Regional Bankfull Characteristics for the Lower Willow Creek Stream Restoration

courtesy of Kelley Thompson and Agro Engineers

Lower Willow Creek

Miners Creek

West Willow Creek

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Short Job Description: Lower Willow Creek
Location: Creede, Colorado

Description of Job: Regional bankfull curve development for the Lower Willow Creek stream restoration.

Report Contributor:

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NRCS Natural Resources Conservation Service

The Natural Resources Conservation Service provides leadership in a partnership effort to help people conserve, maintain, and improve our natural resources and environment.

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Acknowledgements

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Introduction

Willow Creek downstream of Creede is currently in a braided condition (Figure 1, 7 and aerial photo on report cover). This condition is atypical for streams in this region. There is a strong desire among the local community and in various agencies to restore the stream to a more typical sinuous condition, a physical condition that would better support aquatic life once water-quality improvements are made throughout the historically heavily mined watershed. The Natural Resources Conservation Service (NRCS) has taken on the task of designing the stream restoration project. In support of this design effort, a regional bankfull characteristics analysis was performed. This report documents the development and application of regional bankfull curves for application by NRCS designers, local officials, community members, and other interested parties.

Figure 1: Current condition of Willow Creek downstream of Creede.

The Reference Reach

With the current lack of full understanding of the complex physical processes at work within stream systems and the subsequent lack of computer models capable of predicting all of the required stream characteristics for a fully functioning stream, complete stream restorations like Willow Creek require the use of a reference reach. A reference reach is a relatively fully functioning stream reach that is used to extrapolate information from. This reference reach is used in a quantitative manner as a template to predict the proper dimension, pattern and profile of the restored stream (Rosgen 1996) and must be of the same valley type and of similar hydrologic, hydraulic, bed material, and sediment flow characteristics (Rosgen 1996, Shields et al 2003). A reference reach is necessary to design a stream that can transport its sediment load, maintain stable banks and bed, and provide suitable habitat for aquatic and riparian life – it is necessary to minimize the risk of project failure.

Regional Curves

From the confluence of East and West Willow Creeks to the Rio Grande River, there are no stable natural reaches to act as a reference reach for the design of the stream restoration. The Eastern Branch of Willow Creek near the Rio Grande, though fairly stable, can not be used as a reference reach since it does not take all of the bankfull flow. Streams in adjacent watersheds are likely to offer reference reach opportunities for predicting stream characteristics through the use of dimensionless ratios, as discussed in

Rosgen 2003, but this approach has limited use in the determination of bankfull area. Bankfull area is the (arguably) most important parameter in a restoration due to bankfull flow's significance in sediment transport and stream stability (Wolman and Miller 1960; Leopold et al 1964; Leopold 1994; Rosgen 1996). To attain more confidence in a restoration design, regional curves for predicting bankfull area, as well as bankfull width and sinuosity, have been developed and applied specifically to Willow Creek.

Stable reaches throughout the upper Rio Grande watershed have been surveyed to measure their bankfull characteristics. The region used in the analysis is illustrated in Figure 2. Reaches were separated by climatic zone and relevant bankfull characteristics were regressed to develop prediction equations that were then applied to Willow Creek.

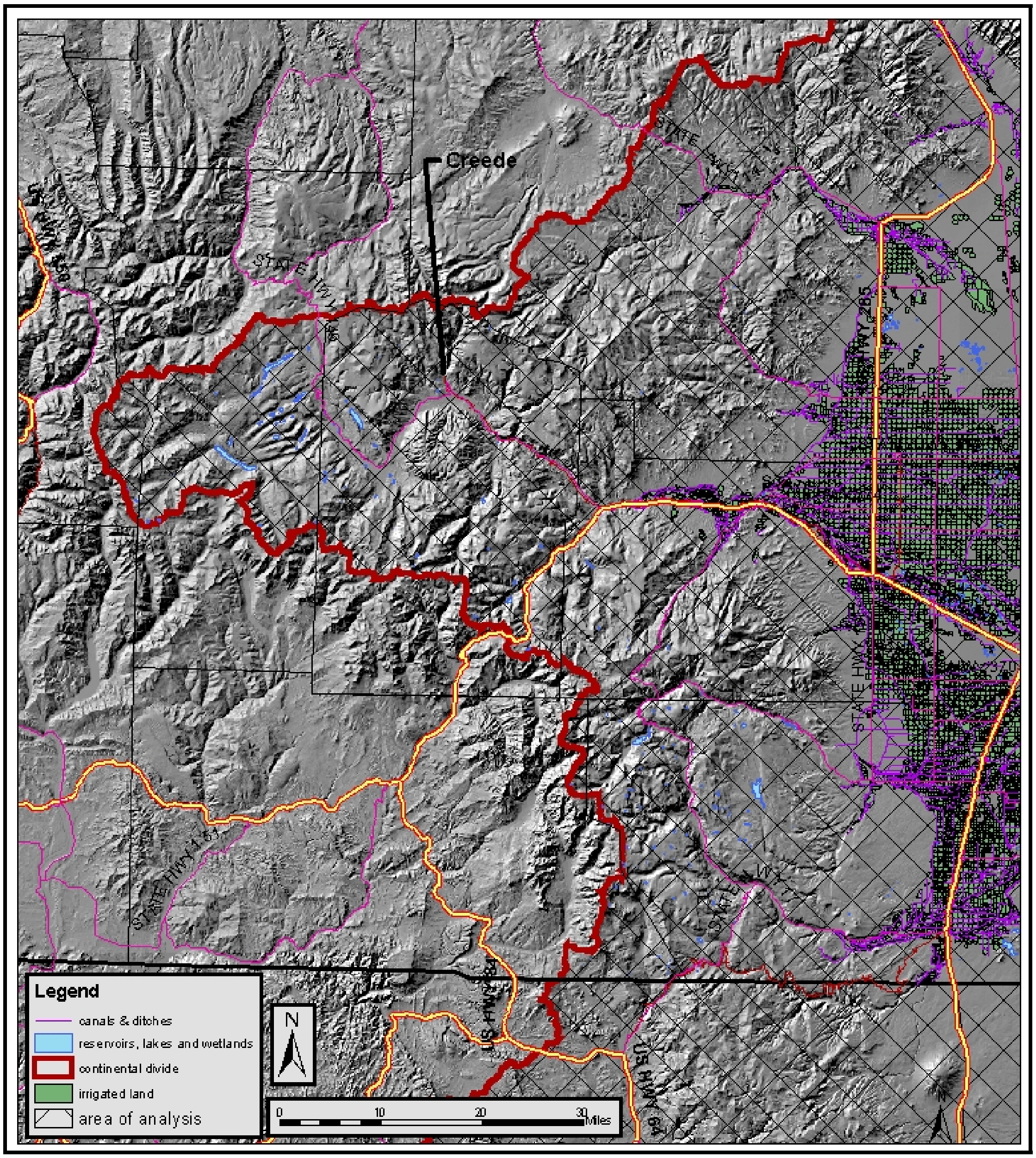

Figure 2: Region of analysis.

