140	Soldier C Nr Soldier	16.9	39.5658	-95.9628	957	1888	3404
6889550	Indian C Nr Topeka	9.72	39.1242	-95.6516	742	1259	1980
6889600	Sb Shunganunga C Nr Pauline	3.84	38.9789	-95.7100	360	767.3	1455
6890300	Spring C Nr Wetmore	21	39.6367	-95.8455	624	1612	3687
6890700	Slough C Tr Nr Oskaloosa	0.83	39.2014	-95.3027	50.3	171.8	485.4
6891050	Stone House Cr At Williamstown	12.9	39.0667	-95.3361	694	1708	3709
6893300	Indian C At Overland Park	26.6	38.9406	-94.6713	2561	3964	5803
6912300	Dragoon C Tr Nr Lyndon	3.76	38.6925	-95.6853	342	1136	3107
6913600	Rock C Nr Ottawa	10.2	38.5542	-95.2675	241	601	1303
6914250	Sf Pottawatomie C Tr Nr Garnett	0.35	38.2334	-95.2480	82.7	169	303
6916700	Middle C Nr Kincaid	2.02	38.0567	-95.1878	294	673.1	1334

Site #	Station Name	CDA (sq mi)	Latitude	Longitude	$Q_{1.2}$ (cfs)	Q_2 (cfs)	Q_5 (cfs)
6917100	Marmaton R Tr Nr Bronson	0.88	37.9056	-95.0955	98.2	199.4	356
6917400	Marmaton R Tr Nr Fort Scott	2.8	37.7906	-94.7966	495	871.7	1393
7138800	Lion C Tr Nr Modoc	1.19	38.4800	-101.0629	36.7	91.2	182.1
7139700	Arkansas R Tr Nr Dodge City	8.66	37.7145	-100.0151	52.7	185.1	485.9
7140300	Whitewoman C Nr Bellefont	14	37.9239	-99.6423	31.0	180.6	714.5
7140600	Pawnee R Tr Nr Kalvesta	6.89	38.0617	-100.3504	64.2	256.8	746.1
7141400	Sf Walnut Cr Tr Nr Dighton	0.81	38.4828	-100.4154	23.8	55.9	107.4
7142100	Rattlesnake C Tr Nr Mullinville	10.3	37.5864	-99.4218	86.9	380.4	1191
7142500	Spring C Nr Dillwyn	14.3	37.9567	-98.8412	55.9	305.6	1171
7143100	L Cheyenne C Tr Nr Claflin	1.48	38.4570	-98.5359	44.7	98	182.4
7143200	Plum C Nr Holyrood	19	38.5981	-98.4245	250	608.3	1251
7143500	L Arkansas R Nr Geneseo	25	38.4567	-98.0903	644	955.8	1319
7144900	Sf Ninnescah R Tr Nr Pratt	1.48	37.6750	-98.7234	131	344.3	726.8
7145300	Clear C Nr Garden Plain	5.03	37.6633	-97.6564	286	597.8	1073
7145800	Antelope C Tr Nr Dalton	0.41	37.2761	-97.2839	60.1	133.5	247.2
7146700	Wb Walnut R Tr Nr Degraff	11	37.9553	-96.8514	613	1314	2445
7147020	Whitewater R Tr Nr Towanda	0.17	37.8508	-97.0606	32.6	85	179.7
7147200	Dry Cr Tr Nr Augusta	0.9	37.6797	-97.0309	120	226.2	372.8
7147990	Cedar C Tr Nr Cambridge	2.41	37.3220	-96.6261	108	479.7	1568
7148700	Dog C Nr Deerhead	5.31	37.2806	-98.8737	54.5	272.3	938.4
7148800	Medicine Lodge R Tr Nr Medicine Lodge	2.04	37.3117	-98.5893	23.8	134.5	507.4
7151600	Rush C Nr Harper	12	37.2534	-98.0801	520	1193	2286
7156600	Cimarron R Tr Nr Moscow	8	37.3353	-101.0504	107	465.5	1399
7156700	Cimarron R Tr Nr Satanta	2.41	37.2709	-100.9271	43.0	189.4	566.7
7157400	Crooked C Tr At Meade	6.57	37.2964	-100.3399	40.3	292.5	1300
7166200	Sandy C Nr Yates Center	6.8	37.8464	-95.8355	670	1204	1948
7169200	Salt C Nr Severy	7.59	37.6200	-96.2522	1118	2628	5259
7169700	Snake C Nr Howard	1.84	37.5411	-96.2403	217	499	970
7170600	Cherry C Nr Cherryvale	15	37.2962	-95.5478	1128	2460	4653
7170800	Mud C Nr Mound Valley	4.22	37.1940	-95.4480	661	1279	2180
7171700	Spring Branch Nr Cedar Vale	3.1	37.1134	-96.4583	235	807.6	2148
7171800	Cedar C Tr Nr Hooser	0.56	37.1075	-96.5745	61.9	156.8	323.1
7171900	Grant C Nr Wauneta	20	37.1095	-96.3989	694	2471	6865
7180300	Spring C Tr Nr Florence	0.55	38.1834	-96.9139	36.1	115.3	291
7182520	Rock C At Burlington	8.27	38.1961	-95.7569	372	1024	2375
7183800	Limestone C Nr Beulah	12	37.4034	-94.8880	1283	3127	6534
7184600	Fly C Nr Faulkner	27	37.1042	-94.9394	1300	4193	11020

CDA = Contributing drainage area
$Q_{1.2}$ = 1.2-year flow (annual maximum series)
Q_2 = Two-year flow (annual maximum series)
Q_5 = Five-year flow (annual maximum series)

B1- List of Streams in the Kansas Reference-Reach Data Set

ID	Stream name
1	Indian Creek at Overland Park
2	Blue River near Stanley
3	Little Osage River at Fulton
4	Marmaton River Tributary near Fort Scott
5	Little Bull Creek near Spring Hill
6	Big Bull Creek near Edgerton
7	Spoon Creek near De Soto
8	Stranger Creek near Tonganoxie
9	Rock Creek near Wellsville
10	South Fork Sugar Creek near Mound City
11	Captains Creek near De Soto
12	Lightning Creek near McCune
13	Salt Creek near Lyndon
14	Unnamed Creek near Kansas Museum of History, Topeka
15	Fall River at Fredonia
16	Sandy Creek near Yates Center
17	South Branch Wakarusa River near Auburn
18	Tributary to SB Wakarusa River near Auburn
19	Soldier Creeek near Delia
20	Soldier Creek near St. Clere
21	Soldier Creeek near Circleville
22	Marais Des Cygnes River near Reading
23	Lost Creek near Belvue
24	Soldier Creek near Goff
25	Soldier Creek near Bancroft
26	Verdigris River near Virgil
27	Verdigris River near Madison
28	Kuenzli Creek near Alma
29	Mill Creek near Paxico
30	Elk River at Elk Falls
31	Otter Creek at Climax
32	Fall River near Eureka
33	Tributary to Fall River near Eureka
34	Tributary to East Branch Fall River near Eureka
35	Illinois Creek near Alma
36	Trib to East Branch Fall River near Eureka
37	Tributary to Rock Creek near Council Grove
38	Emmon Creek near Zeandale
39	Oleson Creek near Eureka

ID	Stream name
40	Black Vermillion River near Frankfort
41	Little Bloody Creek - Upper Reach
42	Little Bloody Creek - Lower Reach
43	Little Bloody Creek - Middle Reach
44	Tributary to Burnt Creek near Reece
45	Little Cedar Creek near Matfield Green
46	Tributary to Thurman Creek near Matfield Green
47	Tributary to Antelope Creek near Zeandale
48	British Pasture, South Creek
49	British Pasture, North Creek-Upstream Reach
50	Tributary to West Branch Fall River near Eureka
51	Tributary to Spring Creek near Reece
52	Norton Creek near Bazaar
53	Tributary to Ivanpah Creek near Eureka
54	Battle Creek near Eureka
55	Sharpes Creek near Bazaar
56	Tributary to Ivanpah Creek near Eureka
57	South Fork Cottonwood River near Matfield Green
58	Palmer Creek near Strong City
59	Rock Creek near Bazaar (Above Tributary)
60	North Branch Hickory Creek near Keighley
61	Schaffer Creek near Hymer (Above Tributary)
62	Little Blue River near Barnes
63	West Branch Walnut River near Burns
64	Cottonwood River near Florence
65	Whitewater River at Towanda
66	Mill Creek at Washington
67	Chapman Creek near Chapman
68	Slate Creek at Wellington
69	Ninnescah River near Peck
70	Solomon River at Niles
71	Little Arkansas River at Highway 50 near Halstead
72	Little Arkansas River at Alta Mills
73	Chikaskia River near Corbin
74	Republican River at Concordia
75	Salt Creek near Ada
76	Buffalo Creek near Jamestown
77	Saline River at Tescott
78	North Fork Ninnescah River Above Cheney Reservoir
79	Red Rock Creek near Pretty Prairie
80	Cow Creek near Lyons

ID	Stream name
81	Smoky Hill River at Ellsworth
82	White Rock Creek near Burr Oak
83	Rattlesnake Creek near Raymond
84	Medicine Lodge River near Kiowa
85	Rattlesnake Creek near Zenith
86	South Fork Solomon River at Osborne
87	Arkansas River at Great Bend
88	Smoky Hill River near Bunker Hill
89	Sand Creek near Medicine Lodge
90	Rattlesnake Creek near Macksville
91	Turkey Creek near Sun City
92	Tributary to Bear Creek near Sun City
93	Mule Creek near Aetna
94	Walnut Creek at Albert
95	Soldier Creek near Belvidere
96	Salt Fork Arkansas River near Buttermilk
97	Medicine Lodge River near Belvidere
98	Thompson Creek near Belvidere
99	EB Nescatunga Creek (Upstream Reach)
100	Big Creek near Hays
101	Rattlesnake Creek near Greensburg
102	Arkansas River near Kinsley
103	Smoky Hill River near Schoenchen
104	Pawnee River near Rozel
105	Walnut Creek at Nekoma
106	East Branch Kiowa Creek near Protection
107	Prairie Dog Creek near Woodruff
108	Middle Kiowa Creek near Protection
109	Bluff Creek near Protection
110	Walnut Creek near Alexander
111	Buckner Creek near Burdett
112	Sappa Creek near Lyle
113	Mulberry Creek near Dodge City
114	Smoky Hill River near Arnold
115	Hackberry Creek at Gove
116	Sappa Creek near Oberlin
117	South Fork Sappa Creek near Achilles
118	Ladder Creek Below Chalk Creek near Scott City
119	Beaver Creek at Ludell
120	Rose Creek near Wallace
121	Bear Creek near Johnson

ID	Stream name
122	Cimarron River near Elkhart
123	South Fork Republican River near CO-KS Line

ID	1
Stream name	Indian Creek at Overland Park
County	Johnson
Township	13 S
Range	25 E
Section	NW 1/4 NE 1/4 NE 1/4 Sec. 7
Latitude	38.94166667
Longitude	94.66944444
USGS quadrangle	Lenexa
USGS gage#	6893300
Drainage area (mi2)	26.6
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Bedrock
Rosgen level 2 stream type	C1
Rosgen valley type	VIII/X
Sinuosity	1.32
Depth (ft)	6.24
Top width (ft)	66
Area (ft2)	351.7
Wetted perimeter (ft)	71.07
Mean depth (ft)	5.328787879
Width/depth ratio	12.38555587
Average adjacent pool depth	9.03
Flood-prone width (ft)	136
Entrench- ment ratio	2.060606061
Sinuosity	1.32
Meander wavelength (ft)	915.28
Radius of of curvature (ft)	99.08
Belt width (ft)	295.85
Bankfull slope (ft/ft)	0.00183
Drainage area (mi2)	26.6
Mean annual precipitation at centroid (in.)	38.9011
Longest flow path (miles)	14.87
Excel file with original survey data	JO071325RR

ID	2
Stream name	Blue River near Stanley
County	Johnson
Township	14 S
Range	25 E
Section	SW 1/4 SW 1/4 SE 1/4 Sec. 19
Latitude	38.8125
Longitude	94.67527778
USGS quadrangle	Stilwell
USGS gage#	6893080
Drainage area (mi2)	46
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.56
Depth (ft)	7.03
Top width (ft)	75
Area (ft2)	382.85
Wetted perimeter (ft)	78.01
Mean depth (ft)	5.104666667
Width/depth ratio	14.69243829
Average adjacent pool depth	7.66
Flood-prone width (ft)	1010
Entrench- ment ratio	13.46666667
Sinuosity	1.56
Meander wavelength (ft)	1220.9
Radius of of curvature (ft)	186.71
Belt width (ft)	392.87
Bankfull slope (ft/ft)	0.00125
Drainage area (mi2)	46
Mean annual precipitation at centroid (in.)	39.1351
Longest flow path (miles)	11.79
Excel file with original survey data	JO191425RR

ID	3
Stream name	Little Osage River at Fulton
County	Bourbon
Township	23 S
Range	24 E
Section	SE 1/4 NE 1/4 NE 1/4 Sec. 25
Latitude	38.01916667
Longitude	94.71333333
USGS quadrangle	Prescott
USGS gage#	6917000
Drainage area (mi2)	295
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	1.5
Depth (ft)	
Top width (ft)	95
Area (ft2)	912.2
Wetted perimeter (ft)	105.05
Mean depth (ft)	9.602105263
Width/depth ratio	9.89366367
Average adjacent pool depth	
Flood-prone width (ft)	1190
Entrench- ment ratio	12.52631579
Sinuosity	1.5
Meander wavelength (ft)	1589.667
Radius of of curvature (ft)	415.1875
Belt width (ft)	681.3
Bankfull slope (ft/ft)	0.00125
Drainage area (mi2)	295
Mean annual precipitation at centroid (in.)	40.9976
Longest flow path (miles)	48.74
Excel file with original survey data	BB252324RR

ID	4
Stream name	Marmaton River Tributary near Fort Scott
County	Bourbon
Township	26 S
Range	24 E
Section	SE 1/4 SE 1/4 SE 1/4 sec. 8
Latitude	37.79055556
Longitude	94.79638889
USGS quadrangle	Marmaton
USGS gage#	6917400
Drainage area (mi2)	2.8
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Gravel
Rosgen level 2 stream type	E4
Rosgen valley type	VIII/X
Sinuosity	1.42
Depth (ft)	
Top width (ft)	38
Area (ft2)	154.6
Wetted perimeter (ft)	42.22443961
Mean depth (ft)	4.068421053
Width/depth ratio	9.340232859
Average adjacent pool depth	
Flood-prone width (ft)	155
Entrench- ment ratio	4.305555556
Sinuosity	1.42
Meander wavelength (ft)	314.73
Radius of of curvature (ft)	39.13
Belt width (ft)	84.38
Bankfull slope (ft/ft)	0.00455
Drainage area (mi2)	2.8
Mean annual precipitation at centroid (in.)	41.4744
Longest flow path (miles)	
Excel file with original survey data	BB082624RR

ID	5
Stream name	Little Bull Creek near Spring Hill
County	Johnson
Township	15 S
Range	23 E
Section	NW 1/4 NW 1/4 NW 1/4 Sec. 16
Latitude	38.75305556
Longitude	94.86944444
USGS quadrangle	Ocheltree
USGS gage#	6914990
Drainage area (mi2)	7.86
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Sand
Rosgen level 2 stream type	E5
Rosgen valley type	VIII/X
Sinuosity	1.43
Depth (ft)	8.53
Top width (ft)	35.95
Area (ft2)	178.65
Wetted perimeter (ft)	41.66
Mean depth (ft)	4.969401947
Width/depth ratio	7.234270921
Average adjacent pool depth	10.03
Flood-prone width (ft)	1090
Entrench- ment ratio	22.70833333
Sinuosity	1.43
Meander wavelength (ft)	563.35
Radius of of curvature (ft)	81.41
Belt width (ft)	163.41
Bankfull slope (ft/ft)	0.00438
Drainage area (mi2)	7.86
Mean annual precipitation at centroid (in.)	38.8702
Longest flow path (miles)	2.46
Excel file with original survey data	JO161523RR

ID	6
Stream name	Big Bull Creek near Edgerton
County	Johnson
Township	15 S
Range	22 E
Section	SW 1/4 SE 1/4 SW 1/4 Sec. 9
Latitude	38.75333333
Longitude	94.97611111
USGS quadrangle	Gardner
USGS gage#	6914950
Drainage area (mi2)	28.7
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Gravel
Rosgen level 2 stream type	E4
Rosgen valley type	VIII/X
Sinuosity	1.4
Depth (ft)	9.14
Top width (ft)	66
Area (ft2)	381.3
Wetted perimeter (ft)	69.7
Mean depth (ft)	5.777272727
Width/depth ratio	11.42407553
Average adjacent pool depth	12.105
Flood-prone width (ft)	550
Entrench- ment ratio	8.333333333
Sinuosity	1.4
Meander wavelength (ft)	1110.475
Radius of of curvature (ft)	212.99
Belt width (ft)	670.475
Bankfull slope (ft/ft)	0.00729
Drainage area (mi2)	28.7
Mean annual precipitation at centroid (in.)	38.6207
Longest flow path (miles)	8.82
Excel file with original survey data	JO091522RR

