JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

Vol. 45, No. 5 AMERICAN WATER RESOURCES ASSOCIATION October 2009

REPLY TO DISCUSSION[1] by David L. Rosgen[2]

"The Role of Observer Variation in Determining Rosgen Stream Types in Northeastern Oregon Mountain Streams"[3]

John M. Buffington, Brett B. Roper, Eric Archer, and Chris Moyer[4,5]

We thank Rosgen (this issue) for his comments, which provide valuable insight regarding his channel classification and its correct application. However, we believe that many of his objections are based on misinterpretation of our analysis, which we hope to clarify through this reply.

Because our measurement techniques differed from those advocated by Rosgen (1996), our study may not represent the range of variability in channel classification that would result from strict adherence to his methods. Nevertheless, this does not invalidate our analysis and the intended study goal of evaluating classification consistency and sources of observed differences. However, some of the identified shortcomings of the classification may stem from our use of methods different from Rosgen's and therefore deserve further analysis.

MOTIVATION AND LITERATURE REVIEW

Rosgen indicates that our literature review is biased. It was not our intent to provide an exhaustive review of prior literature concerning the Rosgen (1994, 1996) classification. Rather, our intent was to state that there has been prior criticism regarding the mechanistic insight offered by the classification and thus its ability to satisfy the classification's first three objectives in a meaningful way, but general agreement that the fourth objective (communication) could be met (Roper *et al.*, 2008, p. 418). Because there had been no formal test of this latter opinion, we focused our analysis on it. A retrospective discussion of the Rosgen classification and response to prior criticism is provided by Rosgen (2003).

CONSISTENCY OF RESULTS

The purpose of our analysis was "to determine whether measurements made by different observers yield consistent classification of Rosgen stream types and, if these classifications differ, to determine the reasons for these differences" (Roper *et al.*, 2008, p. 418). We found that channel classification was not consistent at our study sites and discussed three potential sources of variability: (1) differences in methods between monitoring groups, (2) differences in training, and (3) observer variation in measuring channel characteristics (Roper *et al.*, 2008, pp. 420 and 422-424).

---

[1] Reply No. JAWRA-08-0144-Y of the *Journal of the American Water Resources Association* © 2009 American Water Resources Association. DOI: 10.1111/j.1752-1688.2009.00363.x.

[2] Discussion No. JAWRA-08-0101-D of the *Journal of the American Water Resources Association*. 45(5): 1290-1297.

[3] Paper No. JAWRA-07-0009-P of the *Journal of the American Water Resources Association* 44(2):417-427.

[4] Respectively, Research Geomorphologist (Buffington), U.S. Forest Service, Rocky Mountain Research Station, 322 E. Front St., Boise, Idaho 83702; Fisheries Biologist (Roper and Archer), U.S. Forest Service, Fish and Aquatic Ecology Unit and U.S. Forest Service, PacFish InFish Biological Opinion Effectiveness Monitoring Program, Utah State University, 860 N. 1200 E., Logan, Utah 84321; and Fisheries Biologist (Moyer), Bureau of Land Management, Aquatic and Riparian Effectiveness Monitoring Program, 4077 S.W. Research Way, Corvallis, Oregon 97333 (E-Mail/Buffington: jbuffington@fs.fed.us).

[5] Dr. Ward, who co-authored the original paper, was unavailable to participate in this reply.

Rosgen contends that differences in methodology and training preclude consistent classification. This would be true if our sole intent was to isolate observer variation, in which case one would want to control for the first two sources of variability (methods, training). However, our intent was to document the variability of results that exist in current practice for the monitoring groups examined, which includes variability of all of the above factors (methods, training, and observers). We agree that requiring similar methods and training would increase consistency (Roper *et al.*, 2008, p. 422). However, we disagree with Rosgen's assertion that "similar training and protocols would ensure similar classification results." This would only be possible if one could remove observer variation, which is difficult to do even with the strictest of protocols. Numerous studies attest to the effects of observer variation (Wohl *et al.*, 1996; Kaufmann *et al.*, 1999; Roper *et al.*, 2002). Moreover, Rosgen's assertion contradicts the data presented in our study; we found considerable observer variation within monitoring groups (i.e., when methods and training were controlled), even with the application of our consistency rule, which minimized potential observer differences (Roper *et al.*, 2008, p. 420, table 3).