Regional Curve Development

Regional regression relationships for both bankfull area and width were developed to apply to the Lower Willow Creek stream restoration design. Sinuosity was also analyzed on a regional basis for application to the project design. Watersheds and reaches analyzed in the regional analysis are indicated in Figure 3. Thirty-year average precipitation estimates, from PRISM, have been provided to illustrate the precipitation variability.

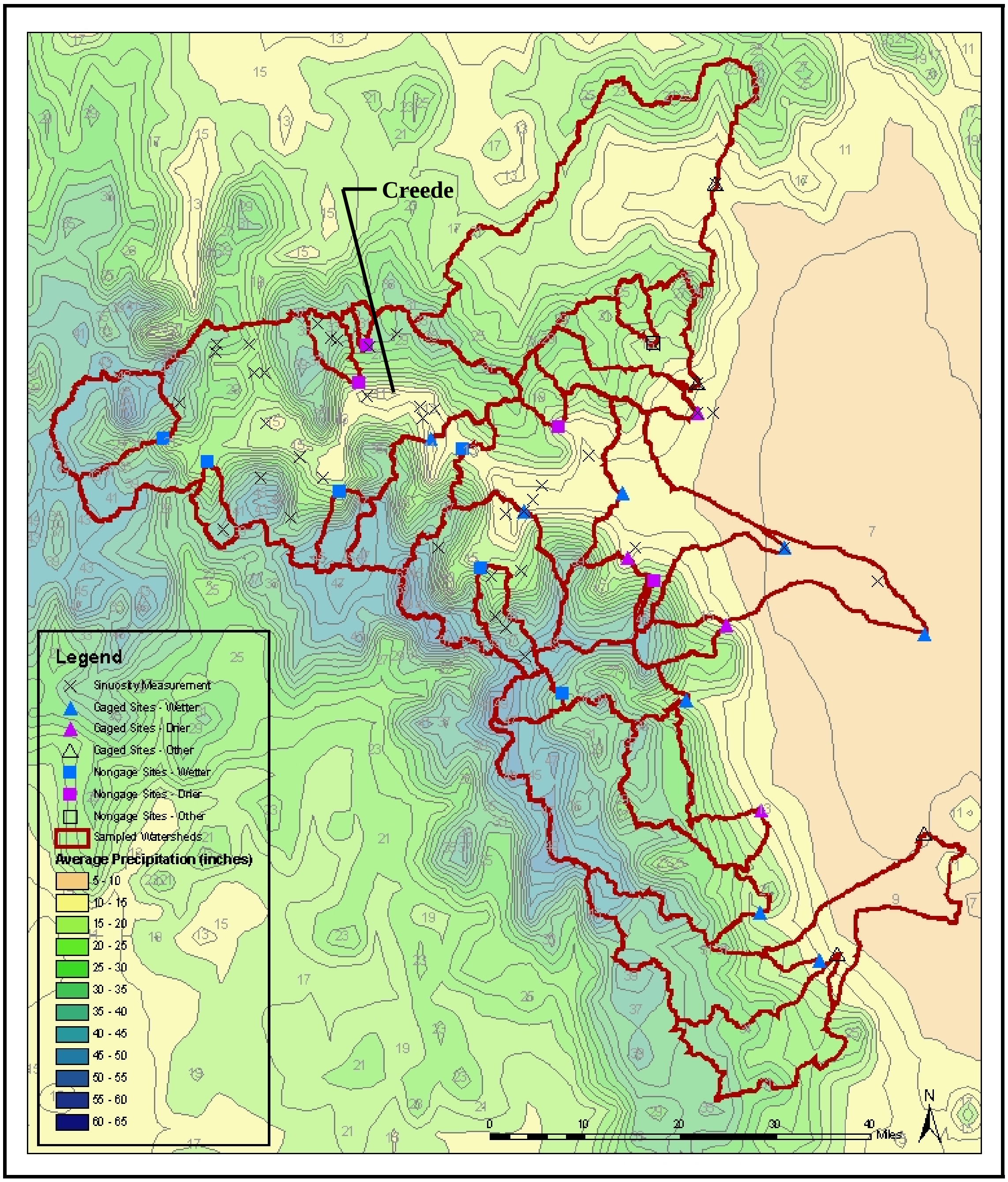

Figure 3: Watersheds and stream reaches used in analysis. Thirty-year average precipitation estimates (from PRISM) are also provided.

Bankfull Area and Width

As discussed in Leopold 1994, streams, from a physical standpoint, are conveyance systems that transport both water and sediment. Local erosion and deposition are natural processes that allow the creation of the bankfull channel. This bankfull channel marks a balance between very frequent low-magnitude events and less frequent high-magnitude events. Very small events are not very effective at transporting sediment, since they perform little work though they do occur often. High discharge events can cause a great deal of erosion and deposition - they can perform a great deal of work and are very effective. But such events occur infrequently. Hence, it is logical that there is some intermediate discharge, neither high nor low, that is both sufficiently frequent and sufficiently effective to be most important in maintaining a channel. This point has been determined to be the channel-forming discharge, which is near coincidence with bankfull discharge. Bankfull area is the cross-sectional area of a stream where flow is at bankfull channel capacity. Determination of the most appropriate bankfull area for Willow Creek is the primary motivation for this study.

While local erosion and deposition is a natural process for all streams, the rates of erosion and deposition can vary widely, with high rates often associated with sparsely vegetated streams, such as the braided stream of Lower Willow Creek, or during significant periods of climatic adjustment (Leopold 1994). On the opposite side of the spectrum, channels bound by well-vegetated streambanks can be very stable. For example, the relatively pristine Thurra River in southeastern Australia has documented lateral average migration rates of 3.6 to 7.8 ft per 100 years and average floodplain deposition rates of 0.1 ft per 100 years. Cutoffs and major channel avulsions have been documented as occurring, on average, once in 1000 and 5000 years, respectively, for this well-vegetated sand-bed stream (Brooks and Brierley 2002).

Both reference reaches and regional bankfull characteristic analyses rely upon stable stream channels to gather information. The reaches in this regional analysis used only sites that were single thread (no islands or braiding) with well-established vegetation. Beyond the typical three terraces expected in the dominant valley type, some sites did express low terraces, which may indicate relatively recent bank stability problems, but existing conditions of reaches used in the analysis were good.