ID	7
Stream name	Spoon Creek near De Soto
County	Johnson
Township	13 S
Range	22 E
Section	NE 1/4 Sec. 20
Latitude	38.90933333
Longitude	94.98833333
USGS quadrangle	De Soto
USGS gage#	
Drainage area (mi2)	12.69
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Gravel
Rosgen level 2 stream type	C4/1
Rosgen valley type	VIII/X
Sinuosity	1.48
Depth (ft)	3.83
Top width (ft)	57.99
Area (ft2)	148.8
Wetted perimeter (ft)	59.71
Mean depth (ft)	2.565959648
Width/depth ratio	22.59973185
Average adjacent pool depth	6.155
Flood-prone width (ft)	236
Entrench- ment ratio	4.069667184
Sinuosity	1.48
Meander wavelength (ft)	620.46
Radius of of curvature (ft)	175.02
Belt width (ft)	345.44
Bankfull slope (ft/ft)	0.00316
Drainage area (mi2)	12.69
Mean annual precipitation at centroid (in.)	38.4951
Longest flow path (miles)	9.66
Excel file with original survey data	JO321322RR

ID	8
Stream name	Stranger Creek near Tonganoxie
County	Leavenworth
Township	11 S
Range	22 E
Section	NE 1/4 NE 1/4 NW 1/4 Sec. 7
Latitude	39.11638889
Longitude	95.0025
USGS quadrangle	Tonganoxie
USGS gage#	6892000
Drainage area (mi2)	406
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	1.36
Depth (ft)	18.78
Top width (ft)	81.56
Area (ft2)	659.43
Wetted perimeter (ft)	112.1
Mean depth (ft)	8.08521334
Width/depth ratio	10.08755076
Average adjacent pool depth	20.46
Flood-prone width (ft)	5800
Entrench- ment ratio	56.8627451
Sinuosity	1.36
Meander wavelength (ft)	1484.6275
Radius of of curvature (ft)	381.1
Belt width (ft)	862.54
Bankfull slope (ft/ft)	0.00026
Drainage area (mi2)	406
Mean annual precipitation at centroid (in.)	38.2006
Longest flow path (miles)	71.36
Excel file with original survey data	LV071122RR

ID	9
Stream name	Rock Creek near Wellsville
County	Miami
Township	15 S
Range	22 E
Section	NW 1/4 SW 1/4 SE 1/4 Sec. 31
Latitude	38.69833333
Longitude	95.00861111
USGS quadrangle	Wellsville
USGS gage#	6914960
Drainage area (mi2)	15.9
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.66
Depth (ft)	
Top width (ft)	80
Area (ft2)	286.3
Wetted perimeter (ft)	51.13
Mean depth (ft)	3.57875
Width/depth ratio	22.35417394
Average adjacent pool depth	
Flood-prone width (ft)	176
Entrench- ment ratio	2.2
Sinuosity	1.66
Meander wavelength (ft)	830.52
Radius of of curvature (ft)	95.8
Belt width (ft)	164.28
Bankfull slope (ft/ft)	0.00421
Drainage area (mi2)	15.9
Mean annual precipitation at centroid (in.)	38.6533
Longest flow path (miles)	10.57
Excel file with original survey data	MI311522RR

ID	10
Stream name	South Fork Sugar Creek near Mound City
County	Linn
Township	21 S
Range	22 E
Section	NE 1/4 Sec. 31
Latitude	38.18283333
Longitude	95.0285
USGS quadrangle	Centerville
USGS gage#	
Drainage area (mi2)	34.69
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Gravel
Rosgen level 2 stream type	C4/1
Rosgen valley type	VIII/X
Sinuosity	1.62
Depth (ft)	5.67
Top width (ft)	128
Area (ft2)	353.13
Wetted perimeter (ft)	132.23
Mean depth (ft)	2.758828125
Width/depth ratio	46.3965112
Average adjacent pool depth	9.575
Flood-prone width (ft)	290
Entrench- ment ratio	2.265625
Sinuosity	1.62
Meander wavelength (ft)	1408.98
Radius of of curvature (ft)	432.47
Belt width (ft)	523
Bankfull slope (ft/ft)	0.00157
Drainage area (mi2)	34.69
Mean annual precipitation at centroid (in.)	39.869
Longest flow path (miles)	13.2
Excel file with original survey data	LN312122RR

ID	11
Stream name	Captains Creek near De Soto
County	Johnson
Township	13 S
Range	21 E
Section	SW 1/4 Sec. 22
Latitude	38.899
Longitude	95.03
USGS quadrangle	Eudora
USGS gage#	
Drainage area (mi2)	32.37
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Gravel
Rosgen level 2 stream type	C4/1
Rosgen valley type	VIII/X
Sinuosity	1.92
Depth (ft)	6.56
Top width (ft)	79.4
Area (ft2)	320.85
Wetted perimeter (ft)	79.47
Mean depth (ft)	4.04093199
Width/depth ratio	19.64893252
Average adjacent pool depth	8.52
Flood-prone width (ft)	201
Entrench- ment ratio	2.531486146
Sinuosity	1.92
Meander wavelength (ft)	661.83
Radius of of curvature (ft)	119.06
Belt width (ft)	214.75
Bankfull slope (ft/ft)	0.00197
Drainage area (mi2)	32.37
Mean annual precipitation at centroid (in.)	38.3871
Longest flow path (miles)	17.57
Excel file with original survey data	JO241321RR

ID	12
Stream name	Lightning Creek near McCune
County	Cherokee
Township	32 S
Range	22 E
Section	NE 1/4 NE 1/4 Sec. 7
Latitude	37.28166667
Longitude	95.03222222
USGS quadrangle	McCune
USGS gage#	7184000
Drainage area (mi2)	197
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Gravel
Rosgen level 2 stream type	E4
Rosgen valley type	VIII/X
Sinuosity	1.66
Depth (ft)	
Top width (ft)	102
Area (ft2)	940.4
Wetted perimeter (ft)	113.84
Mean depth (ft)	9.219607843
Width/depth ratio	11.06337729
Average adjacent pool depth	
Flood-prone width (ft)	5900
Entrench- ment ratio	57.84313725
Sinuosity	1.66
Meander wavelength (ft)	1103.545
Radius of of curvature (ft)	274.61
Belt width (ft)	630.45
Bankfull slope (ft/ft)	0.00054
Drainage area (mi2)	197
Mean annual precipitation at centroid (in.)	42.0084
Longest flow path (miles)	44.79
Excel file with original survey data	CK073222RR

ID	13
Stream name	Salt Creek near Lyndon
County	Osage
Township	16 S
Range	16 E
Section	SW 1/4 SW 1/4 SW 1/4 Sec. 34
Latitude	38.60888889
Longitude	95.63527778
USGS quadrangle	Ludell
USGS gage#	6911500
Drainage area (mi2)	111
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Bedrock
Rosgen level 2 stream type	C1
Rosgen valley type	VIII/X
Sinuosity	1.196
Depth (ft)	
Top width (ft)	124
Area (ft2)	594.6
Wetted perimeter (ft)	148.74
Mean depth (ft)	4.79516129
Width/depth ratio	25.85940128
Average adjacent pool depth	
Flood-prone width (ft)	1700
Entrench- ment ratio	13.70967742
Sinuosity	1.196
Meander wavelength (ft)	927.75
Radius of of curvature (ft)	44.66
Belt width (ft)	296.7425
Bankfull slope (ft/ft)	0.00643
Drainage area (mi2)	111
Mean annual precipitation at centroid (in.)	37.0623
Longest flow path (miles)	36.41
Excel file with original survey data	OS341616RR

ID	14
Stream name	amed Creek near Kansas Museum of History, To
County	Shawnee
Township	11 S
Range	15 E
Section	SE 1/4 NE 1/4 NW 1/4 Sec. 32
Latitude	39.05666667
Longitude	95.77194444
USGS quadrangle	Silver Lake
USGS gage#	6888925
Drainage area (mi2)	3.56
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Sand
Rosgen level 2 stream type	E5
Rosgen valley type	VIII/X
Sinuosity	1.54
Depth (ft)	8.96
Top width (ft)	48
Area (ft2)	235.7
Wetted perimeter (ft)	57.23
Mean depth (ft)	4.910416667
Width/depth ratio	9.775137887
Average adjacent pool depth	9.48
Flood-prone width (ft)	1630
Entrench- ment ratio	33.95833333
Sinuosity	1.54
Meander wavelength (ft)	484.54
Radius of of curvature (ft)	65.04
Belt width (ft)	218.43
Bankfull slope (ft/ft)	0.00221
Drainage area (mi2)	3.56
Mean annual precipitation at centroid (in.)	36.0312
Longest flow path (miles)	2.33
Excel file with original survey data	SN321115RR

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ID	15
Stream name	Fall River at Fredonia
County	Wilson
Township	29 S
Range	14 E
Section	SW 1/4 NW 1/4 sec. 24
Latitude	37.50833333
Longitude	95.83333333
USGS quadrangle	Fredonia
USGS gage#	7169500
Drainage area (mi2)	827
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Cobble
Rosgen level 2 stream type	E3
Rosgen valley type	VIII/X
Sinuosity	1.32
Depth (ft)	16.61
Top width (ft)	140
Area (ft2)	1902.7
Wetted perimeter (ft)	162.35
Mean depth (ft)	13.59071429
Width/depth ratio	10.301151
Average adjacent pool depth	18.235
Flood-prone width (ft)	2670
Entrench- ment ratio	19.07142857
Sinuosity	1.32
Meander wavelength (ft)	1676.19
Radius of of curvature (ft)	257.41
Belt width (ft)	567.64
Bankfull slope (ft/ft)	0.00029
Drainage area (mi2)	827
Mean annual precipitation at centroid (in.)	38.7293
Longest flow path (miles)	83.81
Excel file with original survey data	WL242914RR

ID	16
Stream name	Sandy Creek near Yates Center
County	Woodson
Township	25 S
Range	14 E
Section	NE 1/4 SW 1/4 NE 1/4 sec. 26
Latitude	37.84638889
Longitude	95.83527778
USGS quadrangle	Toronto SE
USGS gage#	7166200
Drainage area (mi2)	6.8
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.44
Depth (ft)	
Top width (ft)	48
Area (ft2)	136.3
Wetted perimeter (ft)	50.52
Mean depth (ft)	2.839583333
Width/depth ratio	16.90388848
Average adjacent pool depth	
Flood-prone width (ft)	328
Entrench- ment ratio	6.833333333
Sinuosity	1.44
Meander wavelength (ft)	441.26
Radius of of curvature (ft)	105.26
Belt width (ft)	195.06
Bankfull slope (ft/ft)	0.0011
Drainage area (mi2)	6.8
Mean annual precipitation at centroid (in.)	38.2572
Longest flow path (miles)	5.48
Excel file with original survey data	WO262514RR

ID	17
Stream name	South Branch Wakarusa River near Auburn
County	Osage
Township	14 S
Range	14 E
Section	NE 1/4 Sec. 4
Latitude	38.86416667
Longitude	95.86316667
USGS quadrangle	Burlingame
USGS gage#	
Drainage area (mi2)	17.81
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.32
Depth (ft)	3.64
Top width (ft)	76.25
Area (ft2)	169.65
Wetted perimeter (ft)	76.87
Mean depth (ft)	2.224918033
Width/depth ratio	34.27092543
Average adjacent pool depth	7.02
Flood-prone width (ft)	400
Entrench- ment ratio	5.245901639
Sinuosity	1.32
Meander wavelength (ft)	657.79
Radius of of curvature (ft)	158.52
Belt width (ft)	238.17
Bankfull slope (ft/ft)	0.00365
Drainage area (mi2)	17.81
Mean annual precipitation at centroid (in.)	35.9655
Longest flow path (miles)	18.18
Excel file with original survey data	OS041414RR

ID	18
Stream name	Tributary to SB Wakarusa River near Auburn
County	Osage
Township	14 S
Range	14 E
Section	NE 1/4 Sec. 4
Latitude	38.86416667
Longitude	95.86316667
USGS quadrangle	Burlingame
USGS gage#	
Drainage area (mi2)	0.33
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	II
Sinuosity	1.65
Depth (ft)	1.45
Top width (ft)	19.36
Area (ft2)	19.84
Wetted perimeter (ft)	27.32
Mean depth (ft)	1.024793388
Width/depth ratio	18.8916129
Average adjacent pool depth	2.945
Flood-prone width (ft)	46.89
Entrench- ment ratio	2.422004132
Sinuosity	1.65
Meander wavelength (ft)	131.99
Radius of of curvature (ft)	27.05
Belt width (ft)	30.75
Bankfull slope (ft/ft)	0.01127
Drainage area (mi2)	0.33
Mean annual precipitation at centroid (in.)	35.97
Longest flow path (miles)	0.66
Excel file with original survey data	OS041414RR

ID	19
Stream name	Soldier Creeek near Delia
County	Shawnee
Township	10 S
Range	14 E
Section	NE 1/4 NW 1/4 NE 1/4 Sec. 8
Latitude	39.20222222
Longitude	95.87361111
USGS quadrangle	Grove
USGS gage#	6889200
Drainage area (mi2)	157
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	1.53
Depth (ft)	17.02
Top width (ft)	65
Area (ft2)	741.2
Wetted perimeter (ft)	76.31
Mean depth (ft)	11.40307692
Width/depth ratio	5.700215866
Average adjacent pool depth	18.365
Flood-prone width (ft)	4690
Entrench- ment ratio	72.15384615
Sinuosity	1.53
Meander wavelength (ft)	736.74
Radius of of curvature (ft)	266.045
Belt width (ft)	425.672
Bankfull slope (ft/ft)	0.00033
Drainage area (mi2)	157
Mean annual precipitation at centroid (in.)	35.622
Longest flow path (miles)	52.07
Excel file with original survey data	SN081014RR

ID	20
Stream name	Soldier Creek near St. Clere
County	Jackson
Township	8 S
Range	13 E
Section	NW 1/4 NE 1/4 NW 1/4 Sec. 12
Latitude	39.37583333
Longitude	95.91805556
USGS quadrangle	Soldier Creek NW
USGS gage#	6889180
Drainage area (mi2)	80
USEPA ecoregion	Flint Hills
Predominant bed material	Sand
Rosgen level 2 stream type	E5
Rosgen valley type	VIII/X
Sinuosity	1.66
Depth (ft)	
Top width (ft)	102
Area (ft2)	1139
Wetted perimeter (ft)	110.43
Mean depth (ft)	11.16666667
Width/depth ratio	9.134328358
Average adjacent pool depth	
Flood-prone width (ft)	3390
Entrench- ment ratio	33.23529412
Sinuosity	1.66
Meander wavelength (ft)	761.75
Radius of of curvature (ft)	126.13
Belt width (ft)	301.415
Bankfull slope (ft/ft)	0.00029
Drainage area (mi2)	80
Mean annual precipitation at centroid (in.)	35.259
Longest flow path (miles)	30.26
Excel file with original survey data	JA120813RR

ID	21
Stream name	Soldier Creeek near Circleville
County	Jackson
Township	7 S
Range	13 E
Section	NW 1/4 NW 1/4 NE 1/4 Sec. 10
Latitude	39.46305556
Longitude	95.95
USGS quadrangle	Soldier Creek Northwest
USGS gage#	6889160
Drainage area (mi2)	49.3
USEPA ecoregion	Western Corn Belt Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.42
Depth (ft)	9.86
Top width (ft)	92
Area (ft2)	653.9
Wetted perimeter (ft)	99.13
Mean depth (ft)	7.107608696
Width/depth ratio	12.94387521
Average adjacent pool depth	11.265
Flood-prone width (ft)	1500
Entrench- ment ratio	16.30434783
Sinuosity	1.42
Meander wavelength (ft)	888
Radius of of curvature (ft)	166.278
Belt width (ft)	270.1
Bankfull slope (ft/ft)	0.001588
Drainage area (mi2)	49.3
Mean annual precipitation at centroid (in.)	35.0932
Longest flow path (miles)	19.73
Excel file with original survey data	JA100713RR

ID	22
Stream name	Marais Des Cygnes River near Reading
County	Lyon
Township	17 S
Range	13 E
Section	NE 1/4 SE 1/4 SW 1/4 Sec. 15
Latitude	38.56666667
Longitude	95.96388889
USGS quadrangle	Reading
USGS gage#	6910800
Drainage area (mi2)	177
USEPA ecoregion	Central Irregular Plains
Predominant bed material	Gravel
Rosgen level 2 stream type	E4
Rosgen valley type	VIII/X
Sinuosity	2.14
Depth (ft)	14.91
Top width (ft)	118.7758621
Area (ft2)	1164.182759
Wetted perimeter (ft)	131.19
Mean depth (ft)	9.801509653
Width/depth ratio	12.11811917
Average adjacent pool depth	20.03
Flood-prone width (ft)	5540
Entrench- ment ratio	43.28125
Sinuosity	2.14
Meander wavelength (ft)	1833
Radius of of curvature (ft)	247.5
Belt width (ft)	742.5
Bankfull slope (ft/ft)	0.00283
Drainage area (mi2)	177
Mean annual precipitation at centroid (in.)	36.16
Longest flow path (miles)	41.4
Excel file with original survey data	LY151713RR

ID	23
Stream name	Lost Creek near Belvue
County	Pottawatomie
Township	9 S
Range	11 E
Section	NW 1/4 Sec 10
Latitude	39.286
Longitude	96.183
USGS quadrangle	Laclede
USGS gage#	
Drainage area (mi2)	4.12
USEPA ecoregion	Flint Hills
Predominant bed material	Bedrock
Rosgen level 2 stream type	B1c
Rosgen valley type	II
Sinuosity	1.64
Depth (ft)	
Top width (ft)	26
Area (ft2)	41.62
Wetted perimeter (ft)	27.13
Mean depth (ft)	1.600769231
Width/depth ratio	16.24219125
Average adjacent pool depth	
Flood-prone width (ft)	51.29
Entrench- ment ratio	1.97
Sinuosity	1.64
Meander wavelength (ft)	232.22
Radius of of curvature (ft)	62.32
Belt width (ft)	138.04
Bankfull slope (ft/ft)	0.00693
Drainage area (mi2)	4.12
Mean annual precipitation at centroid (in.)	36.0984
Longest flow path (miles)	
Excel file with original survey data	PT100911RR