Rosgen also objects to the fact that the monitoring groups did not follow his field methods in terms of where and how data should be obtained. We agree that methodology can have an impact on results and that classification consistency may have differed if Rosgen's (1996) field methods had been followed; however, as discussed above, our intent was to examine the "in practice" variability between the monitoring groups evaluated in our study. Differences in methodology also may explain our finding that channel parameters frequently fell in the gray zone between Rosgen channel types (NC values in table 3 of Roper *et al.*, 2008); as suggested by Rosgen, this result may stem from our use of different methods, rather than indicating a problem with the classification itself. However, this problem occurred even for the Aquatic and Riparian Effectiveness Monitoring Program (AREMP) group, which generally followed Rosgen's (1996) recommended methods (Table 1), suggesting that methodology is not the sole cause of this result. Note that some of the monitoring group protocols were incorrectly reported by Roper *et al.* (2008) and have been corrected and further explained here (see Errata and Table 1).

BANKFULL

For ungaged sites, such as those examined in our study, Rosgen advocates using regional channel dimension curves to guide field identification of bankfull elevation and derived classification parameters (entrenchment ratio and bankfull width-to-depth ratio). These curves plot bankfull channel dimensions as functions of drainage area, a surrogate for downstream bankfull discharge in regions with roughly homogeneous runoff production (Miller, 1958; Emmett, 1972, 1975; Dunne and Leopold, 1978). Rosgen recommends that such curves be developed from gaged sites where one verifies field identification of bankfull stage by comparing its recurrence interval to an expected value of one to two years (1.5 on average) (Dunne and Leopold, 1978, p. 611; Rosgen, 1996, table 5-1 and pp. 5-12, 5-14). A large number of these curves have been developed for the United States (U.S.) following this approach [see recent reviews by Johnson and Fecko (2008) and Wilkerson (2008)]. While a bankfull recurrence interval of one to two years is a useful average value for floodplain channels in temperate climates (Leopold *et al.*, 1964; Leopold, 1994; Wilkerson, 2008), the recurrence interval of bankfull floods can be quite variable about this average (0.5-32 years) (Williams, 1978; Wilkerson, 2008), and bankfull recurrence intervals may be inversely related to drainage area (Wolman, 1955; Wolman and Miller, 1960). Because of these factors, we caution the use of assumed flood recurrence intervals for verifying identification of bankfull stage. When faced with several possible bankfull elevations, Dunne and Leopold (1978, p. 655) recommend selecting the one closest to the 1.5-year recurrence interval. Doing so provides the most likely bankfull elevation in terms of average values, but precludes objective determination of the actual bankfull recurrence interval for the site. Consequently, this approach should be used as a last resort. Furthermore, Rosgen's (1996) recommendation for verifying bankfull elevation by comparing its recurrence interval to an expected value of one to two years has caused some practitioners to adjust their data when it falls outside of the expected range. For example, Mulvihill *et al.* (2005) re-evaluated bankfull elevations when they found that the associated flood recurrence intervals were less than the expected one-year minimum. It is unclear whether their initial estimates of bankfull elevation were truly in error, or whether their data were forced to conform to the expected range of average bankfull recurrence intervals.

We believe that field identification of bankfull stage, using the standard set of field indicators (Leopold and Skibitzke, 1967; Emmett, 1972, 1975; Dunne and Leopold, 1978; Harrelson *et al.*, 1994; Rosgen, 1996), should be the primary method for determining bankfull geometry, as was done by the monitoring groups examined in our study. Nevertheless, we agree that regional channel dimension curves can provide a secondary line of evidence for bankfull

TABLE 1. Protocols for Measuring Attributes of the Rosgen (1996) Channel Classification; Correction and Further Explanation of Those Reported by Roper *et al.* (2008).