The field determination of bankfull stage is the important parameter to identify in this type of study. The procedure used to identify bankfull has been presented in Leopold 1994 and Rosgen 1996. Specifically, within a stream length of 10 to 20 bankfull widths, indicators were noted and flagged, assuring consistency within the reach. Low terraces were noted to prevent the misidentification of them as bankfull indicators. The bankfull indicators themselves included the presence of a floodplain at the elevation of incipient flooding; breaks in slopes of banks; change in particle size distribution; staining of rocks; exposed root hairs below an intact soil layer; and the location of lichens, alders, and willows (used with caution, especially considering the number of recent dry years). The flat depositional tops of floodplains and breaks in slopes were given precedence as indicators. Figure 4 provides a couple of bankfull indicator examples for specific reaches.

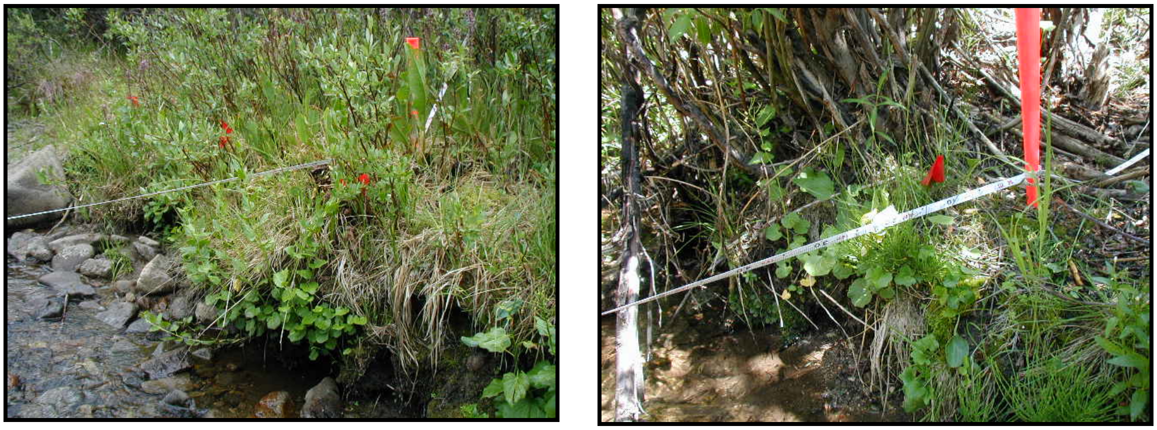

Figure 4: Typical bankfull indicators. Specific indicators shown for West Willow Creek and Miners Creek.

In regional analyses of this type it is traditional to only use reaches at or near streamgages. Such a practice is important for QA/QC reasons. Bankfull stage can be converted to bankfull discharge and a return period at the gage. Bankfull flow has been shown to occur at a frequency from 1 to 2 years (Rosgen 1996) and 1 to 2.5 years (Leopold 1994). Knowing this, it is then possible to compare the return period of the bankfull indicator with the expected range to judge if the indicator is appropriate.

The standard procedure is to run a longitudinal profile to the gage, specifically to the staff plate, and then use the gage's rating table to convert this stage to a discharge. A frequency analysis is performed on the gage's data to convert the discharge to a return period. However, this standard procedure was complicated in this regional analysis due to the lack of staff plates at all gages operated by the Colorado Division of Water Resources, as well as oftentimes mediocre to poor quality stream reaches at the gage. These poorer stream reaches were due to bridge constrictions, grazing practices, or Parshall flumes being used for gaging. In such situations, reaches a distance upstream or downstream of the gage were used. These reaches were not of sufficient distance to significantly alter discharge frequencies but were oftentimes distant enough to require extensive longitudinal profiles across multiple property boundaries, an undesirable situation.

To simplify this situation, bankfull areas were applied to the Manning's equation to attain a discharge that was then compared to the gage's discharge-frequency relationship to attain a return period of bankfull flow. Manning *n* values, which along with the normal depth assumption are the weak link in this approach, were chosen using the guides and procedures set forth in Chow 1959, Arcement et. al. 1989, and Brunner & Goodell 2002. Return periods ranged from 1.3 to 1.8 for the seventeen streamgaged reaches sampled. These values fall within the expected range, indicating a decent selection of bankfull indicators.

Through the use of average precipitation (PRISM), gage discharge-frequency relationships, and bankfull characteristics, reaches were separated into two climatic zones. Relationships were developed to predict bankfull area and width within these zones. Several reaches were identified that did not appear to fall into either of the quantified climatic zones. These sites likely represent additional climate zones, with insufficient data to fully characterize. Mainstem streams are included in the high precipitation zone, with percent irrigated area being an important explanatory variable. Lower precipitation reaches were identified as tributary streams on leeward slopes or within rain-shadowed watersheds.

A reasonable number of data points are necessary to characterize the spatial variability of bankfull area and width in high relief areas. The USGS in Western Montana, for example, is currently developing regional bankfull curves but have had problems developing statistically significant relationships within this climatically variable region. The upper Rio Grande basin has a similar variability. Using only the gaged sites (indicated in Figure 3) will lead to a similar problem occurring within the upper Rio Grande basin. The lack of gages of similar size and in vicinity to Willow Creek also causes prediction problems. Thus, it was necessary to characterize the climatic zones within this highly variable region by using eleven additional ungaged reaches. Possible QA/QC problems resulting from the lack of discharge-frequency relationships at these ungaged sites was compensated for by choosing reaches that had excellent bankfull indicators.

Results of this analysis are shown graphically in bankfull area versus drainage area (and percent irrigated) and bankfull width versus drainage area (and percent irrigated) of Figure 5.

For the lower precipitation regime (which includes Willow Creek at Creede), bankfull area was found to be approximated by

$$A_B = 11.39(1.622)^{\log(A_D)} \qquad (1)$$

where A_B is bankfull area and A_D is drainage area in square miles. This simple linear regression model has an associated R^2 of 0.84 and an F-statistic of 32.2. Eight sites were used to generate the prediction. Drainage areas ranged from 2.7 to 103.5 square miles.

For the lower precipitation regime, bankfull width was found to be approximated by:

$$W_B = 8.706(1.591)^{\log(A_D)} \qquad (2)$$

where W_B is bankfull width an A_D is drainage area in square miles. This simple linear regression has an associated R^2 of 0.84 and an F-statistic of 31.8.