ID	24
Stream name	Soldier Creek near Goff
County	Nemaha
Township	5 S
Range	13 E
Section	NW 1/4 NW 1/4 NE 1/4 Sec. 16
Latitude	39.62416667
Longitude	95.96583333
USGS quadrangle	Soldier
USGS gage#	6889100
Drainage area (mi2)	2.06
USEPA ecoregion	Western Corn Belt Plains
Predominant bed material	Sand
Rosgen level 2 stream type	E5
Rosgen valley type	VIII/X
Sinuosity	1.43
Depth (ft)	5.27
Top width (ft)	28
Area (ft2)	94.6
Wetted perimeter (ft)	32.1
Mean depth (ft)	3.378571429
Width/depth ratio	8.287526427
Average adjacent pool depth	6.295
Flood-prone width (ft)	980
Entrench- ment ratio	35
Sinuosity	1.43
Meander wavelength (ft)	229.58
Radius of of curvature (ft)	61.45
Belt width (ft)	102.54
Bankfull slope (ft/ft)	0.00243
Drainage area (mi2)	2.06
Mean annual precipitation at centroid (in.)	34.6613
Longest flow path (miles)	2.95
Excel file with original survey data	NH160513RR

ID	25
Stream name	Soldier Creek near Bancroft
County	Nemaha
Township	5 S
Range	13 E
Section	NE 1/4 NW 1/4 NW 1/4 Sec. 28
Latitude	39.595
Longitude	95.97138889
USGS quadrangle	Soldier
USGS gage#	6889120
Drainage area (mi2)	10.5
USEPA ecoregion	Western Corn Belt Plains
Predominant bed material	Sand
Rosgen level 2 stream type	E5
Rosgen valley type	VIII/X
Sinuosity	1.6
Depth (ft)	7.58
Top width (ft)	40
Area (ft2)	233.9
Wetted perimeter (ft)	46
Mean depth (ft)	5.8475
Width/depth ratio	6.840530141
Average adjacent pool depth	8.885
Flood-prone width (ft)	1100
Entrench- ment ratio	27.5
Sinuosity	1.6
Meander wavelength (ft)	359.99
Radius of of curvature (ft)	88.52
Belt width (ft)	143.11
Bankfull slope (ft/ft)	0.00192
Drainage area (mi2)	10.5
Mean annual precipitation at centroid (in.)	34.7115
Longest flow path (miles)	5.99
Excel file with original survey data	NH280513RR

ID	26
Stream name	Verdigris River near Virgil
County	Greenwood
Township	24 S
Range	13 E
Section	NE 1/4 SE 1/4 SE 1/4 Sec. 19
Latitude	37.94194444
Longitude	96.01333333
USGS quadrangle	Virgil
USGS gage#	7165750
Drainage area (mi2)	312
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.65
Depth (ft)	11.86
Top width (ft)	132
Area (ft2)	1173.2
Wetted perimeter (ft)	144.12
Mean depth (ft)	8.887878788
Width/depth ratio	14.85168769
Average adjacent pool depth	12.34
Flood-prone width (ft)	2900
Entrench- ment ratio	21.96969697
Sinuosity	1.65
Meander wavelength (ft)	1911.73
Radius of of curvature (ft)	295.86
Belt width (ft)	751.03
Bankfull slope (ft/ft)	0.00557
Drainage area (mi2)	312
Mean annual precipitation at centroid (in.)	37.3015
Longest flow path (miles)	52.14
Excel file with original survey data	GW192413RR

ID	27
Stream name	Verdigris River near Madison
County	Greenwood
Township	22 S
Range	12 E
Section	NW 1/4 SW 1/4 Sec. 16
Latitude	38.1375
Longitude	96.10138889
USGS quadrangle	Madison NE
USGS gage#	7165700
Drainage area (mi2)	181
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	E4
Rosgen valley type	VIII/X
Sinuosity	1.86
Depth (ft)	11.64
Top width (ft)	92
Area (ft2)	788.6
Wetted perimeter (ft)	95.9
Mean depth (ft)	8.57173913
Width/depth ratio	10.73294446
Average adjacent pool depth	13.125
Flood-prone width (ft)	367
Entrench- ment ratio	3.989130435
Sinuosity	1.86
Meander wavelength (ft)	1250
Radius of of curvature (ft)	172.776
Belt width (ft)	301.415
Bankfull slope (ft/ft)	0.0015
Drainage area (mi2)	181
Mean annual precipitation at centroid (in.)	36.4613
Longest flow path (miles)	30.65
Excel file with original survey data	GW162212RR

ID	28
Stream name	Kuenzli Creek near Alma
County	Wabaunsee
Township	12 S
Range	10 E
Section	NW 1/4 Sec 27
Latitude	38.98058333
Longitude	96.17819444
USGS quadrangle	Hessdale
USGS gage#	
Drainage area (mi2)	4.7
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.42
Depth (ft)	0.71
Top width (ft)	20.96
Area (ft2)	14.7
Wetted perimeter (ft)	22.17
Mean depth (ft)	0.701335878
Width/depth ratio	29.88582313
Average adjacent pool depth	3.01
Flood-prone width (ft)	90
Entrench- ment ratio	4.29
Sinuosity	1.42
Meander wavelength (ft)	392.85
Radius of of curvature (ft)	85.08
Belt width (ft)	125.74
Bankfull slope (ft/ft)	0.00676
Drainage area (mi2)	4.7
Mean annual precipitation at centroid (in.)	34.8377
Longest flow path (miles)	4.4
Excel file with original survey data	WB271211RR

ID	29
Stream name	Mill Creek near Paxico
County	Wabaunsee
Township	11 S
Range	11 E
Section	SW 1/4 NE 1/4 SW 1/4 Sec. 27
Latitude	39.06222222
Longitude	96.18111111
USGS quadrangle	McFarland Qaudrangle
USGS gage#	6888500
Drainage area (mi2)	316
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4c-
Rosgen valley type	VIII/X
Sinuosity	1.23
Depth (ft)	15.05
Top width (ft)	116.8333333
Area (ft2)	946.9383333
Wetted perimeter (ft)	120.08
Mean depth (ft)	8.105035663
Width/depth ratio	14.41490676
Average adjacent pool depth	21.49
Flood-prone width (ft)	3870
Entrench- ment ratio	25.97315436
Sinuosity	1.23
Meander wavelength (ft)	1462.15
Radius of of curvature (ft)	536.164
Belt width (ft)	992.5575
Bankfull slope (ft/ft)	0.00074
Drainage area (mi2)	316
Mean annual precipitation at centroid (in.)	34.7361
Longest flow path (miles)	38.3
Excel file with original survey data	WB271111RR

ID	30
Stream name	Elk River at Elk Falls
County	Elk
Township	31 S
Range	11 E
Section	SW 1/4 SE 1/4 SE 1/4 sec. 3
Latitude	37.37555556
Longitude	96.18527778
USGS quadrangle	Longton NW
USGS gage#	7169800
Drainage area (mi2)	220
USEPA ecoregion	Flint Hills
Predominant bed material	Cobble
Rosgen level 2 stream type	B3c
Rosgen valley type	VIII/X
Sinuosity	1.7269
Depth (ft)	7.24
Top width (ft)	133.72
Area (ft2)	1571.94
Wetted perimeter (ft)	138.42
Mean depth (ft)	11.75545917
Width/depth ratio	11.37514053
Average adjacent pool depth	15.28
Flood-prone width (ft)	123
Entrench- ment ratio	1.662162162
Sinuosity	1.7269
Meander wavelength (ft)	1173.33
Radius of of curvature (ft)	209.525
Belt width (ft)	971.718
Bankfull slope (ft/ft)	0.0173063
Drainage area (mi2)	220
Mean annual precipitation at centroid (in.)	37.1731
Longest flow path (miles)	40.49
Excel file with original survey data	EK033111RR

ID	31
Stream name	Otter Creek at Climax
County	Greenwood
Township	27 S
Range	11 E
Section	SW 1/4 SE 1/4 Sec. 8
Latitude	37.70833333
Longitude	96.21666667
USGS quadrangle	Severy North
USGS gage#	7167500
Drainage area (mi2)	129
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	B4c
Rosgen valley type	VIII/X
Sinuosity	1.65
Depth (ft)	
Top width (ft)	79
Area (ft2)	398.9
Wetted perimeter (ft)	83.36
Mean depth (ft)	5.049367089
Width/depth ratio	15.64552519
Average adjacent pool depth	
Flood-prone width (ft)	153
Entrench- ment ratio	1.936708861
Sinuosity	1.65
Meander wavelength (ft)	1180
Radius of of curvature (ft)	133
Belt width (ft)	237.394
Bankfull slope (ft/ft)	0.00178
Drainage area (mi2)	129
Mean annual precipitation at centroid (in.)	36.6312
Longest flow path (miles)	26.22
Excel file with original survey data	GW082711RR

ID	32
Stream name	Fall River near Eureka
County	Greenwood
Township	26 S
Range	11 E
Section	West Line Sec. 17
Latitude	37.78333333
Longitude	96.23333333
USGS quadrangle	Tonovay
USGS gage#	7167000
Drainage area (mi2)	307
USEPA ecoregion	Flint Hills
Predominant bed material	Bedrock
Rosgen level 2 stream type	C1
Rosgen valley type	VIII/X
Sinuosity	1.45
Depth (ft)	8
Top width (ft)	175
Area (ft2)	1228.6
Wetted perimeter (ft)	182.31
Mean depth (ft)	7.020571429
Width/depth ratio	24.92674589
Average adjacent pool depth	14.855
Flood-prone width (ft)	375
Entrench- ment ratio	2.142857143
Sinuosity	1.45
Meander wavelength (ft)	1718.095
Radius of of curvature (ft)	296.83
Belt width (ft)	691.43
Bankfull slope (ft/ft)	0.00429
Drainage area (mi2)	307
Mean annual precipitation at centroid (in.)	36.455
Longest flow path (miles)	37.75
Excel file with original survey data	GW172611RR

ID	33
Stream name	Tributary to Fall River near Eureka
County	Greenwood
Township	26 S
Range	10 E
Section	SW 1/4 Sec 12
Latitude	37.80808333
Longitude	96.26438888
USGS quadrangle	Eureka
USGS gage#	
Drainage area (mi2)	1.58
USEPA ecoregion	Flint Hills
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	C6
Rosgen valley type	VIII/X
Sinuosity	1.04
Depth (ft)	
Top width (ft)	13.7
Area (ft2)	8.5
Wetted perimeter (ft)	14.3
Mean depth (ft)	0.620437956
Width/depth ratio	22.08117647
Average adjacent pool depth	
Flood-prone width (ft)	31.71
Entrench- ment ratio	2.31459854
Sinuosity	1.04
Meander wavelength (ft)	N/A
Radius of of curvature (ft)	N/A
Belt width (ft)	N/A
Bankfull slope (ft/ft)	0.00364
Drainage area (mi2)	1.58
Mean annual precipitation at centroid (in.)	36.2457
Longest flow path (miles)	2.35
Excel file with original survey data	GW122610RR

ID	34
Stream name	Tributary to East Branch Fall River near Eureka
County	Greenwood
Township	25 S
Range	10 E
Section	SE 1/4 Sec 29
Latitude	37.84588889
Longitude	96.33169444
USGS quadrangle	Eureka
USGS gage#	
Drainage area (mi2)	1.39
USEPA ecoregion	Flint Hills
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	C6/1
Rosgen valley type	VIII/X
Sinuosity	1.41
Depth (ft)	1.46
Top width (ft)	25.5
Area (ft2)	27.5
Wetted perimeter (ft)	27.22
Mean depth (ft)	1.078431373
Width/depth ratio	23.64545455
Average adjacent pool depth	3.325
Flood-prone width (ft)	56
Entrench- ment ratio	2.196078431
Sinuosity	1.41
Meander wavelength (ft)	272.02
Radius of of curvature (ft)	68.05
Belt width (ft)	94.18
Bankfull slope (ft/ft)	0.00414
Drainage area (mi2)	1.39
Mean annual precipitation at centroid (in.)	35.8773
Longest flow path (miles)	2.35
Excel file with original survey data	GW292510RR

ID	35
Stream name	Illinois Creek near Alma
County	Wabaunsee
Township	12 S
Range	10 E
Section	NE 1/4 Sec. 31
Latitude	38.96698163
Longitude	96.343
USGS quadrangle	Allendorph
USGS gage#	
Drainage area (mi2)	34.3
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4/1
Rosgen valley type	VIII/X
Sinuosity	1.41
Depth (ft)	6.16
Top width (ft)	73.2
Area (ft2)	420.37
Wetted perimeter (ft)	88.91
Mean depth (ft)	5.742759563
Width/depth ratio	12.74648524
Average adjacent pool depth	8.355
Flood-prone width (ft)	410
Entrench- ment ratio	5.6
Sinuosity	1.41
Meander wavelength (ft)	882.94
Radius of of curvature (ft)	213.85
Belt width (ft)	376.21
Bankfull slope (ft/ft)	0.00321
Drainage area (mi2)	34.3
Mean annual precipitation at centroid (in.)	34.4015
Longest flow path (miles)	12.21
Excel file with original survey data	WB311210RR

ID	36
Stream name	Trib to East Branch Fall River near Eureka
County	Greenwood
Township	24 S
Range	10 E
Section	SW 1/4 Sec 19
Latitude	37.94127778
Longitude	96.36105556
USGS quadrangle	Eureka NE
USGS gage#	
Drainage area (mi2)	2.71
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.3
Depth (ft)	2.33
Top width (ft)	41.1
Area (ft2)	42.3
Wetted perimeter (ft)	33.66
Mean depth (ft)	1.02919708
Width/depth ratio	39.93404255
Average adjacent pool depth	3.365
Flood-prone width (ft)	110
Entrench- ment ratio	2.676399027
Sinuosity	1.3
Meander wavelength (ft)	369.79
Radius of of curvature (ft)	107.36
Belt width (ft)	147.02
Bankfull slope (ft/ft)	0.00409
Drainage area (mi2)	2.71
Mean annual precipitation at centroid (in.)	35.6264
Longest flow path (miles)	3.05
Excel file with original survey data	GW192410RR

ID	37
Stream name	Tributary to Rock Creek near Council Grove
County	Morris
Township	16 S
Range	9 E
Section	NW 1/4 Sec 1
Latitude	38.69546667
Longitude	96.37068333
USGS quadrangle	Bushong
USGS gage#	
Drainage area (mi2)	2.91
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.37
Depth (ft)	1.35
Top width (ft)	37.6
Area (ft2)	48.6
Wetted perimeter (ft)	37.54
Mean depth (ft)	1.292553191
Width/depth ratio	29.08971193
Average adjacent pool depth	3.245
Flood-prone width (ft)	78
Entrench- ment ratio	2.074468085
Sinuosity	1.37
Meander wavelength (ft)	493.37
Radius of of curvature (ft)	0.00616
Belt width (ft)	182.14
Bankfull slope (ft/ft)	0.00616
Drainage area (mi2)	2.91
Mean annual precipitation at centroid (in.)	34.6889
Longest flow path (miles)	2.58
Excel file with original survey data	MR011609RR

ID	38
Stream name	Emmon Creek near Zeandale
County	Riley
Township	11 S
Range	9 E
Section	SE 1/4 Sec. 10
Latitude	39.15
Longitude	96.39333333
USGS quadrangle	Wamego Southwest
USGS gage#	
Drainage area (mi2)	0.64
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	B4c
Rosgen valley type	II
Sinuosity	1.29
Depth (ft)	2.23
Top width (ft)	18.02
Area (ft2)	24.17
Wetted perimeter (ft)	33.28
Mean depth (ft)	1.341287458
Width/depth ratio	13.43485312
Average adjacent pool depth	3.24
Flood-prone width (ft)	30.26
Entrench- ment ratio	4.81
Sinuosity	1.29
Meander wavelength (ft)	276.72
Radius of of curvature (ft)	61.39
Belt width (ft)	91.47
Bankfull slope (ft/ft)	0.01233
Drainage area (mi2)	0.64
Mean annual precipitation at centroid (in.)	33.9874
Longest flow path (miles)	
Excel file with original survey data	RL101109RR

ID	39
Stream name	Oleson Creek near Eureka
County	Greenwood
Township	24 S
Range	9 E
Section	SW 1/4 Sec 2
Latitude	37.98933333
Longitude	96.39483333
USGS quadrangle	Lapland
USGS gage#	
Drainage area (mi2)	2.92
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.23
Depth (ft)	0.91
Top width (ft)	18.3
Area (ft2)	20.8
Wetted perimeter (ft)	17.71
Mean depth (ft)	1.136612022
Width/depth ratio	16.10048077
Average adjacent pool depth	3.83
Flood-prone width (ft)	60.64
Entrench- ment ratio	3.313661202
Sinuosity	1.23
Meander wavelength (ft)	207.9
Radius of of curvature (ft)	66.59
Belt width (ft)	76.59
Bankfull slope (ft/ft)	0.00536
Drainage area (mi2)	2.92
Mean annual precipitation at centroid (in.)	35.4189
Longest flow path (miles)	4.5
Excel file with original survey data	GW022409CR