Attribute and Measurement Protocol as Defined by Rosgen (1996)	**Protocols Used by Each Monitoring Group**	
Entrenchment ratio: Ratio of flood-prone width to bankfull width (flood-prone width = width at an elevation twice the maximum bankfull depth). Measured in unconstrained, relatively narrow, planar channel units (riffle/run/rapid), the location of which varies by stream type: (1) in pool-riffle (C, E, and F) streams, measured in riffle section where thalweg "crosses over" between successive pools; (2) in plane-bed (B) streams, measured in narrowest "rapid" section; and (3) in step-pool (A and G) streams, measured in "run" section between step and pool head (Rosgen, 1996, p. 5-9, figures 5-4 and 5-5). Values determined from cross-sectional survey using a level. Number of cross sections per reach unspecified.	AREMP	Bankfull and flood-prone widths determined from cross-sectional survey using a laser level. Cross section measured at first-occurring location recommended by Rosgen (1996) (e.g., first downstream riffle).
	PIBO	Average value from four cross-sectional surveys using tape and rod; flood-prone elevation measured with a hand level. Cross sections placed at widest section of first four riffles/runs.
	UC	Bankfull width averaged from 21 equally spaced cross sections. Flood-prone width averaged from three equally spaced cross sections (subset of the above 21).
Width-to-depth ratio: Ratio of bankfull channel width to mean bankfull depth. Measured at same locations as above. Values determined from cross-sectional survey using a level. Number of cross sections per reach unspecified.	AREMP	Bankfull width and depth determined from same cross-sectional survey used for entrenchment ratio.
	PIBO	Average value determined from same four cross-sectional surveys used for entrenchment ratio.
	UC	Bankfull width averaged from 21 equally spaced cross sections. Reach-average mean bankfull depth determined from method of Kaufmann *et al.* (1999), assuming a triangular cross section; see Kaufmann *et al.* (2008) for further discussion.
Sinuosity: Ratio of reach length to valley length. Reach length is at least 20 times bankfull width, or 2 meander wavelengths in sinuous channels. Measured from aerial photographs.	AREMP	Reach length is 20 times bankfull width categories, with a minimum reach length of 160 m and a maximum of 480 m. Reach length is measured along the thalweg. Valley length is defined as the straight-line distance between the top and bottom of the channel reach.
	PIBO	Same as AREMP.
	UC	Same as AREMP, except that width categories are not used, and minimum/maximum reach lengths are 150 and 500 m, respectively.
Slope: Reach-average water-surface slope determined from a longitudinal profile using a level.	AREMP	Measured with a laser level. Slope is the change in water-surface elevation between the top and bottom of the reach divided by reach length.
	PIBO	Same as AREMP, but measured with an automatic level.
	UC	Measured with a hand level. Reach slope determined as average of incremental slopes between 21 equally spaced cross sections. Incremental slope is the change in water-surface elevation divided by distance between successive cross sections.
Substrate: Wolman (1954) pebble count of bed and unvegetated stream banks over reach length. Systematic, stratified sampling (Smartt and Grainger, 1974) weighted by length of channel units (e.g., pool, riffle, step) (Rosgen, 1996, figure 5-18).	AREMP	Systematic, unstratified pebble counts at 21 equally spaced transects, 5 particles per transect (105 total), sampled across bed and banks within bankfull limit.
	PIBO	Same as AREMP.
	UC	Same as AREMP, but grain sizes visually estimated.

Notes: AREMP, Aquatic and Riparian Effectiveness Monitoring Program; PIBO, PACFISH/INFISH Biological Opinion Monitoring Program; UC, Upper Columbia Monitoring Program.

Methods and location for measuring attributes differed across groups and, in some cases, from that recommended by Rosgen. AREMP most closely followed Rosgen's recommended approach. Methods used by each group during this study are further described by AREMP (2005), Dugaw *et al.* (2005) for PIBO, and Hillman (2004) for UC, with crew modifications to the latter as noted above.