For the higher precipitation regime, bankfull area was found to be approximated by

$$A_B = 5.174(4.969)^{\log(A_D)}(0.9634)^{I_P} \qquad (3)$$

where A_B is bankful area, A_D is drainage area in square miles, and I_P is percent irrigated area. Importantly, percent irrigated represents the total irrigated area diverted from the stream above the point of interest (not just the irrigated area within the watershed) as a ratio to total contributing drainage area. This multiple linear regression model has an associated R^2 of 0.96 and an F-statistic of 109.6. Thirteen sites were used to generate the

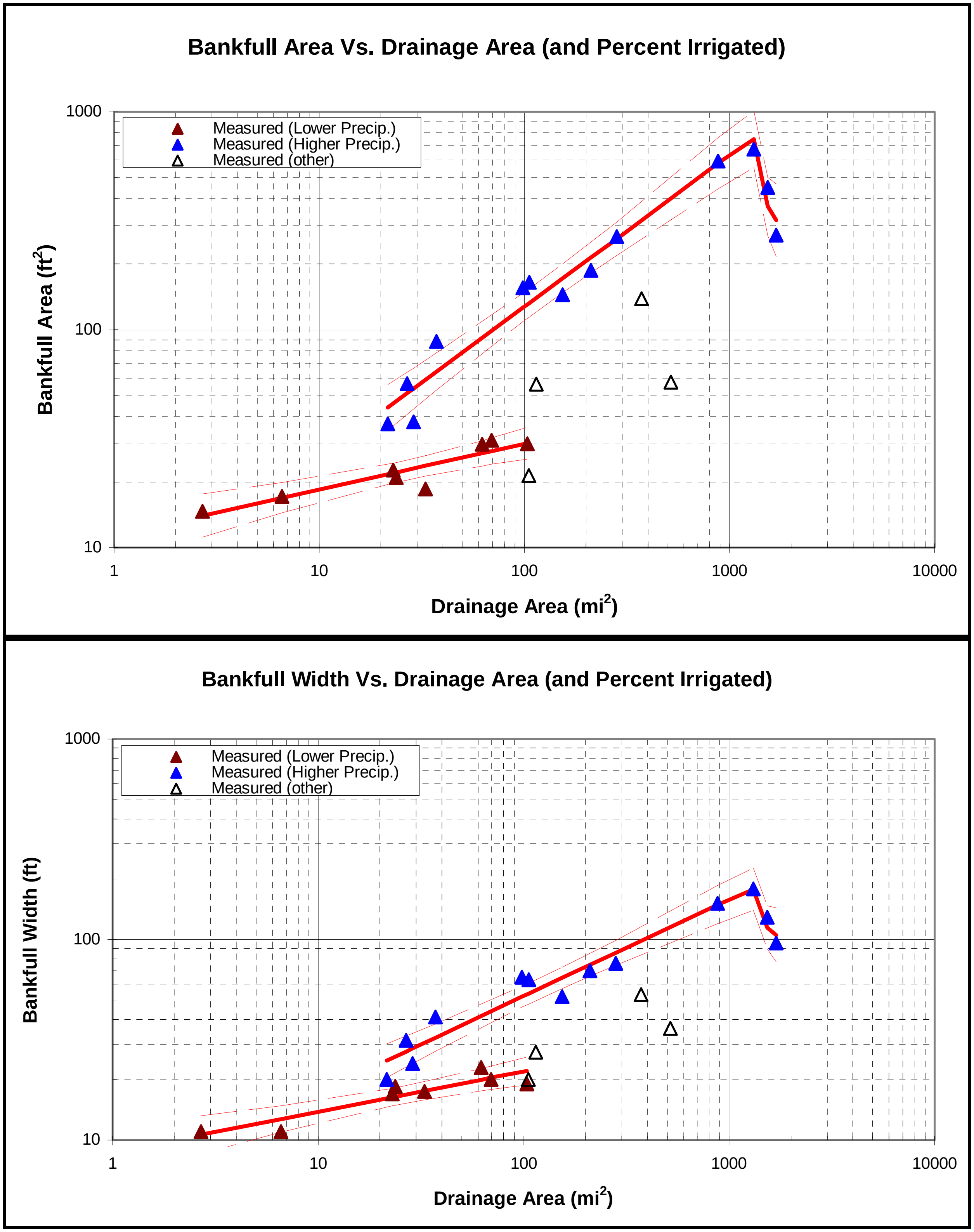

Figure 5: Bankfull area and width vs. drainage area and percent irrigated, with 95% confidence limits.

regression. Drainage areas ranged from 21.6 to 1681 square miles, with percent irrigated area ranging from 0 to 28.2.

For the lower precipitation regime, bankfull width was found to be approximated by:

$$W_B = 5.653(3.040)^{\log(A_D)}(0.9768)^{I_P} \quad (4)$$

where W_B is bankfull width an A_D is drainage area in square miles, and I_P is percent irrigated area. This multiple linear regression has an associated R^2 of 0.94 and an F-statistic of 83.1.

A limited number of data points were used to generate these bankfull area and width relationships. Thirteen data points were used in the higher precipitation regime and eight data points were used in the lower regime. Five data points were also found to not fit either of the curves – they appear to fall into different and undefined climate zones. More data could better define these relationships or illuminate other relationships. Due to the possible specification of unknown climate zones within this region, application of these equations must be done with care. With respect to Lower Willow Creek, the lower curve is considered applicable since several of the sites are immediately adjacent to or within the Willow Creek watershed.

Tables of watershed characteristics, reach characteristics and predictions are provided in Appendix A, in Tables A-1, A-2, and A-3.

Sinuosity

Stream channels are rarely straight – there is almost always a degree of sinuosity in all streams, at least in the thalweg (deepest portion of the channel). A great deal of frictional loss occurs due to sinuosity, with the curves representing a large proportion of the resistance and energy losses for a number of stream types (Leopold 1994). Sinuosity is defined as

$$K = \frac{VS}{CS} = \frac{VL}{CL} \quad (5)$$

where K is sinuosity, VS is valley slope, CS is channel slope, VL is valley length and CL is channel length.

To allow prediction of an average sinuosity for Lower Willow Creek, sinuosity and valley slope was measured for 40 sites within the upper Rio Grande watershed and plotted. Sinuosity ranged from 1.13 to 2.79 while valley slope ranged from 0.060 to 0.00065 ft/ft. The sinuosity and valley slope data are provided in Figure 6 and Appendix B. Locations of sinuosity measurements have been provided in Figure 3.

Sinuosity measurements were made from aerial photography while valley slopes were measured from stream contour crossings on USGS quadrangles. Since specific sites were not visited to measure valley slope, these data should be considered approximate.

Measurements were limited to locations where the streams are not obscured by vegetation in aerial photography. Locations that are constrained by valleys were not used. Effort was made to identify constraint from high terraces. Effort was also made to identify straightening though the presence of oxbow lakes and old channels appearing on aerial photographs, indicating a greater natural sinuosity than currently exists. These reaches were removed from the analysis.