ID	40
Stream name	Black Vermillion River near Frankfort
County	Marshall
Township	4 S
Range	19 E
Section	NE 1/4 NW1/4 NW 1/4 Sec. 29
Latitude	39.68416667
Longitude	96.4375
USGS quadrangle	Frankfort
USGS gage#	6885500
Drainage area (mi2)	410
USEPA ecoregion	Western Corn Belt Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	1.86
Depth (ft)	16.49
Top width (ft)	103
Area (ft2)	1025.4
Wetted perimeter (ft)	111.82
Mean depth (ft)	9.955339806
Width/depth ratio	10.34620636
Average adjacent pool depth	20.89
Flood-prone width (ft)	6500
Entrench- ment ratio	63.10679612
Sinuosity	1.86
Meander wavelength (ft)	1314
Radius of of curvature (ft)	429.89
Belt width (ft)	466.458
Bankfull slope (ft/ft)	0.0002
Drainage area (mi2)	410
Mean annual precipitation at centroid (in.)	32.7977
Longest flow path (miles)	41.18
Excel file with original survey data	MS290409RR

ID	41
Stream name	Little Bloody Creek - Upper Reach
County	Chase
Township	20 S
Range	9 E
Section	SW 1/4 Sec 29
Latitude	38.279
Longitude	96.43866667
USGS quadrangle	Gladstone
USGS gage#	
Drainage area (mi2)	1.95
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4/1
Rosgen valley type	II
Sinuosity	1.46
Depth (ft)	
Top width (ft)	28.64
Area (ft2)	23.98
Wetted perimeter (ft)	47.73
Mean depth (ft)	0.837290503
Width/depth ratio	34.20557131
Average adjacent pool depth	
Flood-prone width (ft)	90.31
Entrench- ment ratio	3.15
Sinuosity	1.46
Meander wavelength (ft)	199.94
Radius of of curvature (ft)	53.38
Belt width (ft)	75.8
Bankfull slope (ft/ft)	0.00866
Drainage area (mi2)	1.95
Mean annual precipitation at centroid (in.)	34.8525
Longest flow path (miles)	3.07
Excel file with original survey data	CS292009RR

ID	42
Stream name	Little Bloody Creek - Lower Reach
County	Chase
Township	20 S
Range	9 E
Section	NW 1/4 Sec 20
Latitude	38.30033333
Longitude	96.4425
USGS quadrangle	Gladstone
USGS gage#	
Drainage area (mi2)	3.85
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	B4c
Rosgen valley type	VIII/X
Sinuosity	1.56
Depth (ft)	2.01
Top width (ft)	29.9
Area (ft2)	31.31
Wetted perimeter (ft)	30.54
Mean depth (ft)	1.047157191
Width/depth ratio	28.55349729
Average adjacent pool depth	3.77
Flood-prone width (ft)	48.45
Entrench- ment ratio	1.62
Sinuosity	1.56
Meander wavelength (ft)	373.11
Radius of of curvature (ft)	92.29
Belt width (ft)	155.59
Bankfull slope (ft/ft)	0.00284
Drainage area (mi2)	3.85
Mean annual precipitation at centroid (in.)	34.8089
Longest flow path (miles)	5.46
Excel file with original survey data	CS202009RR

ID	43
Stream name	Little Bloody Creek - Middle Reach
County	Chase
Township	20 S
Range	9 E
Section	SW 1/4 Sec 20
Latitude	38.28980556
Longitude	96.44594444
USGS quadrangle	Gladstone
USGS gage#	
Drainage area (mi2)	3.27
USEPA ecoregion	Flint Hills
Predominant bed material	Bedrock
Rosgen level 2 stream type	C1
Rosgen valley type	VIII/X
Sinuosity	1.56
Depth (ft)	1.12
Top width (ft)	33.84
Area (ft2)	36.95
Wetted perimeter (ft)	34.31
Mean depth (ft)	1.091903073
Width/depth ratio	30.99176184
Average adjacent pool depth	4.465
Flood-prone width (ft)	82
Entrench- ment ratio	2.42
Sinuosity	1.56
Meander wavelength (ft)	286.83
Radius of of curvature (ft)	68.03
Belt width (ft)	117.87
Bankfull slope (ft/ft)	0.00413
Drainage area (mi2)	3.27
Mean annual precipitation at centroid (in.)	34.8307
Longest flow path (miles)	4.33
Excel file with original survey data	CS202009RR

ID	44
Stream name	Tributary to Burnt Creek near Reece
County	Greenwood
Township	26 S
Range	9 E
Section	SW 1/4 Sec 5
Latitude	37.8097222
Longitude	96.4477777
USGS quadrangle	Reece
USGS gage#	
Drainage area (mi2)	2.9
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.64
Depth (ft)	1.48
Top width (ft)	36.4
Area (ft2)	30
Wetted perimeter (ft)	37.3
Mean depth (ft)	0.824175824
Width/depth ratio	44.16533333
Average adjacent pool depth	3.91
Flood-prone width (ft)	82
Entrench- ment ratio	2.252747253
Sinuosity	1.64
Meander wavelength (ft)	329.74
Radius of of curvature (ft)	83.4
Belt width (ft)	142.62
Bankfull slope (ft/ft)	0.00642
Drainage area (mi2)	2.9
Mean annual precipitation at centroid (in.)	35.5193
Longest flow path (miles)	2.8
Excel file with original survey data	GW052609RR

ID	45
Stream name	Little Cedar Creek near Matfield Green
County	Chase
Township	20 S
Range	9 E
Section	SW 1/4 Sec 29
Latitude	38.11833333
Longitude	96.4585
USGS quadrangle	Teterville
USGS gage#	
Drainage area (mi2)	4.5
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.33
Depth (ft)	1.95
Top width (ft)	36
Area (ft2)	38.16
Wetted perimeter (ft)	36.35
Mean depth (ft)	1.06
Width/depth ratio	33.96226415
Average adjacent pool depth	2.98
Flood-prone width (ft)	78
Entrench- ment ratio	2.17
Sinuosity	1.33
Meander wavelength (ft)	501.26
Radius of of curvature (ft)	101.63
Belt width (ft)	133.61
Bankfull slope (ft/ft)	0.00429
Drainage area (mi2)	4.5
Mean annual precipitation at centroid (in.)	34.9383
Longest flow path (miles)	2.46
Excel file with original survey data	CS192209RR

ID	46
Stream name	Tributary to Thurman Creek near Matfield Green
County	Chase
Township	22 S
Range	9 E
Section	SE 1/4 Sec 31
Latitude	38.09116667
Longitude	96.45866667
USGS quadrangle	Teterville
USGS gage#	
Drainage area (mi2)	4.36
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.33
Depth (ft)	3.39
Top width (ft)	36.21
Area (ft2)	64.82
Wetted perimeter (ft)	41.64
Mean depth (ft)	1.790113228
Width/depth ratio	20.22777075
Average adjacent pool depth	6.645
Flood-prone width (ft)	89.44
Entrench- ment ratio	2.470035902
Sinuosity	1.33
Meander wavelength (ft)	649.25
Radius of of curvature (ft)	143.16
Belt width (ft)	221.65
Bankfull slope (ft/ft)	0.00433
Drainage area (mi2)	4.36
Mean annual precipitation at centroid (in.)	34.9751
Longest flow path (miles)	4
Excel file with original survey data	CS312209RR

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ID	47
Stream name	Tributary to Antelope Creek near Zeandale
County	Wabaunsee
Township	11 S
Range	9 E
Section	NE 1/4 Sec 23
Latitude	38.08406667
Longitude	96.45923333
USGS quadrangle	Wamego Southwest
USGS gage#	
Drainage area (mi2)	0.48
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	B4c
Rosgen valley type	VIII/X
Sinuosity	1.53
Depth (ft)	1.52
Top width (ft)	13.28
Area (ft2)	12.18
Wetted perimeter (ft)	13.66
Mean depth (ft)	0.917168675
Width/depth ratio	14.47934319
Average adjacent pool depth	2.15
Flood-prone width (ft)	22.86
Entrench- ment ratio	1.721385542
Sinuosity	1.53
Meander wavelength (ft)	164.15
Radius of of curvature (ft)	37.83
Belt width (ft)	65.09
Bankfull slope (ft/ft)	0.01044
Drainage area (mi2)	0.48
Mean annual precipitation at centroid (in.)	33.9
Longest flow path (miles)	
Excel file with original survey data	WB231109RR

ID	48
Stream name	British Pasture, South Creek
County	Riley
Township	11 S
Range	8 E
Section	NE 1/4 Sec. 24
Latitude	39.08033333
Longitude	96.468
USGS quadrangle	Wamego Southwest
USGS gage#	
Drainage area (mi2)	0.2
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4b
Rosgen valley type	II
Sinuosity	1.06
Depth (ft)	1.42
Top width (ft)	10.26
Area (ft2)	5.14
Wetted perimeter (ft)	15.67
Mean depth (ft)	0.500974659
Width/depth ratio	20.48007782
Average adjacent pool depth	1.66
Flood-prone width (ft)	34.75
Entrench- ment ratio	3.39
Sinuosity	1.06
Meander wavelength (ft)	124.74
Radius of of curvature (ft)	28.94
Belt width (ft)	30.83
Bankfull slope (ft/ft)	0.02399
Drainage area (mi2)	0.2
Mean annual precipitation at centroid (in.)	33.8726
Longest flow path (miles)	0.62
Excel file with original survey data	RL241108RR

ID	49
Stream name	British Pasture, North Creek-Upstream Reach
County	Riley
Township	11 S
Range	8 E
Section	SW 1/4 Sec. 13
Latitude	39.09066667
Longitude	96.475
USGS quadrangle	Wamego Southwest
USGS gage#	
Drainage area (mi2)	0.32
USEPA ecoregion	Flint Hills
Predominant bed material	Bedrock
Rosgen level 2 stream type	B1
Rosgen valley type	II
Sinuosity	1.1
Depth (ft)	0.87
Top width (ft)	15.99
Area (ft2)	23.16
Wetted perimeter (ft)	19.68
Mean depth (ft)	1.448405253
Width/depth ratio	11.03972798
Average adjacent pool depth	3.185
Flood-prone width (ft)	34.66
Entrench- ment ratio	2.17
Sinuosity	1.1
Meander wavelength (ft)	165.83
Radius of of curvature (ft)	50.32
Belt width (ft)	29.29
Bankfull slope (ft/ft)	0.02118
Drainage area (mi2)	0.32
Mean annual precipitation at centroid (in.)	33.79
Longest flow path (miles)	0.63
Excel file with original survey data	RL131108RR

ID	50
Stream name	Tributary to West Branch Fall River near Eureka
County	Greenwood
Township	24 S
Range	8 E
Section	NW 1/4 Sec 36
Latitude	37.92589
Longitude	96.47833
USGS quadrangle	Lapland
USGS gage#	
Drainage area (mi2)	2.19
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	B4c
Rosgen valley type	II
Sinuosity	1.14
Depth (ft)	1.03
Top width (ft)	25.4
Area (ft2)	26.5
Wetted perimeter (ft)	26.81
Mean depth (ft)	1.043307087
Width/depth ratio	24.34566038
Average adjacent pool depth	1.91
Flood-prone width (ft)	48.57
Entrench- ment ratio	1.912204724
Sinuosity	1.14
Meander wavelength (ft)	360.57
Radius of of curvature (ft)	100.19
Belt width (ft)	95.47
Bankfull slope (ft/ft)	0.01438
Drainage area (mi2)	2.19
Mean annual precipitation at centroid (in.)	35.2531
Longest flow path (miles)	3.09
Excel file with original survey data	GW252408RR

ID	51
Stream name	Tributary to Spring Creek near Reece
County	Greenwood
Township	26 S
Range	8 E
Section	Se 1/4 Sec 13
Latitude	37.787
Longitude	96.4795
USGS quadrangle	Reece
USGS gage#	
Drainage area (mi2)	3.14
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.33
Depth (ft)	1.43
Top width (ft)	37.7
Area (ft2)	33.7
Wetted perimeter (ft)	37.38
Mean depth (ft)	0.893899204
Width/depth ratio	42.17477745
Average adjacent pool depth	2.245
Flood-prone width (ft)	110
Entrench- ment ratio	2.917771883
Sinuosity	1.33
Meander wavelength (ft)	266.58
Radius of of curvature (ft)	64.6
Belt width (ft)	42.33
Bankfull slope (ft/ft)	0.00571
Drainage area (mi2)	3.14
Mean annual precipitation at centroid (in.)	35.4168
Longest flow path (miles)	3.37
Excel file with original survey data	GW132608CR

ID	52
Stream name	Norton Creek near Bazaar
County	Chase
Township	20 S
Range	8 E
Section	SE 1/4 Sec 35
Latitude	38.26598333
Longitude	96.48705
USGS quadrangle	Gladstone
USGS gage#	
Drainage area (mi2)	8.21
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4/1
Rosgen valley type	VIII/X
Sinuosity	1.35
Depth (ft)	2.09
Top width (ft)	22.2
Area (ft2)	31.33
Wetted perimeter (ft)	23.93
Mean depth (ft)	1.411261261
Width/depth ratio	15.73060964
Average adjacent pool depth	4.56
Flood-prone width (ft)	68.94
Entrench- ment ratio	3.105405405
Sinuosity	1.35
Meander wavelength (ft)	481.44
Radius of of curvature (ft)	137.84
Belt width (ft)	208.5
Bankfull slope (ft/ft)	0.00346
Drainage area (mi2)	8.21
Mean annual precipitation at centroid (in.)	34.7238
Longest flow path (miles)	
Excel file with original survey data	CS262008RR

ID	53
Stream name	Tributary to Ivanpah Creek near Eureka
County	Greenwood
Township	25 S
Range	8 E
Section	NE 1/4 Sec 3
Latitude	37.90813889
Longitude	96.50811111
USGS quadrangle	Rosalia NE
USGS gage#	
Drainage area (mi2)	2.56
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	B4c
Rosgen valley type	VIII/X
Sinuosity	1.42
Depth (ft)	2.33
Top width (ft)	44.4
Area (ft2)	102.7
Wetted perimeter (ft)	34.31
Mean depth (ft)	2.313063063
Width/depth ratio	19.19532619
Average adjacent pool depth	3.365
Flood-prone width (ft)	82
Entrench- ment ratio	1.846846847
Sinuosity	1.42
Meander wavelength (ft)	403.72
Radius of of curvature (ft)	101.06
Belt width (ft)	154.03
Bankfull slope (ft/ft)	0.00347
Drainage area (mi2)	2.56
Mean annual precipitation at centroid (in.)	35.13
Longest flow path (miles)	2.44
Excel file with original survey data	GW192410RR

ID	54
Stream name	Battle Creek near Eureka
County	Greenwood
Township	24 S
Range	8 E
Section	NW 1/4 Sec 3
Latitude	37.99366667
Longitude	96.51425
USGS quadrangle	Rosalia NE
USGS gage#	
Drainage area (mi2)	3.31
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.6
Depth (ft)	1.49
Top width (ft)	15.1
Area (ft2)	17.7
Wetted perimeter (ft)	22.48
Mean depth (ft)	1.17218543
Width/depth ratio	12.8819209
Average adjacent pool depth	2.745
Flood-prone width (ft)	35.39
Entrench- ment ratio	2.343708609
Sinuosity	1.6
Meander wavelength (ft)	310.47
Radius of of curvature (ft)	114.66
Belt width (ft)	121.53
Bankfull slope (ft/ft)	0.00548
Drainage area (mi2)	3.31
Mean annual precipitation at centroid (in.)	34.9515
Longest flow path (miles)	3.28
Excel file with original survey data	GW032408RR

ID	55
Stream name	Sharpes Creek near Bazaar
County	Chase
Township	21 S
Range	8 E
Section	SW 1/4 Sec 10
Latitude	38.23816667
Longitude	96.51483333
USGS quadrangle	Matfield Green
USGS gage#	
Drainage area (mi2)	21.74
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4/1
Rosgen valley type	VIII/X
Sinuosity	1.61
Depth (ft)	5
Top width (ft)	108.59
Area (ft2)	288.85
Wetted perimeter (ft)	102.89
Mean depth (ft)	2.660005525
Width/depth ratio	40.82322347
Average adjacent pool depth	8.425
Flood-prone width (ft)	280
Entrench- ment ratio	2.578506308
Sinuosity	1.61
Meander wavelength (ft)	483.98
Radius of of curvature (ft)	139.06
Belt width (ft)	266.48
Bankfull slope (ft/ft)	0.00169
Drainage area (mi2)	21.74
Mean annual precipitation at centroid (in.)	34.6057
Longest flow path (miles)	9.99
Excel file with original survey data	CS102108RR

ID	56
Stream name	Tributary to Ivanpah Creek near Eureka
County	Greenwood
Township	25 S
Range	8 E
Section	SE 1/4 Sec 9
Latitude	37.88388888
Longitude	96.52897222
USGS quadrangle	Rosalia NE
USGS gage#	
Drainage area (mi2)	3.45
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.3
Depth (ft)	1.56
Top width (ft)	22.9
Area (ft2)	21.6
Wetted perimeter (ft)	23.64
Mean depth (ft)	0.943231441
Width/depth ratio	24.27824074
Average adjacent pool depth	4.34
Flood-prone width (ft)	58
Entrench- ment ratio	2.532751092
Sinuosity	1.3
Meander wavelength (ft)	352.04
Radius of of curvature (ft)	104.2
Belt width (ft)	171.25
Bankfull slope (ft/ft)	0.00824
Drainage area (mi2)	3.45
Mean annual precipitation at centroid (in.)	35.1
Longest flow path (miles)	3.39
Excel file with original survey data	BT092508CR