identification that might help to reduce uncertainty of field identification, particularly when several possible bankfull elevations are present (Dunne and Leopold, 1978; Leopold, 1994; Rosgen, 1996). However, channel dimension curves are average values of log-log plots with considerable scatter (Emmett, 1972, 1975; Dunne and Leopold, 1978; Leopold, 1994), and channel dimensions tend to be more poorly correlated with drainage area than with bankfull discharge (Emmett, 1975; Castro and Jackson, 2001). As such, these curves provide reconnaissance-level predictions of bankfull dimensions at a given field site (Emmett, 1972; Dunne and Leopold, 1978), and frequently have as much uncertainty as that due to observer differences in field identification of bankfull. For example, data compiled from a variety of sources indicate that the 95% prediction intervals on regional bankfull depth curves can range from ± 33-152% uncertainty, with a median value of ± 51% (Figure 1 and Table 2). This uncertainty is comparable to observer variability in determining bankfull depths at our study sites ($\bar{x} \pm 2s = \pm 38\%$ on average across the monitoring groups). Hence, the uncertainty in our measurements and consequent stream type classifications are the same order of magnitude that one might expect from using regional channel dimension curves to guide field identification of bankfull. Results also demonstrate that the 95% prediction intervals vary directly with drainage area (Figure 2).

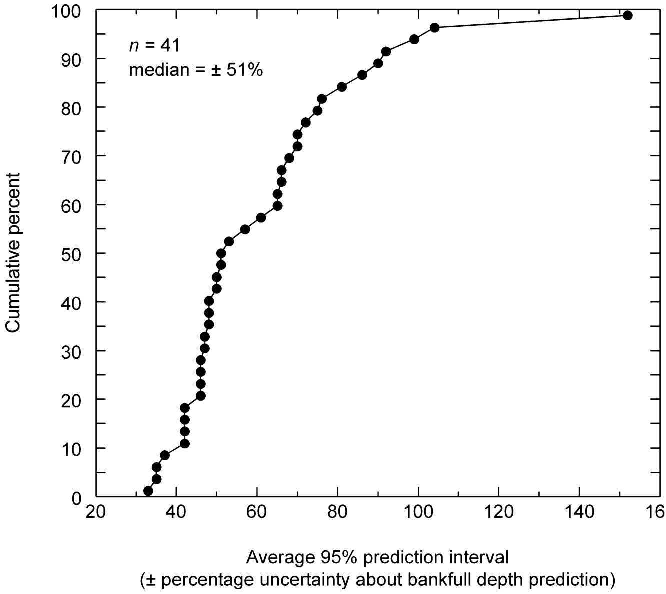

FIGURE 1. Cumulative Distribution of Average 95% Prediction Intervals (±percentage uncertainty about the bankfull depth prediction across the range of a given regional regression) for a Subset of the Table 2 Data that Met the Following Quality Criteria: Bankfull Depth Regression Having $n \geq 5$ and $R^2 \geq 0.75$. Data matching these criteria are shown by bold PI values (Table 2).

Regardless of one's technique for determining bankfull, we believe that the larger issue that is not being addressed is the sensitivity of the Rosgen classification to bankfull identification (Johnson and Heil, 1996; Roper *et al.*, 2008), which can be exacerbated by uncertainty in field identification of bankfull (Williams, 1978; Johnson and Heil, 1996; Juracek and Fitzpatrick, 2003), potentially leading to misclassification (Rosgen, 2003). Calibrating bankfull identification to an expected bankfull recurrence interval helps to reduce uncertainty if the channel is typical (i.e., has a bankfull recurrence interval of one to two years), but does not entirely remove the uncertainty (a range of potential bankfull elevations may be present within the range of one-year to two-year flood stages), and does not address the underlying issue of sensitivity of the classification to bankfull elevation. Developing methods for making the classification more robust to this parameter, or using alternative classification parameters, warrants further investigation. For example, Simon *et al.* (2007) propose using the effective discharge (Wolman and Miller, 1960), rather than bankfull, for classifying streams. The effective discharge is geomorphically significant because it transports the most sediment over time and is believed to control long-term channel morphology (Wolman and Miller, 1960). Bankfull stage is used in Rosgen's (1996) approach, in part, because it is equivalent to the effective discharge, as has been shown for temperate, floodplain rivers of the western U.S. (Andrews, 1980; Andrews and Nankervis, 1995; Whiting *et al.*, 1999). Given the uncertainty in field identification of bankfull, formal analysis of the effective discharge (*sensu* Wolman and Miller, 1960) might be a useful alternative to bankfull determination if the goal is to classify rivers based on the geometry of the channel-forming flow. This is particularly important for steeper, non-floodplain rivers (A and B channels) where bankfull is difficult to determine (e.g., Roper *et al.*, 2008, pp. 423-424) and where it has not been demonstrated that bankfull flow approximates the effective discharge; few studies have examined the effective discharge of steep, non-floodplain rivers and its relation to bankfull flow (Nolan *et al.*, 1987; Nash, 1994). The effective discharge can be readily determined by coupling discharge data with standard bed-load transport equations, but is best determined from local bed-load transport rating curves (Barry *et al.*, 2008), which require considerably more investment of time and effort to obtain. Furthermore, the effective discharge calculation typically uses mean daily flows (or even 1 h to 15-min flows for small, flashy basins; Biedenharn *et al.*, 2001) and is therefore more involved than determining the annual recurrence interval of bankfull floods; however, daily flow values are readily available from many USGS gages