For the mainstem Rio Grande, archived aerial photographs were used by Agro Engineers to identify past channel locations for the Rio Grande Headwaters Restoration Project (2001). The GIS layers created through this interpretation were used to assess the level of straightening during the past 60 years and estimate sinuosity for the Monte Vista measurement site.

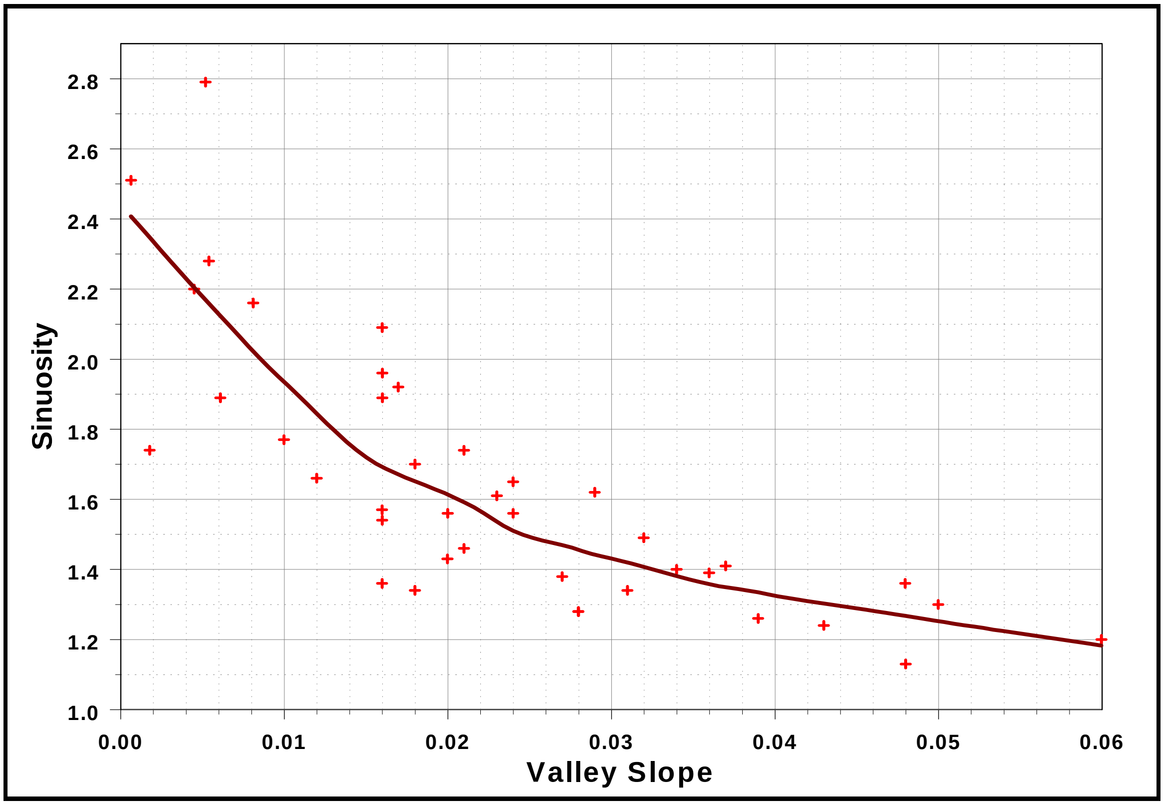

Figure 6: Sinuosity versus valley slope in the Upper Rio Grande watershed, with a Loess Curve (a locally-weighted linear regression).

Though a trend is evident, scatter in these data are also evident – in addition to measurement error, other variables beyond valley slope appear to influence sinuosity. Such variables may include bed material size, climate, and vegetation prevalence.

A local regression (loess) curve has been provided in the sinuosity versus valley slope plot. Loess is a generalization of running means, with individual curve points being weighted in a linear regression by its distance from the point of interest. Connecting the points creates the smooth curve. Use of the curve enables the prediction of an average sinuosity for specific valley slopes in the Upper Rio Grande watershed.

Application to Willow Creek

Figure 7 provides an aerial photograph of Lower Willow Creek, just downstream of the flume. The braiding and channel instability is blatant. Note the sparse vegetation on the floodplain.

Figure 7: Willow Creek braiding. Photo courtesy of Kelley Thompson and Agro Engineers.

Equations 1 and 2 were implemented to predicted bankfull area and width for the Lower Willow Creek. A drainage area of 37.9 square miles (at the downstream end of the flume) was used for these computations. Results are provided in Table 1.

An average sinuosity for the Lower Willow Creek was predicted through the use of Figure 6, using the valley slope for the reach (0.022 ft/ft). For consistency with how the figure was created, valley slope was computed from USGS topography. Results are provided in Table 1.

Table 1: Predicted bankfull characteristics for Lower Willow Creek.

Bankfull Area (ft^2)	24.4
Bankfull Width (ft)	18.1
Sinuosity	1.57

Use of these values would create a stream with an average depth of 1.35 ft, a width/depth ratio of 13.4, and an average channel slope of 0.014 ft/ft. With a dominant bed material of gravels or cobbles, these parameters would create a Rosgen C4 or C3 stream. (This is assuming that the stream will not be designed as entrenched.)

Verification and Other Data Needs

These predictions should be considered approximate – effort needs to be made to verify these results. Also, these results provide only the most basic characteristics needed in a stream design – other characteristics need to be measured and computed.

Bankfull area is the most important parameter to define in a braided to sinuous stream conversion. To verify this bankfull area prediction, one method would be to extrapolate the bankfull area of a suitable reference reach in an adjacent watershed through the use of return-interval flows, a normal depth assumption, and regional flow-frequency equations for ungaged watersheds. The equations developed for and applied to Willow Creek (Yochum & Hyde 2002) would be appropriate. Additionally, if sufficient indicators exist it could also be useful to look at bankfull area just downstream of the flume on Willow Creek, before the stream becomes braided. Due to the instability and likely poor indicators, bankfull area estimates from such a location should be considered approximate and used with care.

To verify sinuosity, the sinuosity from an appropriate reference reach should be compared to the result from the regional analysis.

Other variables need to be determined for this stream design. Such variables need to be gathered from an appropriate reference reach in an adjacent watershed and applied to Willow Creek using dimensionless ratios. These variables include floodprone width; meander length, belt width and radius of curvature; riffle slope and maximum depth; run slope and depth; pool slope, depth, width, length and pool to pool spacing; and glide slope, depth and width (Rosgen 2003). Dimensionless ratios used to transfer the characteristics from the reference reach to the design reach include riffle slope/average water surface slope and pool depth/riffle depth but there are many more. Definition of these variables and ratios in the design is necessary to appropriately and complimentarily design the dimension, pattern and profile of the stream. Insufficient determination of these variables will greatly increase the risk of the project not satisfying the project objectives of restoring Willow Creek to a stable form that can provide relatively full biologic function (when the watershed is sufficiently restored).