ID	57
Stream name	outh Fork Cottonwood River near Matfield Gree
County	Chase
Township	21 S
Range	8 E
Section	NE 1/4 Sec 31
Latitude	38.18466667
Longitude	96.5615
USGS quadrangle	Matfield Green
USGS gage#	
Drainage area (mi2)	112.24
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4/1
Rosgen valley type	VIII/X
Sinuosity	1.52
Depth (ft)	
Top width (ft)	124.9
Area (ft2)	805.61
Wetted perimeter (ft)	127.16
Mean depth (ft)	6.450040032
Width/depth ratio	19.3642209
Average adjacent pool depth	
Flood-prone width (ft)	1060
Entrench- ment ratio	8.486789432
Sinuosity	1.52
Meander wavelength (ft)	1348.16
Radius of of curvature (ft)	293.21
Belt width (ft)	525.38
Bankfull slope (ft/ft)	0.00119
Drainage area (mi2)	112.24
Mean annual precipitation at centroid (in.)	34.4418
Longest flow path (miles)	19.1
Excel file with original survey data	CS102108RR

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ID	58
Stream name	Palmer Creek near Strong City
County	Chase
Township	18 S
Range	8 E
Section	SE 1/4 Sec 18
Latitude	38.49216667
Longitude	96.58316667
USGS quadrangle	Strong City
USGS gage#	
Drainage area (mi2)	5.09
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4/1
Rosgen valley type	VIII/X
Sinuosity	1.28
Depth (ft)	3.12
Top width (ft)	50.9
Area (ft2)	89.37
Wetted perimeter (ft)	49.71
Mean depth (ft)	1.755795678
Width/depth ratio	28.98970572
Average adjacent pool depth	6.685
Flood-prone width (ft)	180
Entrench- ment ratio	3.536345776
Sinuosity	1.28
Meander wavelength (ft)	536.19
Radius of of curvature (ft)	138.56
Belt width (ft)	129.32
Bankfull slope (ft/ft)	0.00638
Drainage area (mi2)	5.09
Mean annual precipitation at centroid (in.)	31.12
Longest flow path (miles)	4.89
Excel file with original survey data	CS181808RR

ID	59
Stream name	Rock Creek near Bazaar (Above Tributary)
County	Chase
Township	18 S
Range	8 E
Section	SE 1/4 Sec 18
Latitude	38.212
Longitude	96.636
USGS quadrangle	Homestead
USGS gage#	
Drainage area (mi2)	2.83
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.52
Depth (ft)	1.16
Top width (ft)	34.3
Area (ft2)	20.09
Wetted perimeter (ft)	39.41
Mean depth (ft)	0.585714286
Width/depth ratio	58.56097561
Average adjacent pool depth	2.34
Flood-prone width (ft)	90.9
Entrench- ment ratio	2.650145773
Sinuosity	1.52
Meander wavelength (ft)	237.34
Radius of of curvature (ft)	73.5
Belt width (ft)	136.09
Bankfull slope (ft/ft)	0.00407
Drainage area (mi2)	2.83
Mean annual precipitation at centroid (in.)	34.126
Longest flow path (miles)	
Excel file with original survey data	CS232107RR

ID	60
Stream name	North Branch Hickory Creek near Keighley
County	Butler
Township	28 S
Range	7 E
Section	NE 1/4 Sec 14
Latitude	37.61738333
Longitude	96.62603333
USGS quadrangle	Latham
USGS gage#	
Drainage area (mi2)	16.82
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.46
Depth (ft)	4.32
Top width (ft)	52.3
Area (ft2)	177.79
Wetted perimeter (ft)	56.4
Mean depth (ft)	3.399426386
Width/depth ratio	15.38494853
Average adjacent pool depth	5.965
Flood-prone width (ft)	120
Entrench- ment ratio	2.294455067
Sinuosity	1.46
Meander wavelength (ft)	658.21
Radius of of curvature (ft)	142.3
Belt width (ft)	295.69
Bankfull slope (ft/ft)	0.00239
Drainage area (mi2)	16.82
Mean annual precipitation at centroid (in.)	35.0101
Longest flow path (miles)	9.32
Excel file with original survey data	BU142807RR

ID	61
Stream name	Schaffer Creek near Hymer (Above Tributary)
County	Chase
Township	18 S
Range	7 E
Section	SW 1/4 Sec 5
Latitude	38.51436667
Longitude	96.67985
USGS quadrangle	Diamond Springs
USGS gage#	
Drainage area (mi2)	6.18
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.35
Depth (ft)	2.25
Top width (ft)	56
Area (ft2)	80.11
Wetted perimeter (ft)	56.65
Mean depth (ft)	1.430535714
Width/depth ratio	39.14617401
Average adjacent pool depth	4.625
Flood-prone width (ft)	150
Entrench- ment ratio	2.678571429
Sinuosity	1.35
Meander wavelength (ft)	423.99
Radius of of curvature (ft)	97.83
Belt width (ft)	152.11
Bankfull slope (ft/ft)	0.00473
Drainage area (mi2)	6.18
Mean annual precipitation at centroid (in.)	33.7579
Longest flow path (miles)	3.65
Excel file with original survey data	CS051807RR

ID	62
Stream name	Little Blue River near Barnes
County	Washington
Township	3 S
Range	5 E
Section	NW 1/4 NW 1/4 SW 1/4 Sec. 22
Latitude	39.77583333
Longitude	96.85805556
USGS quadrangle	Hanover SE
USGS gage#	6884400
Drainage area (mi2)	3320
USEPA ecoregion	Central Great Plains
Predominant bed material	Gravel
Rosgen level 2 stream type	C4c-
Rosgen valley type	VIII/X
Sinuosity	1.67
Depth (ft)	11.7
Top width (ft)	334
Area (ft2)	2425
Wetted perimeter (ft)	275.95
Mean depth (ft)	7.260479042
Width/depth ratio	46.00247423
Average adjacent pool depth	12.7
Flood-prone width (ft)	3100
Entrench- ment ratio	9.281437126
Sinuosity	1.67
Meander wavelength (ft)	2475.93
Radius of of curvature (ft)	575.75
Belt width (ft)	1099
Bankfull slope (ft/ft)	0.00041
Drainage area (mi2)	3320
Mean annual precipitation at centroid (in.)	31.2706
Longest flow path (miles)	195
Excel file with original survey data	WS220305RR

ID	63
Stream name	West Branch Walnut River near Burns
County	Butler
Township	22 S
Range	5 E
Section	S 1/2 Sec. 22
Latitude	38.02761667
Longitude	96.87216667
USGS quadrangle	Florence Southeast
USGS gage#	
Drainage area (mi2)	0.75
USEPA ecoregion	Flint Hills
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	1.99
Depth (ft)	1.42
Top width (ft)	10.4
Area (ft2)	14.99
Wetted perimeter (ft)	12.98
Mean depth (ft)	1.441346154
Width/depth ratio	7.215476985
Average adjacent pool depth	2.5
Flood-prone width (ft)	580
Entrench- ment ratio	55.76923077
Sinuosity	1.99
Meander wavelength (ft)	135.07
Radius of of curvature (ft)	35.23
Belt width (ft)	75.61
Bankfull slope (ft/ft)	0.00256
Drainage area (mi2)	0.75
Mean annual precipitation at centroid (in.)	33.6078
Longest flow path (miles)	2.46
Excel file with original survey data	BU222305RR

ID	64
Stream name	Cottonwood River near Florence
County	Marion
Township	21 S
Range	5 E
Section	NW 1/4 NW 1/4 SW 1/4 Sec. 10
Latitude	38.23611111
Longitude	96.87694444
USGS quadrangle	Florence
USGS gage#	7180400
Drainage area (mi2)	754
USEPA ecoregion	Flint Hills
Predominant bed material	Gravel
Rosgen level 2 stream type	E4
Rosgen valley type	VIII/X
Sinuosity	1.41
Depth (ft)	15.4
Top width (ft)	115.84
Area (ft2)	1196.01
Wetted perimeter (ft)	128.06
Mean depth (ft)	10.32467196
Width/depth ratio	11.21972693
Average adjacent pool depth	16.59
Flood-prone width (ft)	2440
Entrench- ment ratio	18.20895522
Sinuosity	1.41
Meander wavelength (ft)	2488.5
Radius of of curvature (ft)	391.66
Belt width (ft)	1060.325
Bankfull slope (ft/ft)	0.00302
Drainage area (mi2)	754
Mean annual precipitation at centroid (in.)	33.2792
Longest flow path (miles)	52.48
Excel file with original survey data	MN102105RR

ID	65
Stream name	Whitewater River at Towanda
County	Butler
Township	26 S
Range	4 E
Section	SE 1/4 SW 1/4 SE 1/4 Sec. 8
Latitude	37.79583333
Longitude	97.0125
USGS quadrangle	Benton
USGS gage#	7147070
Drainage area (mi2)	426
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	E5
Rosgen valley type	VIII/X
Sinuosity	1.816
Depth (ft)	16.96
Top width (ft)	105
Area (ft2)	1209.5
Wetted perimeter (ft)	93.04
Mean depth (ft)	11.51904762
Width/depth ratio	9.115336916
Average adjacent pool depth	19.435
Flood-prone width (ft)	5530
Entrench- ment ratio	52.66666667
Sinuosity	1.816
Meander wavelength (ft)	1045.7
Radius of of curvature (ft)	164.14
Belt width (ft)	330.205
Bankfull slope (ft/ft)	0.00073
Drainage area (mi2)	426
Mean annual precipitation at centroid (in.)	33.2975
Longest flow path (miles)	45.94
Excel file with original survey data	BU082604RR

ID	66
Stream name	Mill Creek at Washington
County	Washington
Township	3 S
Range	3 E
Section	SW 1/4 SW 1/4 SE 1/4 Sec. 1
Latitude	39.81388889
Longitude	97.03888889
USGS quadrangle	Washington
USGS gage#	6884200
Drainage area (mi2)	344
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	E5
Rosgen valley type	VIII/X
Sinuosity	1.7799
Depth (ft)	11.52
Top width (ft)	93
Area (ft2)	738.7
Wetted perimeter (ft)	54.24
Mean depth (ft)	7.943010753
Width/depth ratio	11.70840666
Average adjacent pool depth	14.56
Flood-prone width (ft)	650
Entrench- ment ratio	6.989247312
Sinuosity	1.7799
Meander wavelength (ft)	1232.465
Radius of of curvature (ft)	199.69
Belt width (ft)	340.135
Bankfull slope (ft/ft)	0.00055
Drainage area (mi2)	344
Mean annual precipitation at centroid (in.)	30.7349
Longest flow path (miles)	60.37
Excel file with original survey data	WS010303RR

ID	67
Stream name	Chapman Creek near Chapman
County	Dickinson
Township	12 S
Range	3 E
Section	SW 1/4 SE 1/4 SE 1/4 Sec. 1
Latitude	39.03111111
Longitude	97.04
USGS quadrangle	Upland
USGS gage#	6878000
Drainage area (mi2)	300
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	1.919
Depth (ft)	
Top width (ft)	62
Area (ft2)	521.2
Wetted perimeter (ft)	72.91
Mean depth (ft)	8.406451613
Width/depth ratio	7.375287797
Average adjacent pool depth	
Flood-prone width (ft)	4230
Entrench- ment ratio	68.22580645
Sinuosity	1.919
Meander wavelength (ft)	925.96
Radius of of curvature (ft)	285.37
Belt width (ft)	470.12
Bankfull slope (ft/ft)	0.00038
Drainage area (mi2)	300
Mean annual precipitation at centroid (in.)	31.9542
Longest flow path (miles)	60.17
Excel file with original survey data	DK011203RR

ID	68
Stream name	Slate Creek at Wellington
County	Sumner
Township	32 S
Range	1 West
Section	SE 1/4 NE 1/4 SE 1/4 Sec. 22
Latitude	37.25
Longitude	97.40333333
USGS quadrangle	Rome
USGS gage#	7145700
Drainage area (mi2)	154
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	E5
Rosgen valley type	VIII/X
Sinuosity	1.56
Depth (ft)	7.62
Top width (ft)	54
Area (ft2)	284.26
Wetted perimeter (ft)	61.35499788
Mean depth (ft)	5.264074074
Width/depth ratio	10.25821431
Average adjacent pool depth	8.955
Flood-prone width (ft)	224
Entrench- ment ratio	4.226415094
Sinuosity	1.56
Meander wavelength (ft)	447.92
Radius of of curvature (ft)	127.74
Belt width (ft)	125.38
Bankfull slope (ft/ft)	0.00058
Drainage area (mi2)	154
Mean annual precipitation at centroid (in.)	31.7135
Longest flow path (miles)	45.226634
Excel file with original survey data	SU223201RR

ID	69
Stream name	Ninnescah River near Peck
County	Sumner
Township	30 S
Range	1 West
Section	NW 1/4 SW 1/4 NW 1/4 Sec. 10
Latitude	37.45722222
Longitude	97.42222222
USGS quadrangle	Zyba
USGS gage#	7145500
Drainage area (mi2)	1790
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5c-
Rosgen valley type	VIII/X
Sinuosity	1.22
Depth (ft)	
Top width (ft)	204
Area (ft2)	1627.6
Wetted perimeter (ft)	210.4740653
Mean depth (ft)	7.978431373
Width/depth ratio	25.56893586
Average adjacent pool depth	
Flood-prone width (ft)	1400
Entrench- ment ratio	6.862745098
Sinuosity	1.22
Meander wavelength (ft)	2323.505
Radius of of curvature (ft)	579.25
Belt width (ft)	386.86
Bankfull slope (ft/ft)	0.00029
Drainage area (mi2)	1790
Mean annual precipitation at centroid (in.)	31.5404
Longest flow path (miles)	130.920852
Excel file with original survey data	SU103001RR

ID	70
Stream name	Solomon River at Niles
County	Ottawa
Township	12 S
Range	1 West
Section	NW 1/4 SE 1/4 NW 1/4 Sec. 31
Latitude	38.96888889
Longitude	97.47611111
USGS quadrangle	Osborne
USGS gage#	6876900
Drainage area (mi2)	6770
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	2.82
Depth (ft)	15.11
Top width (ft)	115.93
Area (ft2)	1507.92
Wetted perimeter (ft)	113.267449
Mean depth (ft)	13.00715949
Width/depth ratio	8.912783768
Average adjacent pool depth	18.2
Flood-prone width (ft)	5400
Entrench- ment ratio	52.94117647
Sinuosity	2.82
Meander wavelength (ft)	1340
Radius of of curvature (ft)	261.906
Belt width (ft)	3520.95
Bankfull slope (ft/ft)	0.00024
Drainage area (mi2)	6770
Mean annual precipitation at centroid (in.)	30.0547
Longest flow path (miles)	453.592027
Excel file with original survey data	OT311201RR

ID	71
Stream name	ittle Arkansas River at Highway 50 near Halstea
County	Harvey
Township	23 S
Range	2 West
Section	NW 1/4 NE 1/4 NE 1/4 Sec. 28
Latitude	38.02861111
Longitude	97.54027778
USGS quadrangle	Halstead
USGS gage#	7143672
Drainage area (mi2)	759
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	1.34
Depth (ft)	13.55
Top width (ft)	115
Area (ft2)	1047.9
Wetted perimeter (ft)	119.566722
Mean depth (ft)	9.112173913
Width/depth ratio	12.62047905
Average adjacent pool depth	15.675
Flood-prone width (ft)	10422
Entrench- ment ratio	90.62608696
Sinuosity	1.34
Meander wavelength (ft)	1005.71
Radius of of curvature (ft)	167.62
Belt width (ft)	867.802
Bankfull slope (ft/ft)	0.00038
Drainage area (mi2)	759
Mean annual precipitation at centroid (in.)	30.8635
Longest flow path (miles)	81.503657
Excel file with original survey data	HV282302RR

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ID	72
Stream name	Little Arkansas River at Alta Mills
County	Harvey
Township	22 S
Range	2 West
Section	SW 1/4 NW 1/4 NW 1/4 Sec. 30
Latitude	38.11222222
Longitude	97.59166667
USGS quadrangle	Halstead
USGS gage#	7143665
Drainage area (mi2)	681
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	E5
Rosgen valley type	VIII/X
Sinuosity	1.4148
Depth (ft)	14.52
Top width (ft)	99
Area (ft2)	1058.2
Wetted perimeter (ft)	109.2303387
Mean depth (ft)	10.68888889
Width/depth ratio	9.261954262
Average adjacent pool depth	19.47
Flood-prone width (ft)	10560
Entrench- ment ratio	106.6666667
Sinuosity	1.4148
Meander wavelength (ft)	1173.3
Radius of of curvature (ft)	214.76
Belt width (ft)	930.534
Bankfull slope (ft/ft)	0.00036
Drainage area (mi2)	681
Mean annual precipitation at centroid (in.)	30.5835
Longest flow path (miles)	72.802923
Excel file with original survey data	HV302202RR

ID	73
Stream name	Chikaskia River near Corbin
County	Sumner
Township	33 S
Range	3 West
Section	NW 1/4 SW 1/4 SW 1/4 Sec. 36
Latitude	37.12888889
Longitude	97.60111111
USGS quadrangle	Perth
USGS gage#	7151500
Drainage area (mi2)	794
USEPA ecoregion	Central Great Plains
Predominant bed material	Bedrock
Rosgen level 2 stream type	C1c-
Rosgen valley type	VIII/X
Sinuosity	1.71
Depth (ft)	5.4
Top width (ft)	143
Area (ft2)	728.7
Wetted perimeter (ft)	146.1306981
Mean depth (ft)	5.095804196
Width/depth ratio	28.06230273
Average adjacent pool depth	6.3
Flood-prone width (ft)	395
Entrench- ment ratio	2.762237762
Sinuosity	1.71
Meander wavelength (ft)	1127.25
Radius of of curvature (ft)	318.47
Belt width (ft)	184.32
Bankfull slope (ft/ft)	0.00089
Drainage area (mi2)	794
Mean annual precipitation at centroid (in.)	30.9753
Longest flow path (miles)	118.343461
Excel file with original survey data	SU363303RR