TABLE 2. Select Regional Bankfull Depth Predictions.

Source	Physiographic Province or Region[1]	c	f	R^2	n	A (km^2)[2]	BF RI (years)	95% PI (%)[3]
Wolman (1955)	Piedmont (Brandywine Ck. basin, southeastern PA)	0.28	0.43	0.67	9	67-743 (181)	1.2-2.7	69
Hack (1957)[4]	Valley and Ridge (Middle and North R. basins, VA): limestone and dolomite	0.39	0.18	0.45	29	1-982 (21)	nd	89
	"……: Martinsbury shale (Middle R. only)	0.23	0.40	0.67	8	3-912 (65)	nd	106
	"……: sandstone	0.76	0.21	0.45	9	0.3-170 (10)	nd	126
	"……: alluvial terrace area	0.98	−0.01	0.00	13	14-264 (91)	nd	148
	Valley and Ridge (Calfpasture R. basin, VA)	0.50	0.06	0.11	10	4-331 (39)	nd	99
	Blue Ridge (Tye R. basin, VA, granodiorite)	0.52	0.22	0.05	5	6-83 (19)	nd	397
	Piedmont (Gillis Falls basin, MD)	0.77	0.10	0.12	10	0.4-100 (6)	nd	107
	Coastal Plain (MD)	0.65	−0.03	0.01	6	5-32 (17)	nd	79
Miller (1958)[4]	S. Rocky Mountains (north-central NM): R. Santa Barbara	0.32	0.20	0.53	18	1-94 (10)	nd	63
	"……: R. Santa Cruz	0.34	0.11	0.32	13	4-223 (25)	nd	30
	"……: Pojoaque R.	0.32	0.08	0.29	20	1-91 (9)	nd	42
	"……: Pecos R.	0.34	0.18	0.47	53	1-603 (22)	nd	52
Nixon (1959)	England and Wales	0.60	0.28	0.43	27	158-9,868 (1,295)	nd	70
Schumm (1960)[5]	Great Plains (Republican R. basin, CO, NE and KS)	0.09	0.31	0.81	7	3,781-64,491 (16,835)	nd	**70**
	Great Plains (Powder R. basin, WY and MT)	0.22	0.28	0.84	15	280-41,181 (3,885)	nd	**66**
Brush (1961)[4]	Valley and Ridge (Susquehanna R. basin, central PA)[6]	0.47	0.25	0.70	118	0.3-919 (18)	nd	52
Kilpatrick and Barnes (1964)	Piedmont (AL, GA, SC, and NC)	1.10	0.24	0.81	33	3-1,632 (91)	1.0-14	**46**
Leopold and Skibitzke (1967)	N. Rocky Mountains (Middle Fork Salmon R. basin, central ID)[7]	0.36	0.25	0.77	7	5-16,835 (233)	~1.5	**92**
	Arctic Mountains (John R. basin, northern AK)[8]	0.45	0.24	0.89	7	67-46,620 (1,684)	nd	**81**
Miller *et al.* (1971)	Piedmont (E. Branch Brandywine Ck. and Pickering Ck., southeastern PA)	0.54	0.23	0.76	24	1-743 (22)	1.5[9]	**75**
Emmett (1972)	S. of the Yukon R., AK[6]	0.29	0.31	0.84	22	52-516,446 (3,885)	1.2-2.3	**99**
	Coastal Trough (Copper R. basin, south-central AK)	0.28	0.30	0.85	13	52-53,354 (1,684)	1.2-2.3	**86**
	N. Plateaus and W. Alaska (Yukon R. basin, central AK)	0.55	0.24	0.85	9	922-516,446 (16,835)	1.3-1.7	**152**
Kellerhals *et al.* (1972)	Cordillera and Interior Plains (Alberta)	0.20	0.33	0.83	101	31-292,670 (2,590)	2.0[9]	**65**
	Cordillera and Interior Plains (Alberta)	0.32	0.32	0.73	66	31-292,670 (2,590)	1.4->100[10]	94
Emmett (1975)	N. Rocky Mountains (U. Salmon R. basin, central ID)	0.27	0.27	0.88	39	7-4,662 (168)	1.1-16.5	**61**
Dunne and Leopold (1978)	Wyoming Basin (U. Green R. basin, southwestern WY)	0.42	0.19	0.81	11	16-10,282 (246)	1.5[9]	**51**
Andrews (1984)	S. Rocky Mountains and Wyoming Basin (Yampa, Platte, and Colorado R. basins, CO)	0.24	0.29	0.79	24	4-8,832 (181)	nd	**57**
Elliott and Cartier (1986)	Colorado Plateau (Piceance R. basin, west-central CO)	0.04	0.57	0.84	17	9-1,632 (130)	nd	**104**
Azary (1999)[8]	Pacific Boarder (Santa Ana R., southern CA)	0.20	0.37	0.78	7	6-99 (19)	nd	**90**
Harman *et al.* (1999)[8]	Piedmont (NC)	0.62	0.32	0.88	13	0.5-322 (17)	1.1-1.8	**51**