Finally (and as alluded to above), riparian vegetation is essential to insure a stable stream channel. In addition to seeding and cuttings, plant transplants are necessary to minimize the risk of project failure. Willow bushes of a fair degree of maturity and from a similar elevation as the Willow Creek project (for the proper genetics), need to be transplanted onto the project site.

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Appendix A

Table A-1: Watershed/reach characteristics and predictions, drier watersheds.

Site ID	Gage Description	Years of Record (years)	Years in Record
08223500	ROCK CREEK NEAR MONTE VISTA, CO	25	1935-70
08220500	PINOS CREEK NEAR DEL NORTE, CO	68	'20, '24, '36-2001
08231000	LA GARITA CREEK NEAR LA GARITA, CO.	81	'20, 1922-2001
0822150a	Embargo Creek	----	----
0821700a	Miners Creek at undeveloped FS campground	----	----
0821700e	West Willow Creek above Creede	----	----
0822150b	San Fransico Creek	----	----
08238000	LA JARA CREEK AT GALLEGOS RANCH, NR CAPULIN, CO	73	'16-17, '19-23, '36-20

Site ID	Drainage Area (mi^2)	Discharge Frequency (log-Pearson), w/o generalized skew: 200-yr (cfs)	100-yr (cfs)	50-yr (cfs)	25-yr (cfs)	10-yr (cfs)	5-yr (cfs)	2-yr (cfs)	1.25-yr (cfs)
08223500	32.9	305	282	256	228	185	148	89.4	47.8
08220500	69.3	755	678	599	519	411	325	199	115
08231000	62.3	840	711	591	481	348	257	141	76.7
0822150a	23.0	----	----	----	----	----	----	----	----
0821700a	23.7	----	----	----	----	----	----	----	----
0821700e	6.6	----	----	----	----	----	----	----	----
0822150b	2.7	----	----	----	----	----	----	----	----
08238000	103.5	1030	896	769	645	486	367	207	111

Site ID	Average Precip. (in)	Irrigated Area (acres)	Percent Irrigated	Bankfull Area (ft^2)	Bankfull Area: log(Area)	log(Area Fit)	logArea Residual	SE fit	0.95 CL logLower
08223500	29.9	0	0.00	18.6	1.2695	1.3760	-0.1065	0.0192	1.3291
08220500	31.0	75	0.17	31.1	1.4928	1.4433	0.0495	0.0249	1.3824
08231000	20.8	42	0.11	29.8	1.4742	1.4328	0.0414	0.0237	1.3748
0822150a	22.8	0	0.00	22.7	1.3560	1.3424	0.0136	0.0186	1.2969
0821700a	31.4	0	0.00	21.0	1.3222	1.3445	-0.0223	0.0186	1.2990
0821700e	31.0	0	0.00	17.2	1.2355	1.2289	0.0066	0.0282	1.1599
0822150b	30.7	0	0.00	14.7	1.1673	1.1470	0.0203	0.0402	1.0486
08238000	27.9	23.9	0.04	29.9	1.4757	1.4790	-0.0033	0.0295	1.4069

Site ID	Bankfull Area: 0.95 CL logUpper	Lower (ft^2)	Upper (ft^2)	Fit (ft^2)	Percent Error	Manning Estimate	Channel Slope (ft/ft)	Bankfull Flow (cfs)	Return Period (years)
08223500	1.4229	21.3	26.5	23.8	27.8	0.060	0.017	60	1.5
08220500	1.5042	24.1	31.9	27.8	-10.8	0.070	0.027	141	1.5
08231000	1.4908	23.7	31.0	27.1	-9.1	0.060	0.016	109	1.7
0822150a	1.3880	19.8	24.4	22.0	-3.1	0.060	0.024	101	----
0821700a	1.3900	19.9	24.5	22.1	5.3	0.040	0.020	115	----
0821700e	1.2979	14.5	19.9	16.9	-1.5	0.045	0.027	115	----
0822150b	1.2454	11.2	17.6	14.0	-4.6	0.065	0.050	83	----
08238000	1.5511	25.5	35.6	30.1	0.8	0.040	0.006	114	1.3

Table A-1: Watershed/reach characteristics and predictions, drier watersheds.

Site ID	Bankfull Width (ft)	Bankfull Width log(width)	log(Width Fit)	log(Width Residual)	SE fit	CL (Prediction) logLower	logUpper	Lower (ft)	Upper (ft)
08223500	17.5	1.243	1.246	-0.003	0.018	1.201	1.291	15.9	19.6
08220500	20	1.301	1.311	-0.010	0.024	1.252	1.369	17.9	23.4
08231000	23	1.362	1.301	0.061	0.023	1.245	1.357	17.6	22.7
0822150a	17	1.230	1.214	0.016	0.018	1.170	1.258	14.8	18.1
0821700a	18.5	1.267	1.216	0.051	0.018	1.172	1.260	14.9	18.2
0821700e	11	1.041	1.105	-0.064	0.027	1.039	1.172	10.9	14.8
0822150b	11	1.041	1.027	0.015	0.039	0.932	1.121	8.5	13.2
08238000	19	1.279	1.345	-0.066	0.028	1.275	1.414	18.9	26.0

Site ID	Bankfull Width Fit (ft)	Percent Error	log(Bankful Width)	Average Depth (ft)	W/D	Max. Depth (ft)	Approx. Entrench-ment	Rosgen Classification
08223500	17.6	0.7	1.243	1.06	16.5	1.46	3.1	C3
08220500	20.5	2.3	1.301	1.56	12.8	1.90	1.8	B3
08231000	20.0	-13.1	1.362	1.30	17.7	1.58	1.4	B3c
0822150a	16.4	-3.7	1.230	1.34	12.7	1.61	14.7	C3b
0821700a	16.4	-11.1	1.267	1.14	16.2	2.67	1.7	B3
0821700e	12.7	15.8	1.041	1.56	7.1	1.92	9.2	E3
0822150b	10.6	-3.4	1.041	1.34	8.2	1.71	2.0	A3
08238000	22.1	16.5	1.279	1.57	12.1	1.96	5.4	C4

Table A-2: Watershed/reach characteristics and predictions, wetter watersheds.