ID	74
Stream name	Republican River at Concordia
County	Cloud
Township	5 S
Range	3 West
Section	SW 1/4 SW 1/4 NE 1/4 Sec. 28
Latitude	39.59027778
Longitude	97.65888889
USGS quadrangle	Concordia
USGS gage#	6856000
Drainage area (mi2)	23560
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5c-
Rosgen valley type	VIII/X
Sinuosity	1.21
Depth (ft)	6.25
Top width (ft)	290
Area (ft2)	1608.81
Wetted perimeter (ft)	282.7295367
Mean depth (ft)	5.54762069
Width/depth ratio	52.27466264
Average adjacent pool depth	7.795
Flood-prone width (ft)	6700
Entrench- ment ratio	23.42657343
Sinuosity	1.21
Meander wavelength (ft)	3800
Radius of of curvature (ft)	1018.176
Belt width (ft)	1053.726
Bankfull slope (ft/ft)	0.000473
Drainage area (mi2)	23560
Mean annual precipitation at centroid (in.)	28.8632
Longest flow path (miles)	
Excel file with original survey data	CD280503RR

ID	75
Stream name	Salt Creek near Ada
County	Ottawa
Township	10 S
Range	5 West
Section	NW 1/4 NW 1/4 SW 1/4 Sec. 36
Latitude	39.14166667
Longitude	97.83611111
USGS quadrangle	Tescott NE
USGS gage#	6876700
Drainage area (mi2)	384
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	2.18
Depth (ft)	10.8
Top width (ft)	49
Area (ft2)	374.9
Wetted perimeter (ft)	57.47754856
Mean depth (ft)	7.651020408
Width/depth ratio	6.4043745
Average adjacent pool depth	11.9
Flood-prone width (ft)	2300
Entrench- ment ratio	46.93877551
Sinuosity	2.18
Meander wavelength (ft)	642.086
Radius of of curvature (ft)	143.28
Belt width (ft)	168.4925
Bankfull slope (ft/ft)	0.00036
Drainage area (mi2)	384
Mean annual precipitation at centroid (in.)	28.2757
Longest flow path (miles)	72.355068
Excel file with original survey data	OT361005RR

ID	76
Stream name	Buffalo Creek near Jamestown
County	Cloud
Township	5 S
Range	5 West
Section	SE 1/4 NE 1/4 SE 1/4 Sec. 15
Latitude	39.61444444
Longitude	97.85611111
USGS quadrangle	Jamestown
USGS gage#	6855800
Drainage area (mi2)	330
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	1.77
Depth (ft)	
Top width (ft)	61
Area (ft2)	351.2
Wetted perimeter (ft)	64.97937105
Mean depth (ft)	5.757377049
Width/depth ratio	10.59510251
Average adjacent pool depth	
Flood-prone width (ft)	5400
Entrench- ment ratio	88.52459016
Sinuosity	1.77
Meander wavelength (ft)	924
Radius of of curvature (ft)	176
Belt width (ft)	770
Bankfull slope (ft/ft)	0.0008
Drainage area (mi2)	330
Mean annual precipitation at centroid (in.)	28.209
Longest flow path (miles)	48.796585
Excel file with original survey data	CD150505RR

ID	77
Stream name	Saline River at Tescott
County	Ottawa
Township	12 S
Range	5 West
Section	NE 1/4 SE 1/4 SE 1/4 Sec. 16
Latitude	39.00416667
Longitude	97.87388889
USGS quadrangle	Tescott SE
USGS gage#	6869500
Drainage area (mi2)	2820
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	2.52
Depth (ft)	11.1
Top width (ft)	69
Area (ft2)	637.8
Wetted perimeter (ft)	81.4309081
Mean depth (ft)	9.243478261
Width/depth ratio	7.464722484
Average adjacent pool depth	14.2
Flood-prone width (ft)	1830
Entrench- ment ratio	26.52173913
Sinuosity	2.52
Meander wavelength (ft)	876.09
Radius of of curvature (ft)	160.93
Belt width (ft)	643.4575
Bankfull slope (ft/ft)	0.00021
Drainage area (mi2)	2820
Mean annual precipitation at centroid (in.)	28.239
Longest flow path (miles)	392.943898
Excel file with original survey data	OT161205RR

ID	78
Stream name	rth Fork Ninnescah River Above Cheney Reserv
County	Reno
Township	25 S
Range	6 West
Section	NE 1/4 SE 1/4 NE 1/4 Sec. 19
Latitude	37.84472222
Longitude	97.93583333
USGS quadrangle	Pretty Prairie
USGS gage#	7144780
Drainage area (mi2)	550
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5c-
Rosgen valley type	VIII/X
Sinuosity	1.35
Depth (ft)	2.6
Top width (ft)	144
Area (ft2)	344
Wetted perimeter (ft)	146.2668254
Mean depth (ft)	2.388888889
Width/depth ratio	60.27906977
Average adjacent pool depth	3.1
Flood-prone width (ft)	2510
Entrench- ment ratio	17.43055556
Sinuosity	1.35
Meander wavelength (ft)	1429.02
Radius of of curvature (ft)	318.85
Belt width (ft)	227.505
Bankfull slope (ft/ft)	0.00083
Drainage area (mi2)	550
Mean annual precipitation at centroid (in.)	29.1225
Longest flow path (miles)	75.752159
Excel file with original survey data	RN192506RR

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ID	79
Stream name	Red Rock Creek near Pretty Prairie
County	Reno
Township	25 S
Range	6 West
Section	SE 1/4 NE 1/4 SE 1/4 Sec. 6
Latitude	37.9
Longitude	98.01666667
USGS quadrangle	Partridge
USGS gage#	7144730
Drainage area (mi2)	53.2
USEPA ecoregion	Central Great Plains
Predominant bed material	Bedrock
Rosgen level 2 stream type	C1
Rosgen valley type	VIII/X
Sinuosity	1.5476
Depth (ft)	4.4
Top width (ft)	34
Area (ft2)	115.9
Wetted perimeter (ft)	34.39468485
Mean depth (ft)	3.408823529
Width/depth ratio	9.974115617
Average adjacent pool depth	5
Flood-prone width (ft)	159
Entrench- ment ratio	4.676470588
Sinuosity	1.5476
Meander wavelength (ft)	348.89
Radius of of curvature (ft)	71.43
Belt width (ft)	65.42
Bankfull slope (ft/ft)	0.00301
Drainage area (mi2)	53.2
Mean annual precipitation at centroid (in.)	28.7157
Longest flow path (miles)	14.269394
Excel file with original survey data	RN062506RR

ID	80
Stream name	Cow Creek near Lyons
County	Rice
Township	20 S
Range	8 West
Section	SW 1/4 NW 1/4 SE 1/4 Sec. 15
Latitude	38.30833333
Longitude	98.19166667
USGS quadrangle	Lyons
USGS gage#	7143300
Drainage area (mi2)	499
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	1.94
Depth (ft)	11.84
Top width (ft)	72
Area (ft2)	473
Wetted perimeter (ft)	79.94986118
Mean depth (ft)	6.569444444
Width/depth ratio	10.95983087
Average adjacent pool depth	13.125
Flood-prone width (ft)	5700
Entrench- ment ratio	79.16666667
Sinuosity	1.94
Meander wavelength (ft)	571.9
Radius of of curvature (ft)	71.82
Belt width (ft)	223.416
Bankfull slope (ft/ft)	0.00025
Drainage area (mi2)	499
Mean annual precipitation at centroid (in.)	27.6391
Longest flow path (miles)	89.985912
Excel file with original survey data	RC152008RR

ID	81
Stream name	Smoky Hill River at Ellsworth
County	Ellsworth
Township	15 S
Range	8 West
Section	SW 1/4 SW 1/4 SE 1/4 Sec. 20
Latitude	38.72666667
Longitude	98.23333333
USGS quadrangle	Ellsworth
USGS gage#	6864500
Drainage area (mi2)	7580
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5c-
Rosgen valley type	VIII/X
Sinuosity	1.12
Depth (ft)	
Top width (ft)	137
Area (ft2)	923.3
Wetted perimeter (ft)	147.5448289
Mean depth (ft)	6.739416058
Width/depth ratio	20.32817069
Average adjacent pool depth	
Flood-prone width (ft)	1720
Entrench- ment ratio	12.55474453
Sinuosity	1.12
Meander wavelength (ft)	1249.96
Radius of of curvature (ft)	310.598
Belt width (ft)	148.5
Bankfull slope (ft/ft)	0.00036
Drainage area (mi2)	7580
Mean annual precipitation at centroid (in.)	27.1512
Longest flow path (miles)	426.196197
Excel file with original survey data	EW201508RR

ID	82
Stream name	White Rock Creek near Burr Oak
County	Jewell
Township	2 S
Range	8 West
Section	SE 1/4 NE 1/4 NE 1/4 Sec. 7
Latitude	39.89861111
Longitude	98.25138889
USGS quadrangle	North Branch
USGS gage#	6853800
Drainage area (mi2)	227
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	2.138888889
Depth (ft)	8.5
Top width (ft)	50
Area (ft2)	287.3
Wetted perimeter (ft)	60.14193933
Mean depth (ft)	5.746
Width/depth ratio	8.701705534
Average adjacent pool depth	9.6
Flood-prone width (ft)	470
Entrench- ment ratio	9.4
Sinuosity	2.138888889
Meander wavelength (ft)	534
Radius of of curvature (ft)	89.7
Belt width (ft)	495
Bankfull slope (ft/ft)	0.00095
Drainage area (mi2)	227
Mean annual precipitation at centroid (in.)	26.822
Longest flow path (miles)	58.201983
Excel file with original survey data	JW070208RR

ID	83
Stream name	Rattlesnake Creek near Raymond
County	Rice
Township	21 S
Range	10 West
Section	SW 1/4 NW 1/4 NW 1/4 Sec. 15
Latitude	38.23055556
Longitude	98.41666667
USGS quadrangle	Alden NW
USGS gage#	7142620
Drainage area (mi2)	1167
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	E5
Rosgen valley type	VIII/X
Sinuosity	1.66
Depth (ft)	3.2
Top width (ft)	36
Area (ft2)	103.7
Wetted perimeter (ft)	39.98200988
Mean depth (ft)	2.880555556
Width/depth ratio	12.4975892
Average adjacent pool depth	4.3
Flood-prone width (ft)	420
Entrench- ment ratio	11.66666667
Sinuosity	1.66
Meander wavelength (ft)	504.31
Radius of of curvature (ft)	120.447
Belt width (ft)	241.66
Bankfull slope (ft/ft)	0.00043
Drainage area (mi2)	1167
Mean annual precipitation at centroid (in.)	26.6733
Longest flow path (miles)	193.443629
Excel file with original survey data	RC152110RR

ID	84
Stream name	Medicine Lodge River near Kiowa
County	Barber
Township	34 S
Range	11 West
Section	NW 1/4 SE 1/4 SW 1/4 Sec. 36
Latitude	37.03805556
Longitude	98.46777778
USGS quadrangle	Kiowa
USGS gage#	7149000
Drainage area (mi2)	903
USEPA ecoregion	Southwestern Tablelands
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.44
Depth (ft)	5.71
Top width (ft)	103.5
Area (ft2)	470.13
Wetted perimeter (ft)	117.4396486
Mean depth (ft)	4.542318841
Width/depth ratio	22.78571884
Average adjacent pool depth	7.81
Flood-prone width (ft)	5400
Entrench- ment ratio	45.76271186
Sinuosity	1.44
Meander wavelength (ft)	1475
Radius of of curvature (ft)	302.89
Belt width (ft)	311.72
Bankfull slope (ft/ft)	0.00144
Drainage area (mi2)	903
Mean annual precipitation at centroid (in.)	27.0655
Longest flow path (miles)	96.532621
Excel file with original survey data	BA363411RR

ID	85
Stream name	Rattlesnake Creek near Zenith
County	Stafford
Township	22 S
Range	11 West
Section	SW 1/4 SW 1/4 NW 1/4 Sec. 33
Latitude	38.09361111
Longitude	98.54583333
USGS quadrangle	Hudson SE
USGS gage#	7142575
Drainage area (mi2)	519
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5c-
Rosgen valley type	VIII/X
Sinuosity	1.45
Depth (ft)	2.65
Top width (ft)	55
Area (ft2)	98.6
Wetted perimeter (ft)	55.91420006
Mean depth (ft)	1.792727273
Width/depth ratio	30.67951318
Average adjacent pool depth	3.75
Flood-prone width (ft)	426
Entrench- ment ratio	7.745454545
Sinuosity	1.45
Meander wavelength (ft)	787.5
Radius of of curvature (ft)	126.74
Belt width (ft)	281.5
Bankfull slope (ft/ft)	0.00074
Drainage area (mi2)	519
Mean annual precipitation at centroid (in.)	26.1074
Longest flow path (miles)	168.679269
Excel file with original survey data	SF332211RR

ID	86
Stream name	South Fork Solomon River at Osborne
County	Osborne
Township	7 S
Range	12 West
Section	SW 1/4 NW 1/4 SW 1/4 Sec. 20
Latitude	39.42861111
Longitude	98.69444444
USGS quadrangle	Osborne
USGS gage#	6874000
Drainage area (mi2)	2010
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	E5
Rosgen valley type	VIII/X
Sinuosity	1.423
Depth (ft)	6.82
Top width (ft)	60
Area (ft2)	324.6
Wetted perimeter (ft)	61.49005613
Mean depth (ft)	5.41
Width/depth ratio	11.09057301
Average adjacent pool depth	7.765
Flood-prone width (ft)	972
Entrench- ment ratio	16.2
Sinuosity	1.423
Meander wavelength (ft)	620
Radius of of curvature (ft)	172.11
Belt width (ft)	176.74
Bankfull slope (ft/ft)	0.00033
Drainage area (mi2)	2010
Mean annual precipitation at centroid (in.)	24.9898
Longest flow path (miles)	262.292713
Excel file with original survey data	OB200712RR

ID	87
Stream name	Arkansas River at Great Bend
County	Barton
Township	19 S
Range	13 West
Section	SW 1/4 NW 1/4 SE 1/4 Sec. 33
Latitude	38.35305556
Longitude	98.76388889
USGS quadrangle	Great Bead
USGS gage#	7141300
Drainage area (mi2)	34356
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.1596
Depth (ft)	
Top width (ft)	111
Area (ft2)	490.9
Wetted perimeter (ft)	114.1087764
Mean depth (ft)	4.422522523
Width/depth ratio	25.09879813
Average adjacent pool depth	
Flood-prone width (ft)	468
Entrench- ment ratio	4.216216216
Sinuosity	1.1596
Meander wavelength (ft)	1153.89
Radius of of curvature (ft)	295.41
Belt width (ft)	264
Bankfull slope (ft/ft)	0.00122
Drainage area (mi2)	34356
Mean annual precipitation at centroid (in.)	25.1572
Longest flow path (miles)	
Excel file with original survey data	BT331913RR

ID	88
Stream name	Smoky Hill River near Bunker Hill
County	Russell
Township	14 S
Range	13 West
Section	NW 1/4 SW 1/4 NW 1/4 Sec. 33
Latitude	38.79388889
Longitude	98.78055556
USGS quadrangle	Homer
USGS gage#	6864050
Drainage area (mi2)	7075
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5c-
Rosgen valley type	VIII/X
Sinuosity	1.42
Depth (ft)	
Top width (ft)	116
Area (ft2)	839.8
Wetted perimeter (ft)	124.1744889
Mean depth (ft)	7.239655172
Width/depth ratio	16.02286259
Average adjacent pool depth	
Flood-prone width (ft)	2800
Entrench- ment ratio	24.13793103
Sinuosity	1.42
Meander wavelength (ft)	1070.545
Radius of of curvature (ft)	273.4
Belt width (ft)	308.68
Bankfull slope (ft/ft)	0.00075
Drainage area (mi2)	7075
Mean annual precipitation at centroid (in.)	25.109
Longest flow path (miles)	379.84828
Excel file with original survey data	RS331413RR

ID	89
Stream name	Sand Creek near Medicine Lodge
County	Barber
Township	33 S
Range	14 West
Section	NE 1/4 Sec. 11
Latitude	37.19616667
Longitude	98.8075
USGS quadrangle	Pump Creek
USGS gage#	
Drainage area (mi2)	0.85
USEPA ecoregion	Southwestern Tablelands
Predominant bed material	Sand
Rosgen level 2 stream type	B5c
Rosgen valley type	II
Sinuosity	1.09
Depth (ft)	
Top width (ft)	15.83
Area (ft2)	19.46
Wetted perimeter (ft)	18.02183094
Mean depth (ft)	1.229311434
Width/depth ratio	12.87712744
Average adjacent pool depth	
Flood-prone width (ft)	27.23
Entrench- ment ratio	1.720151611
Sinuosity	1.09
Meander wavelength (ft)	210.38
Radius of of curvature (ft)	84.2
Belt width (ft)	63.2
Bankfull slope (ft/ft)	0.00834
Drainage area (mi2)	0.85
Mean annual precipitation at centroid (in.)	25.7058
Longest flow path (miles)	1.463638
Excel file with original survey data	BA113312RR

ID	90
Stream name	Rattlesnake Creek near Macksville
County	Stafford
Township	25 S
Range	14 West
Section	SW 1/4 SW 1/4 Sec. 16
Latitude	37.87166667
Longitude	98.87583333
USGS quadrangle	Hopewell
USGS gage#	7142300
Drainage area (mi2)	356
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	E5
Rosgen valley type	VIII/X
Sinuosity	2.38
Depth (ft)	3.2
Top width (ft)	26.6
Area (ft2)	56.1
Wetted perimeter (ft)	25.38
Mean depth (ft)	2.109022556
Width/depth ratio	12.61247772
Average adjacent pool depth	5.05
Flood-prone width (ft)	1200
Entrench- ment ratio	46.15384615
Sinuosity	2.38
Meander wavelength (ft)	352.675
Radius of of curvature (ft)	75.125
Belt width (ft)	182.305
Bankfull slope (ft/ft)	0.00077
Drainage area (mi2)	356
Mean annual precipitation at centroid (in.)	24.99
Longest flow path (miles)	
Excel file with original survey data	SF162514RR

ID	91
Stream name	Turkey Creek near Sun City
County	Barber
Township	30 S
Range	15 West
Section	SW 1/4 Sec. 13
Latitude	37.4295
Longitude	98.91916667
USGS quadrangle	Sun City
USGS gage#	
Drainage area (mi2)	60.15
USEPA ecoregion	Southwestern Tablelands
Predominant bed material	Gravel
Rosgen level 2 stream type	B4c
Rosgen valley type	VIII/X
Sinuosity	1.17
Depth (ft)	2.37
Top width (ft)	59.14
Area (ft2)	56.06
Wetted perimeter (ft)	81.73166855
Mean depth (ft)	0.947920189
Width/depth ratio	62.38921869
Average adjacent pool depth	2.44
Flood-prone width (ft)	79
Entrench- ment ratio	1.335813324
Sinuosity	1.17
Meander wavelength (ft)	442.3
Radius of of curvature (ft)	112.22
Belt width (ft)	85.18
Bankfull slope (ft/ft)	0.00374
Drainage area (mi2)	60.15
Mean annual precipitation at centroid (in.)	25.3148
Longest flow path (miles)	19.53874
Excel file with original survey data	BA133015RR

ID	92
Stream name	Tributary to Bear Creek near Sun City
County	Barber
Township	32 S
Range	15 West
Section	SE 1/4 Sec. 2
Latitude	37.28416667
Longitude	98.91933333
USGS quadrangle	Sun City Southwest
USGS gage#	
Drainage area (mi2)	1.48
USEPA ecoregion	Southwestern Tablelands
Predominant bed material	Sand
Rosgen level 2 stream type	B5c
Rosgen valley type	II
Sinuosity	1.38
Depth (ft)	1.25
Top width (ft)	13.06
Area (ft2)	7.71
Wetted perimeter (ft)	13.26989896
Mean depth (ft)	0.590352221
Width/depth ratio	22.12238651
Average adjacent pool depth	1.56
Flood-prone width (ft)	25.5
Entrench- ment ratio	1.952526799
Sinuosity	1.38
Meander wavelength (ft)	143.03
Radius of of curvature (ft)	38.83
Belt width (ft)	54.83
Bankfull slope (ft/ft)	0.01329
Drainage area (mi2)	1.48
Mean annual precipitation at centroid (in.)	25.4287
Longest flow path (miles)	1.958855
Excel file with original survey data	BA023215RR

ID	93
Stream name	Mule Creek near Aetna
County	Barber
Township	33 S
Range	15 West
Section	SE 1/4 Sec. 31
Latitude	37.12316667
Longitude	98.9855
USGS quadrangle	Aetna
USGS gage#	
Drainage area (mi2)	202.78
USEPA ecoregion	Southwestern Tablelands
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.38
Depth (ft)	
Top width (ft)	60.5
Area (ft2)	86.1
Wetted perimeter (ft)	47.34457534
Mean depth (ft)	1.423140496
Width/depth ratio	42.5116144
Average adjacent pool depth	
Flood-prone width (ft)	860
Entrench- ment ratio	14.21487603
Sinuosity	1.38
Meander wavelength (ft)	622.53
Radius of of curvature (ft)	131.25
Belt width (ft)	164.59
Bankfull slope (ft/ft)	0.0018
Drainage area (mi2)	202.78
Mean annual precipitation at centroid (in.)	25.2905
Longest flow path (miles)	62.96122
Excel file with original survey data	BA333315RR

ID	94
Stream name	Walnut Creek at Albert
County	Barton
Township	18 S
Range	15 West
Section	SW 1/4 NW 1/4 NW 1/4 Sec. 29
Latitude	38.46111111
Longitude	99.01388889
USGS quadrangle	Albert
USGS gage#	7141900
Drainage area (mi2)	1310
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	1.33
Depth (ft)	
Top width (ft)	36
Area (ft2)	203.4
Wetted perimeter (ft)	43.04996149
Mean depth (ft)	5.65
Width/depth ratio	6.371681416
Average adjacent pool depth	
Flood-prone width (ft)	120
Entrench- ment ratio	3.333333333
Sinuosity	1.33
Meander wavelength (ft)	963.8
Radius of of curvature (ft)	303.78
Belt width (ft)	642.57
Bankfull slope (ft/ft)	0.00067
Drainage area (mi2)	1310
Mean annual precipitation at centroid (in.)	24.0674
Longest flow path (miles)	185.288867
Excel file with original survey data	BT291815RR

ID	95
Stream name	Soldier Creek near Belvidere
County	Comanche
Township	29 S
Range	16 West
Section	SW 1/4 Sec. 24
Latitude	37.50383333
Longitude	99.02933333
USGS quadrangle	Haviland
USGS gage#	
Drainage area (mi2)	15.32
USEPA ecoregion	Southwestern Tablelands
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.21
Depth (ft)	2.05
Top width (ft)	24.48
Area (ft2)	29.38
Wetted perimeter (ft)	24.80854685
Mean depth (ft)	1.200163399
Width/depth ratio	20.3972226
Average adjacent pool depth	2.53
Flood-prone width (ft)	154.26
Entrench- ment ratio	6.301470588
Sinuosity	1.21
Meander wavelength (ft)	239.08
Radius of of curvature (ft)	68.85
Belt width (ft)	85.05
Bankfull slope (ft/ft)	0.00249
Drainage area (mi2)	15.32
Mean annual precipitation at centroid (in.)	25.0004
Longest flow path (miles)	10.543377
Excel file with original survey data	KW242916RR

ID	96
Stream name	Salt Fork Arkansas River near Buttermilk
County	Comanche
Township	34 S
Range	16 West
Section	NW 1/4 Sec. 18
Latitude	37.08883333
Longitude	99.10233333
USGS quadrangle	Fancy Canyon
USGS gage#	
Drainage area (mi2)	149.61
USEPA ecoregion	Southwestern Tablelands
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.26
Depth (ft)	2.31
Top width (ft)	74.67
Area (ft2)	104.2
Wetted perimeter (ft)	73.36237131
Mean depth (ft)	1.395473416
Width/depth ratio	53.50872265
Average adjacent pool depth	3.81
Flood-prone width (ft)	198.7
Entrench- ment ratio	2.661041918
Sinuosity	1.26
Meander wavelength (ft)	523.41
Radius of of curvature (ft)	104.51
Belt width (ft)	130.78
Bankfull slope (ft/ft)	0.00119
Drainage area (mi2)	149.61
Mean annual precipitation at centroid (in.)	24.996
Longest flow path (miles)	30.836229
Excel file with original survey data	CM183416RR

ID	97
Stream name	Medicine Lodge River near Belvidere
County	Comanche
Township	30 S
Range	17 West
Section	SW 1/4 Sec. 13
Latitude	37.4385
Longitude	99.13666667
USGS quadrangle	Iron Mountain
USGS gage#	
Drainage area (mi2)	70.31
USEPA ecoregion	Southwestern Tablelands
Predominant bed material	Sand
Rosgen level 2 stream type	B5c
Rosgen valley type	VIII/X
Sinuosity	1.27
Depth (ft)	2.33
Top width (ft)	28.7
Area (ft2)	45.22
Wetted perimeter (ft)	31.40010559
Mean depth (ft)	1.575609756
Width/depth ratio	18.21517028
Average adjacent pool depth	4.34
Flood-prone width (ft)	46.34
Entrench- ment ratio	1.614634146
Sinuosity	1.27
Meander wavelength (ft)	324.05
Radius of of curvature (ft)	106.93
Belt width (ft)	106.78
Bankfull slope (ft/ft)	0.00202
Drainage area (mi2)	70.31
Mean annual precipitation at centroid (in.)	24.706
Longest flow path (miles)	26.157213
Excel file with original survey data	KW133017RR

ID	98
Stream name	Thompson Creek near Belvidere
County	Kiowa
Township	29 S
Range	17 West
Section	SE 1/4 Sec. 15
Latitude	37.51683333
Longitude	99.166
USGS quadrangle	Brenham
USGS gage#	
Drainage area (mi2)	9.6
USEPA ecoregion	Southwestern Tablelands
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	II
Sinuosity	1.27
Depth (ft)	2.52
Top width (ft)	23.22
Area (ft2)	39.94
Wetted perimeter (ft)	25.78195081
Mean depth (ft)	1.720068906
Width/depth ratio	13.49945919
Average adjacent pool depth	3.81
Flood-prone width (ft)	48
Entrench- ment ratio	2.067183463
Sinuosity	1.27
Meander wavelength (ft)	214.99
Radius of of curvature (ft)	52.87
Belt width (ft)	51.99
Bankfull slope (ft/ft)	0.00318
Drainage area (mi2)	9.6
Mean annual precipitation at centroid (in.)	24.6093
Longest flow path (miles)	9.190506
Excel file with original survey data	KW152917RR

ID	99
Stream name	EB Nescatunga Creek (Upstream Reach)
County	Comanche
Township	33 S
Range	17 West
Section	NW 1/4 Sec. 5
Latitude	37.20783333
Longitude	99.19766667
USGS quadrangle	Nescatunga Creek North
USGS gage#	
Drainage area (mi2)	16.09
USEPA ecoregion	Southwestern Tablelands
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.28
Depth (ft)	1.29
Top width (ft)	14
Area (ft2)	8.39
Wetted perimeter (ft)	7.875493534
Mean depth (ft)	0.599285714
Width/depth ratio	23.36114422
Average adjacent pool depth	2.3
Flood-prone width (ft)	56
Entrench- ment ratio	4
Sinuosity	1.28
Meander wavelength (ft)	127.88
Radius of of curvature (ft)	48.3
Belt width (ft)	42.43
Bankfull slope (ft/ft)	0.00464
Drainage area (mi2)	16.09
Mean annual precipitation at centroid (in.)	24.725
Longest flow path (miles)	8.658351
Excel file with original survey data	CM053317RR

ID	100
Stream name	Big Creek near Hays
County	Ellis
Township	14 S
Range	17 West
Section	NW 1/4 NW 1/4 NE 1/4 Sec. 30
Latitude	38.8125
Longitude	99.25388889
USGS quadrangle	Hays South
USGS gage#	6863500
Drainage area (mi2)	594
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	1.94
Depth (ft)	4.2
Top width (ft)	28
Area (ft2)	139.7
Wetted perimeter (ft)	34.65593104
Mean depth (ft)	4.989285714
Width/depth ratio	5.61202577
Average adjacent pool depth	5.75
Flood-prone width (ft)	54
Entrench- ment ratio	1.928571429
Sinuosity	1.94
Meander wavelength (ft)	483.235
Radius of of curvature (ft)	101.05
Belt width (ft)	68.0025
Bankfull slope (ft/ft)	0.00023
Drainage area (mi2)	594
Mean annual precipitation at centroid (in.)	23.1728
Longest flow path (miles)	170.981217
Excel file with original survey data	EL301417RR

ID	101
Stream name	Rattlesnake Creek near Greensburg
County	Kiowa
Township	27 S
Range	18 West
Section	SW 1/4 Sec. 17
Latitude	37.69116667
Longitude	99.3145
USGS quadrangle	Greensburg Northeast
USGS gage#	
Drainage area (mi2)	208.29
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5c-
Rosgen valley type	VIII/X
Sinuosity	1.59
Depth (ft)	1.27
Top width (ft)	25.95
Area (ft2)	35.47
Wetted perimeter (ft)	26.81493771
Mean depth (ft)	1.366859345
Width/depth ratio	18.98512828
Average adjacent pool depth	2.325
Flood-prone width (ft)	75.83
Entrench- ment ratio	2.922157996
Sinuosity	1.59
Meander wavelength (ft)	520.35
Radius of of curvature (ft)	145.05
Belt width (ft)	210.55
Bankfull slope (ft/ft)	0.00066
Drainage area (mi2)	208.29
Mean annual precipitation at centroid (in.)	24.0449
Longest flow path (miles)	69.341064
Excel file with original survey data	KW172718RR

ID	102
Stream name	Arkansas River near Kinsley
County	Edwards
Township	24 S
Range	19 West
Section	SW 1/4 SE 1/4 Sec. 26
Latitude	37.92583333
Longitude	99.37527778
USGS quadrangle	Lewis
USGS gage#	7140000
Drainage area (mi2)	33066
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5c-
Rosgen valley type	VIII/X
Sinuosity	1.09
Depth (ft)	4.4
Top width (ft)	84
Area (ft2)	226.65
Wetted perimeter (ft)	86.27543269
Mean depth (ft)	2.698214286
Width/depth ratio	31.13170086
Average adjacent pool depth	6.4
Flood-prone width (ft)	1500
Entrench- ment ratio	17.85714286
Sinuosity	1.09
Meander wavelength (ft)	875.6
Radius of of curvature (ft)	270.6
Belt width (ft)	222.51
Bankfull slope (ft/ft)	0.00096
Drainage area (mi2)	33066
Mean annual precipitation at centroid (in.)	23.402
Longest flow path (miles)	
Excel file with original survey data	ED262419RR

ID	103
Stream name	Smoky Hill River near Schoenchen
County	Ellis
Township	15 S
Range	19 West
Section	SE 1/4 SW 1/4 SE 1/4 Sec. 25
Latitude	38.71222222
Longitude	99.38138889
USGS quadrangle	La Crosse NW
USGS gage#	6862700
Drainage area (mi2)	5760
USEPA ecoregion	Central Great Plains
Predominant bed material	Gravel
Rosgen level 2 stream type	C4
Rosgen valley type	VIII/X
Sinuosity	1.15
Depth (ft)	2.4
Top width (ft)	33
Area (ft2)	68.5
Wetted perimeter (ft)	35.59218331
Mean depth (ft)	2.075757576
Width/depth ratio	15.89781022
Average adjacent pool depth	2.75
Flood-prone width (ft)	385
Entrench- ment ratio	11.66666667
Sinuosity	1.15
Meander wavelength (ft)	503.62
Radius of of curvature (ft)	69.4
Belt width (ft)	110
Bankfull slope (ft/ft)	0.00066
Drainage area (mi2)	5760
Mean annual precipitation at centroid (in.)	22.7127
Longest flow path (miles)	326.724877
Excel file with original survey data	EL251519RR

ID	104
Stream name	Pawnee River near Rozel
County	Pawnee
Township	21 S
Range	19 West
Section	SW 1/4 SW 1/4 Sec. 22
Latitude	38.20722222
Longitude	99.405
USGS quadrangle	Rozel
USGS gage#	7141200
Drainage area (mi2)	2010
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	1.7095
Depth (ft)	
Top width (ft)	60
Area (ft2)	402.7
Wetted perimeter (ft)	68.57339822
Mean depth (ft)	6.711666667
Width/depth ratio	8.939657313
Average adjacent pool depth	
Flood-prone width (ft)	207
Entrench- ment ratio	3.45
Sinuosity	1.7095
Meander wavelength (ft)	701.03
Radius of of curvature (ft)	121.31
Belt width (ft)	184.975
Bankfull slope (ft/ft)	0.00045
Drainage area (mi2)	2010
Mean annual precipitation at centroid (in.)	22.839
Longest flow path (miles)	165.994645
Excel file with original survey data	PN222119RR

ID	105
Stream name	Walnut Creek at Nekoma
County	Rush
Township	18 S
Range	19 West
Section	SW 1/4 NW 1/4 NW 1/4 Sec. 21
Latitude	38.47694444
Longitude	99.43694444
USGS quadrangle	Nekoma
USGS gage#	7141780
Drainage area (mi2)	1150
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	2.0305
Depth (ft)	
Top width (ft)	38
Area (ft2)	210.1
Wetted perimeter (ft)	44.68765053
Mean depth (ft)	5.528947368
Width/depth ratio	6.872917658
Average adjacent pool depth	
Flood-prone width (ft)	5200
Entrench- ment ratio	136.8421053
Sinuosity	2.0305
Meander wavelength (ft)	567.43
Radius of of curvature (ft)	103.64
Belt width (ft)	166.83
Bankfull slope (ft/ft)	0.00038
Drainage area (mi2)	1150
Mean annual precipitation at centroid (in.)	22.5504
Longest flow path (miles)	143.900896
Excel file with original survey data	RH211819RR

ID	106
Stream name	East Branch Kiowa Creek near Protection
County	Comanche
Township	31 S
Range	20 West
Section	NE 1/4 Sec. 23
Latitude	37.33783333
Longitude	99.459
USGS quadrangle	East Kiowa Creek South
USGS gage#	
Drainage area (mi2)	27.71
USEPA ecoregion	Southwestern Tablelands
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.26
Depth (ft)	1.71
Top width (ft)	16
Area (ft2)	14.56
Wetted perimeter (ft)	16.59748742
Mean depth (ft)	0.91
Width/depth ratio	17.58241758
Average adjacent pool depth	1.94
Flood-prone width (ft)	61.48
Entrench- ment ratio	3.8425
Sinuosity	1.26
Meander wavelength (ft)	247.53
Radius of of curvature (ft)	76.34
Belt width (ft)	106.15
Bankfull slope (ft/ft)	0.00236
Drainage area (mi2)	27.71
Mean annual precipitation at centroid (in.)	23.8993
Longest flow path (miles)	17.880549
Excel file with original survey data	CM233120RR