Site ID	Gage Description	Years of Record	Years in Record
0821700d	Rio Grande abv. Rio Grande Reservoir	----	----
0821700c	Squaw Creek near mouth	----	----
0821700b	Red Mountain Creek, just below Ivy Creek	----	----
0821750a	Rio Grande downstream of Wagonwheel Gap	----	----
0821950a	Park Creek	----	----
08219500	SOUTH FORK RIO GRANDE AT SOUTH FORK, CO	75	'11-22, 1930-2001
08220000	RIO GRANDE NEAR DEL NORTE, CO	112	1890-2001
08221500	RIO GRANDE NEAR MONTE VISTA, CO	76	1926-2001
08223000	RIO GRANDE AT ALAMOSA, CO	88	'13-42, 1944-2001
0823600a	Alamosa River	----	----
08236000	ALAMOSA RIVER ABOVE TERRACE RESERVOIR, CO	74	'11, '10-18, '25-27, '35
08246500	CONEJOS RIVER NEAR MOGOTE, CO	93	'03-05, '11, '13-2001
08248000	LOS PINOS RIVER NEAR ORTIZ, CO	83	'15-20, '25-2001

Site ID	Drainage Area (mi^2)	Discharge Frequency (log-Pearson), w/o generalized skew							
		200-yr (cfs)	100-yr (cfs)	50-yr (cfs)	25-yr (cfs)	10-yr (cfs)	5-yr (cfs)	2-yr (cfs)	1.25-yr (cfs)
0821700d	98.3	----	----	----	----	----	----	----	----
0821700c	21.6	----	----	----	----	----	----	----	----
0821700b	28.8	----	----	----	----	----	----	----	----
0821750a	880.8	----	----	----	----	----	----	----	----
0821950a	37.2	----	----	----	----	----	----	----	----
08219500	210.6	6,510	5570	4720	3940	3000	2350	1500	990
08220000	1311.1	14,600	13100	11600	10200	8390	6980	4970	3580
08221500	1534	16,100	12700	9950	7680	5260	3800	2190	1370
08223000	1691	18,600	14100	10400	7470	4500	2810	1170	503
0823600a	26.8	----	----	----	----	----	----	----	----
08236000	105.8	3,820	3280	2790	2340	1810	1430	953	661
08246500	281.4	6,460	5760	5100	4470	3670	3080	2260	1710
08248000	153.9	3,350	3120	2870	2600	2200	1850	1280	839

Site ID	Average Precip. (in)	Irrigated Area (acres)	Percent Irrigated	Bankfull Area (ft^2)	Bankfull Area				
					log(Area)	log(Area Fit)	logArea Residual	SE fit	0.95 CL logLower
0821700d	39.0	0	0.0	156	2.193	2.102	0.092	0.029	2.037
0821700c	32.3	0	0.0	36.9	1.567	1.643	-0.076	0.047	1.538
0821700b	39.5	0	0.0	37.7	1.576	1.730	-0.153	0.042	1.636
0821750a	29.6	0	0.0	595	2.775	2.764	0.010	0.053	2.647
0821950a	33.7	0	0.0	88.4	1.946	1.808	0.139	0.038	1.722
08219500	30.9	0	0.0	187	2.272	2.331	-0.059	0.032	2.261
08220000	27.9	5708	0.7	674	2.829	2.874	-0.045	0.058	2.744
08221500	26.6	221200	22.5	450	2.653	2.566	0.087	0.060	2.433
08223000	25.1	305200	28.2	272	2.435	2.503	-0.069	0.075	2.336
0823600a	43.0	0	0.0	56.7	1.754	1.708	0.045	0.043	1.612
08236000	35.9	0	0.0	165	2.217	2.123	0.094	0.029	2.059
08246500	35.8	207.1	0.1	268	2.428	2.417	0.011	0.034	2.341
08248000	31.2	0	0.0	145	2.161	2.237	-0.075	0.029	2.171

Table A-2: Watershed/reach characteristics and predictions, wetter watersheds.

Site ID	Bankfull Area 0.95 CL logUpper	Bankfull Area Lower (ft^2)	Bankfull Area Upper (ft^2)	Bankfull Area Fit (ft^2)	%error	Manning Estimate	Channel Slope (ft/ft)	Bankfull Flow (cfs)	Return Period (years)
0821700d	2.167	108.8	146.7	126.3	-19.0	0.040	0.0085	953	----
0821700c	1.747	34.5	55.9	43.9	19.0	0.050	0.025	251	----
0821700b	1.824	43.2	66.6	53.7	42.4	0.045	0.014	194	----
0821750a	2.881	444.1	761.1	581.4	-2.3	0.040	0.0029	2937	1.75
0821950a	1.893	52.8	78.2	64.2	-27.3	0.045	0.0102	484	----
08219500	2.402	182.4	252.1	214.5	14.7	0.035	0.0045	1017	1.30
08220000	3.004	554.7	1008.5	747.9	11.0	0.030	0.0026	3940	1.47
08221500	2.700	270.7	501.0	368.3	-18.2	0.035	0.0014	1646	1.54
08223000	2.670	216.9	468.1	318.6	17.2	0.025	0.00038	622	1.44
0823600a	1.805	40.9	63.8	51.1	-9.9	0.045	0.019	370	----
08236000	2.188	114.4	154.1	132.8	-19.5	0.045	0.0071	858	1.78
08246500	2.494	219.2	311.7	261.4	-2.5	0.035	0.0044	1718	1.26
08248000	2.302	148.3	200.6	172.4	18.9	0.035	0.0078	1059	1.66

Site ID	Bankfull Width (ft)	Bankfull Width log(width)	log(Width Fit)	logWidth Residual	SE fit	0.95 CL (Prediction) logLower	logUpper	Lower	Upper
0821700d	65	1.813	1.715	0.098	0.024	1.662	1.767	45.9	58.5
0821700c	20	1.301	1.396	-0.095	0.038	1.312	1.481	20.5	30.3
0821700b	24	1.380	1.457	-0.077	0.034	1.381	1.533	24.0	34.1
0821750a	152	2.182	2.174	0.008	0.042	2.080	2.269	120.2	185.7
0821950a	41	1.613	1.511	0.102	0.031	1.442	1.580	27.7	38.0
08219500	70	1.845	1.874	-0.029	0.025	1.817	1.931	65.7	85.2
08220000	179	2.253	2.251	0.002	0.047	2.146	2.356	140.0	226.8
08221500	129	2.111	2.060	0.050	0.048	1.952	2.168	89.6	147.2
08223000	96	1.982	2.022	-0.040	0.060	1.888	2.157	77.2	143.6
0823600a	31.5	1.498	1.442	0.056	0.035	1.364	1.520	23.1	33.1
08236000	63	1.799	1.730	0.070	0.023	1.678	1.782	47.6	60.5
08246500	76	1.881	1.934	-0.053	0.028	1.872	1.995	74.5	98.9
08248000	52	1.716	1.808	-0.092	0.024	1.755	1.861	56.9	72.7