ID	107
Stream name	Prairie Dog Creek near Woodruff
County	Phiilips
Township	1 S
Range	19 West
Section	NW 1/4 NW 1/4 Sec. 9
Latitude	39.98583333
Longitude	99.4775
USGS quadrangle	Woodruff
USGS gage#	6848500
Drainage area (mi2)	1000
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	E5
Rosgen valley type	VIII/X
Sinuosity	2.18
Depth (ft)	6.49
Top width (ft)	33
Area (ft2)	167.8
Wetted perimeter (ft)	39.03784371
Mean depth (ft)	5.084848485
Width/depth ratio	6.489868892
Average adjacent pool depth	8.89
Flood-prone width (ft)	440
Entrench- ment ratio	13.33333333
Sinuosity	2.18
Meander wavelength (ft)	422.525
Radius of of curvature (ft)	160.22
Belt width (ft)	643.5
Bankfull slope (ft/ft)	0.00118
Drainage area (mi2)	1000
Mean annual precipitation at centroid (in.)	23.2248
Longest flow path (miles)	209.546538
Excel file with original survey data	PL090119RR

ID	108
Stream name	Middle Kiowa Creek near Protection
County	Comanche
Township	31 S
Range	20 West
Section	SE 1/4 Sec. 15
Latitude	37.338
Longitude	99.4785
USGS quadrangle	East Kiowa Creek South
USGS gage#	
Drainage area (mi2)	77.07
USEPA ecoregion	Southwestern Tablelands
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.39
Depth (ft)	
Top width (ft)	21.95
Area (ft2)	36.17
Wetted perimeter (ft)	19.0588883
Mean depth (ft)	1.647835991
Width/depth ratio	13.32050041
Average adjacent pool depth	
Flood-prone width (ft)	60.91
Entrench- ment ratio	2.774943052
Sinuosity	1.39
Meander wavelength (ft)	312.81
Radius of of curvature (ft)	90.75
Belt width (ft)	134.73
Bankfull slope (ft/ft)	0.00263
Drainage area (mi2)	77.07
Mean annual precipitation at centroid (in.)	23.8477
Longest flow path (miles)	21.49345
Excel file with original survey data	CM153120RR

ID	109
Stream name	Bluff Creek near Protection
County	Comanche
Township	34 S
Range	20 West
Section	SE 1/4 Sec. 28
Latitude	37.051
Longitude	99.48766667
USGS quadrangle	Protection Southwest
USGS gage#	
Drainage area (mi2)	600.1
USEPA ecoregion	Southwestern Tablelands
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.35
Depth (ft)	2.99
Top width (ft)	58.9
Area (ft2)	134.91
Wetted perimeter (ft)	38.77830771
Mean depth (ft)	2.29049236
Width/depth ratio	25.71499518
Average adjacent pool depth	5.5
Flood-prone width (ft)	305
Entrench- ment ratio	5.178268251
Sinuosity	1.35
Meander wavelength (ft)	890.32
Radius of of curvature (ft)	263.02
Belt width (ft)	477.44
Bankfull slope (ft/ft)	0.00112
Drainage area (mi2)	600.1
Mean annual precipitation at centroid (in.)	24.0086
Longest flow path (miles)	73.137873
Excel file with original survey data	CM283420

ID	110
Stream name	Walnut Creek near Alexander
County	Ness
Township	18 S
Range	21 West
Section	NW 1/4 NW 1/4 NW 1/4 Sec. 26
Latitude	38.46472222
Longitude	99.62222222
USGS quadrangle	Alexander
USGS gage#	7141770
Drainage area (mi2)	1025
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	2.16
Depth (ft)	9.3
Top width (ft)	41
Area (ft2)	292.3
Wetted perimeter (ft)	41.24164856
Mean depth (ft)	7.129268293
Width/depth ratio	5.750940814
Average adjacent pool depth	11.2
Flood-prone width (ft)	170
Entrench- ment ratio	4.146341463
Sinuosity	2.16
Meander wavelength (ft)	415.2
Radius of of curvature (ft)	100.75
Belt width (ft)	249.025
Bankfull slope (ft/ft)	0.00071
Drainage area (mi2)	1025
Mean annual precipitation at centroid (in.)	21.9163
Longest flow path (miles)	124.242694
Excel file with original survey data	NS261821RR

ID	111
Stream name	Buckner Creek near Burdett
County	Hodgeman
Township	22 S
Range	21 West
Section	NW 1/4 SW 1/4 SW 1/4 Sec. 4
Latitude	38.1625
Longitude	99.6425
USGS quadrangle	Hanston NW
USGS gage#	7141175
Drainage area (mi2)	735
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	1.83
Depth (ft)	6.2
Top width (ft)	30
Area (ft2)	107.1
Wetted perimeter (ft)	33.77732238
Mean depth (ft)	3.57
Width/depth ratio	8.403361345
Average adjacent pool depth	7.1
Flood-prone width (ft)	61
Entrench- ment ratio	2.033333333
Sinuosity	1.83
Meander wavelength (ft)	528
Radius of of curvature (ft)	172.11
Belt width (ft)	247.5
Bankfull slope (ft/ft)	0.00087
Drainage area (mi2)	735
Mean annual precipitation at centroid (in.)	22.1915
Longest flow path (miles)	96.834658
Excel file with original survey data	HG042221RR

ID	112
Stream name	Sappa Creek near Lyle
County	Norton
Township	1 S
Range	24 West
Section	NE 1/4 NE 1/4 NW 1/4 Sec. 2
Latitude	40
Longitude	99.99305556
USGS quadrangle	Norton NW
USGS gage#	6845110
Drainage area (mi2)	1488
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	2.57
Depth (ft)	7.6
Top width (ft)	30
Area (ft2)	175.9
Wetted perimeter (ft)	37.67154114
Mean depth (ft)	5.863333333
Width/depth ratio	5.116543491
Average adjacent pool depth	9.1
Flood-prone width (ft)	1400
Entrench- ment ratio	46.66666667
Sinuosity	2.57
Meander wavelength (ft)	360.43
Radius of of curvature (ft)	104.58
Belt width (ft)	149.63
Bankfull slope (ft/ft)	0.00046
Drainage area (mi2)	1488
Mean annual precipitation at centroid (in.)	22.3344
Longest flow path (miles)	225.244107
Excel file with original survey data	NT020124RR

ID	113
Stream name	Mulberry Creek near Dodge City
County	Ford
Township	28 S
Range	25 West
Section	NW 1/4 Sec. 24
Latitude	37.59805556
Longitude	100.0144444
USGS quadrangle	Ensign SW
USGS gage#	7139800
Drainage area (mi2)	73.8
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	1.87
Depth (ft)	
Top width (ft)	12
Area (ft2)	13.1
Wetted perimeter (ft)	10.96841547
Mean depth (ft)	1.091666667
Width/depth ratio	10.99236641
Average adjacent pool depth	
Flood-prone width (ft)	37
Entrench- ment ratio	3.083333333
Sinuosity	1.87
Meander wavelength (ft)	380.94
Radius of of curvature (ft)	67.558
Belt width (ft)	301.415
Bankfull slope (ft/ft)	0.00132
Drainage area (mi2)	73.8
Mean annual precipitation at centroid (in.)	22.1242
Longest flow path (miles)	26.319365
Excel file with original survey data	FO242825RR

ID	114
Stream name	Smoky Hill River near Arnold
County	Trego
Township	14 S
Range	24 West
Section	SW 1/4 NW 1/4 Sec. 29
Latitude	38.80861111
Longitude	100.0202778
USGS quadrangle	Gibson Creek
USGS gage#	6861000
Drainage area (mi2)	5220
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.08
Depth (ft)	3.2
Top width (ft)	93
Area (ft2)	99.5
Wetted perimeter (ft)	169.4186455
Mean depth (ft)	1.069892473
Width/depth ratio	86.92462312
Average adjacent pool depth	3.9
Flood-prone width (ft)	730
Entrench- ment ratio	4.345238095
Sinuosity	1.08
Meander wavelength (ft)	1566.795
Radius of of curvature (ft)	295.62
Belt width (ft)	290
Bankfull slope (ft/ft)	0.00127
Drainage area (mi2)	5220
Mean annual precipitation at centroid (in.)	21.1838
Longest flow path (miles)	282.198433
Excel file with original survey data	TR291424RR

ID	115
Stream name	Hackberry Creek at Gove
County	Gove
Township	13 S
Range	29 West
Section	SW 1/4 NE 1/4 Sec. 1
Latitude	38.95416667
Longitude	100.4847222
USGS quadrangle	Gove
USGS gage#	6860500
Drainage area (mi2)	421
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	B5c
Rosgen valley type	VIII/X
Sinuosity	1.94
Depth (ft)	2.07
Top width (ft)	39
Area (ft2)	38.6
Wetted perimeter (ft)	39.61074441
Mean depth (ft)	0.98974359
Width/depth ratio	39.40414508
Average adjacent pool depth	2.445
Flood-prone width (ft)	64
Entrench- ment ratio	1.641025641
Sinuosity	1.94
Meander wavelength (ft)	970.15
Radius of of curvature (ft)	250
Belt width (ft)	342.68
Bankfull slope (ft/ft)	0.00203
Drainage area (mi2)	421
Mean annual precipitation at centroid (in.)	20.3666
Longest flow path (miles)	103.448085
Excel file with original survey data	GV011329RR

ID	116
Stream name	Sappa Creek near Oberlin
County	Decatur
Township	3 S
Range	29 West
Section	NW 1/4 NW 1/4 NW 1/4 Sec. 12
Latitude	39.8125
Longitude	100.5333333
USGS quadrangle	Oberlin
USGS gage#	6845000
Drainage area (mi2)	923
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	E6
Rosgen valley type	VIII/X
Sinuosity	1.5773
Depth (ft)	4.45
Top width (ft)	30
Area (ft2)	99.4
Wetted perimeter (ft)	35.0854665
Mean depth (ft)	3.313333333
Width/depth ratio	9.054325956
Average adjacent pool depth	5.85
Flood-prone width (ft)	209
Entrench- ment ratio	6.966666667
Sinuosity	1.5773
Meander wavelength (ft)	469.5
Radius of of curvature (ft)	95.25
Belt width (ft)	97.25
Bankfull slope (ft/ft)	0.00094
Drainage area (mi2)	923
Mean annual precipitation at centroid (in.)	21.1533
Longest flow path (miles)	152.51509
Excel file with original survey data	DC120329RR

ID	117
Stream name	South Fork Sappa Creek near Achilles
County	Decatur
Township	4 S
Range	30 West
Section	SW 1/4 SW 1/4 NW 1/4 Sec. 29
Latitude	39.67694444
Longitude	100.7216667
USGS quadrangle	Oberlin Northeast
USGS gage#	6844900
Drainage area (mi2)	378
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	C6
Rosgen valley type	VIII/X
Sinuosity	1.5011
Depth (ft)	3.83
Top width (ft)	39
Area (ft2)	87.8
Wetted perimeter (ft)	39.25256826
Mean depth (ft)	2.251282051
Width/depth ratio	17.32346241
Average adjacent pool depth	4.86
Flood-prone width (ft)	884
Entrench- ment ratio	22.66666667
Sinuosity	1.5011
Meander wavelength (ft)	352.104
Radius of of curvature (ft)	50.0098
Belt width (ft)	948.7528
Bankfull slope (ft/ft)	0.00149
Drainage area (mi2)	378
Mean annual precipitation at centroid (in.)	20.6345
Longest flow path (miles)	128.657246
Excel file with original survey data	DC290430RR

ID	118
Stream name	Ladder Creek Below Chalk Creek near Scott City
County	Logan
Township	14 S
Range	32 West
Section	SW 1/4 Sec. 34
Latitude	38.78333333
Longitude	100.8666667
USGS quadrangle	Elkader
USGS gage#	6859500
Drainage area (mi2)	1330
USEPA ecoregion	Central Great Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.38
Depth (ft)	
Top width (ft)	95
Area (ft2)	42
Wetted perimeter (ft)	95.28493597
Mean depth (ft)	0.442105263
Width/depth ratio	214.8809524
Average adjacent pool depth	
Flood-prone width (ft)	212
Entrench- ment ratio	2.231578947
Sinuosity	1.38
Meander wavelength (ft)	693.77
Radius of of curvature (ft)	111.94
Belt width (ft)	107.09
Bankfull slope (ft/ft)	0.00132
Drainage area (mi2)	1330
Mean annual precipitation at centroid (in.)	19.5232
Longest flow path (miles)	219.103173
Excel file with original survey data	LG341432RR--2

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ID	119
Stream name	Beaver Creek at Ludell
County	Rawlins
Township	2 S
Range	32 West
Section	SE 1/4 NW 1/4 SW 1/4 Sec. 30
Latitude	39.84805556
Longitude	100.95
USGS quadrangle	Ludell
USGS gage#	6846000
Drainage area (mi2)	1120
USEPA ecoregion	Central Great Plains
Predominant bed material	Silt/Clay
Rosgen level 2 stream type	C6
Rosgen valley type	VIII/X
Sinuosity	1.859
Depth (ft)	3.24
Top width (ft)	29
Area (ft2)	43.1
Wetted perimeter (ft)	29.51230704
Mean depth (ft)	1.486206897
Width/depth ratio	19.51276102
Average adjacent pool depth	3.57
Flood-prone width (ft)	178
Entrench- ment ratio	6.137931034
Sinuosity	1.859
Meander wavelength (ft)	317.04
Radius of of curvature (ft)	72.72
Belt width (ft)	106.87
Bankfull slope (ft/ft)	0.00263
Drainage area (mi2)	1120
Mean annual precipitation at centroid (in.)	20.4647
Longest flow path (miles)	192.068763
Excel file with original survey data	RA300232RR

ID	120
Stream name	Rose Creek near Wallace
County	Wallace
Township	13 S
Range	39 West
Section	NE 1/4 Sec. 34
Latitude	38.88333333
Longitude	101.6333333
USGS quadrangle	Sharon Springs SE
USGS gage#	6858000
Drainage area (mi2)	28.5
USEPA ecoregion	Western High Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.71
Depth (ft)	
Top width (ft)	13
Area (ft2)	11.1
Wetted perimeter (ft)	14.62841518
Mean depth (ft)	0.853846154
Width/depth ratio	15.22522523
Average adjacent pool depth	
Flood-prone width (ft)	98
Entrench- ment ratio	7.538461538
Sinuosity	1.71
Meander wavelength (ft)	218.45
Radius of of curvature (ft)	59.38
Belt width (ft)	54.29
Bankfull slope (ft/ft)	0.00371
Drainage area (mi2)	28.5
Mean annual precipitation at centroid (in.)	17.7241
Longest flow path (miles)	20.550053
Excel file with original survey data	WA341339RR

ID	121
Stream name	Bear Creek near Johnson
County	Stanton
Township	28 S
Range	41 West
Section	NW 1/4 SW 1/4 Sec. 12
Latitude	37.62638889
Longitude	101.7611111
USGS quadrangle	Johnson Northeast
USGS gage#	7156220
Drainage area (mi2)	835
USEPA ecoregion	Western High Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.24
Depth (ft)	
Top width (ft)	21
Area (ft2)	20.2
Wetted perimeter (ft)	22.6340272
Mean depth (ft)	0.961904762
Width/depth ratio	21.83168317
Average adjacent pool depth	
Flood-prone width (ft)	53
Entrench- ment ratio	2.523809524
Sinuosity	1.24
Meander wavelength (ft)	923
Radius of of curvature (ft)	146.665
Belt width (ft)	800
Bankfull slope (ft/ft)	0.00302
Drainage area (mi2)	835
Mean annual precipitation at centroid (in.)	16.217
Longest flow path (miles)	119.097347
Excel file with original survey data	ST122841RR

ID	122
Stream name	Cimarron River near Elkhart
County	Morton
Township	34 S
Range	42 West
Section	NW 1/4 NW 1/4 NW 1/4 Sec. 4
Latitude	37.125
Longitude	101.8972222
USGS quadrangle	Elkhart North
USGS gage#	7155590
Drainage area (mi2)	2420
USEPA ecoregion	Western High Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.87
Depth (ft)	3.53
Top width (ft)	58
Area (ft2)	121.4
Wetted perimeter (ft)	59.49944715
Mean depth (ft)	2.093103448
Width/depth ratio	27.71004942
Average adjacent pool depth	4.615
Flood-prone width (ft)	208
Entrench- ment ratio	3.586206897
Sinuosity	1.87
Meander wavelength (ft)	641.5
Radius of of curvature (ft)	236
Belt width (ft)	232.2
Bankfull slope (ft/ft)	0.002
Drainage area (mi2)	2420
Mean annual precipitation at centroid (in.)	16.8597
Longest flow path (miles)	197.334296
Excel file with original survey data	MT043442RR01

ID	123
Stream name	South Fork Republican River near CO-KS Line
County	Cheyenne
Township	4 S
Range	42 West
Section	SE 1/4 SW 1/4 Sec. 27
Latitude	39.66944444
Longitude	102.0111111
USGS quadrangle	Hale Ponds
USGS gage#	6827000
Drainage area (mi2)	1860
USEPA ecoregion	Western High Plains
Predominant bed material	Sand
Rosgen level 2 stream type	C5
Rosgen valley type	VIII/X
Sinuosity	1.23
Depth (ft)	3
Top width (ft)	38
Area (ft2)	103.1
Wetted perimeter (ft)	40.75403284
Mean depth (ft)	2.713157895
Width/depth ratio	14.00581959
Average adjacent pool depth	4.045
Flood-prone width (ft)	122
Entrench- ment ratio	3.210526316
Sinuosity	1.23
Meander wavelength (ft)	454.4
Radius of of curvature (ft)	203.71
Belt width (ft)	148.1775
Bankfull slope (ft/ft)	0.00124
Drainage area (mi2)	1860
Mean annual precipitation at centroid (in.)	17.5571
Longest flow path (miles)	116.041027
Excel file with original survey data	CN270442RR