Site ID	Bankfull Width Fit (ft)	Bankfull Width Percent Error	Bankfull Width log(Bnkfl Width)	Average Depth (ft)	W/D	Max. Depth (ft)	Approx. Entrench-ment	Rosgen Classification
0821700d	51.8	-20.3	1.813	2.40	27.1	3.34	4.9	C3
0821700c	24.9	24.6	1.301	1.85	10.8	2.87	1.9	B2
0821700b	28.6	19.3	1.380	1.57	15.3	2.01	5.4	C3
0821750a	149.4	-1.7	2.182	3.29	46.2	5.07	1.12	F3
0821950a	32.4	-20.9	1.613	2.16	19	2.74	5.1	C3
08219500	74.8	6.9	1.845	2.67	26.2	3.69	1.2	F3
08220000	178.2	-0.4	2.253	3.77	47.5	5.34	3.4	C3
08221500	114.9	-11.0	2.111	3.49	37	4.44	2.2	C4
08223000	105.3	9.7	1.982	2.83	33.9	3.46	3.3	C5c-
0823600a	27.7	-12.2	1.498	1.80	17.5	2.59	2.0	B3
08236000	53.7	-14.8	1.799	2.61	24.1	3.44	3.8	C3
08246500	85.8	13.0	1.881	3.52	21.6	4.44	5.3	C3
08248000	64.3	23.7	1.716	2.78	18.7	3.45	2.5	C3

Table A-3: Watershed/reach characteristics, other watersheds.

Site ID	Gage Description	Years of Record	Years in Record
08248500	SAN ANTONIO RIVER AT MOUTH, NEAR MANASSA, CO	78	1923-32, 1934-2001
08227000	SAGUACHE CREEK NEAR SAGUACHE, CO.	90	1911-12, 1914-2001
08230500	CARNERO CREEK NEAR LA GARITA, CO.	78	'20-23, '26-28, '30, '32
0823050a	Middle Fork of Carnero Creek	----	----
08247500	SAN ANTONIO RIVER AT ORTIZ, CO	78	1920, 1925-2001

Site ID	Drainage Area (mi^2)	Discharge Frequency (log-Pearson), w/o generalized skew 200-yr (cfs)	100-yr (cfs)	50-yr (cfs)	25-yr (cfs)	10-yr (cfs)	5-yr (cfs)	2-yr (cfs)	1.25-yr (cfs)
08248500	372.1	2,570	2440	2280	2090	1770	1450	889	458
08227000	518.0	1,390	1220	1040	880	672	519	313	185
08230500	105.3	1,690	1290	958	694	424	271	118	53
0823050a	17.6	----	----	----	----	----	----	----	----
08247500	114.5	1,850	1680	1510	1320	1060	'08247500'	835	496

Site ID	Average Precip. (in)	Irrigated Area (acres)	Percent Irrigated	Bankfull Area (ft^2)	Manning Estimate	Channel Slope (ft/ft)	Bankfull Flow (cfs)	Return Period (years)	Bankfull Width (ft)
08248500	23.9	12833	5.39	139	0.025	0.00092	472	1.28	53
08227000	18.6	2465	0.74	57.5	0.035	0.0054	240	1.62	36
08230500	21.4	102	0.15	21.4	0.050	0.015	85.5	1.70	20
0823050a	22.7	10.5	0.09	9.7	0.040	0.014	46.7	----	7.2
08247500	25.90	0	0.00	56.4	0.045	0.0125	321	1.47	27.5

Site ID	Average Depth (ft)	W/D	Max. Depth (ft)	Approx. Entrench-ment	Rosgen Classification
08248500	2.62	20.2	3.31	2.1	C4c-
08227000	1.60	23	1.86	7.8	C3
08230500	1.07	18.7	1.87	2.0	B3c
0823050a	1.34	5.4	1.85	21.7	E3
08247500	2.05	13.4	2.79	4.3	C4

Appendix B

Table B-1: Sinuosity sites and measurements.

Gage ID	Stream	Stream Length (ft.)	Valley Length (ft.)	Sinuosity	Valley Slope (ft/ft)
08227000	SAGUACHE CREEK NEAR SAGUACHE, CO.	3,081	1,350	2.28	0.0054
----	Middle Fork of Carnero Creek	564	410	1.38	0.027
08230500	CARNERO CREEK NEAR LA GARITA, CO.	660	350	1.89	0.016
08231000	LA GARITA CREEK NEAR LA GARITA, CO.	550	280	1.96	0.016
----	Crooked Creek	950	440	2.16	0.0081
----	Rio Grande	13,640	6,210	2.20	0.0045
----	North Clear Creek	4,300	2,270	1.89	0.0061
----	Upper North Clear Creek	620	440	1.41	0.037
----	Buck Creek	780	500	1.56	0.024
----	Upper Buck Creek	1,010	890	1.13	0.048
----	Rito Hondo	1,320	820	1.61	0.023
----	Spring Creek	1,200	770	1.56	0.020
----	Upper Miners Creek	560	430	1.30	0.050
----	Middle Miners Creek	1,780	1,080	1.65	0.024
----	Middle Miners Creek	1,240	850	1.46	0.021
----	Lower Miners Creek	2,800	1,610	1.74	0.021
----	W. Willow Creek	1,130	810	1.40	0.034
----	E. Willow Creek	990	800	1.24	0.043
----	Farmers Creek	1,250	840	1.49	0.032
----	Bellows Creek	2,190	1,640	1.34	0.031
----	Lower Bellows Creek	2,080	1,350	1.54	0.016
----	AlderCreek	755	455	1.66	0.012
----	Bear Creek	1,280	920	1.39	0.036
----	Embargo Creek	2,300	1,350	1.70	0.018
----	Lower La Garita Creek	3,070	1,470	2.09	0.016
----	Squaw Creek	1,250	770	1.62	0.029
----	Texas Creek	600	470	1.28	0.028
----	Lower Trout Creek	7,560	2,710	2.79	0.0052
----	Upper Trout Creek	1,790	1,340	1.34	0.018
----	Park Creek	1,390	1,020	1.36	0.016
----	Lake Fork	660	550	1.20	0.060
----	Upper Park Creek	1,110	870	1.28	0.028
----	Upper Park Creek	870	690	1.26	0.039
----	Upper Park Creek	960	610	1.57	0.016
----	Beaver Creek	3,080	1,740	1.77	0.010
----	Trout Creek	1,890	1,320	1.43	0.020
----	Elk Creek	1,290	950	1.36	0.048
----	Pinos Creek	1,460	760	1.92	0.017
08221500	RIO GRANDE NEAR MONTE VISTA, CO	20,350	11,680	1.74	0.0018
----	Rio Grande, upstream of Alamosa	22,690	9,050	2.51	0.00065