TABLE 2. (Continued).

Source	Physiographic Province or Region[1]	*c*	*f*	R^2	*n*	A (km^2)[2]	BF RI (years)	95% PI (%)[3]
Maner (1999)	Ozark Plateaus (AR)	0.34	0.42	0.90	11	47-2,147 (246)	1.4[11]	**47**
Pruitt *et al.* (1999)	Interior Low Plateau (western KY)	0.39	0.40	0.89	7	40-1,679 (220)	nd	**68**
Smith and Turrini-Smith (1999)[8]	Coastal Plain (western TN)	0.64	0.22	0.68	14	16-5,980 (233)	1	75
Whiting *et al.* (1999)	N. Rocky Mountains (north-central ID)	0.19	0.33	0.67	22	1-381 (21)	1.1-4.8	72
Harman *et al.* (2000)[8]	Blue Ridge Mountains (NC)	0.45	0.31	0.79	14	5-326 (52)	1.1-1.9	**46**
Kuck (2000)[8]	Cascade-Sierra Mountains (S. Umpqua R., western OR)	0.43	0.39	0.97	12	1-1,181 (23)	1.5[11]	**42**
Castro and Jackson (2001)	Pacific Northwest[6,12]	0.43	0.24	0.29	74	46-20,927 (1,295)	1.0-3.1	109
	Pacific Maritime Mountains	0.29	0.39	0.49	21	142-8,011 (1,166)	1.0-3.0	99
	W. Interior Basin and Ranges	0.30	0.24	0.58	23	46-20,927 (1,295)	1.0-3.1	87
	W. Cordillera	0.25	0.33	0.44	30	51-13,183 (907)	1.0-3.0	85
Jaquith and Kline (2001)	St. Lawrence Valley and New England (VT)	0.39	0.30	0.87	20	8-360 (65)	~2	**35**
McCandless and Everett (2002)	Piedmont (MD)	0.50	0.34	0.86	23	4-262 (39)	1.3-1.8	**33**
Doll *et al.* (2003)[8]	Coastal Plain (NC)	0.52	0.30	0.74	16	0.6-417 (17)	1.0-1.3	93
McCandless (2003a)	Appalachian Plateau and Valley and Ridge (MD and PA)	0.39	0.31	0.91	14	0.5-264 (17)	1.1-1.8	**48**
Miller and Davis (2003)	Appalachian Plateau (Catskill Mountains, NY)[6]	0.41	0.31	0.85	18	10-860 (91)	1.2-2.7	**42**
	Region 4	0.43	0.32	0.85	10	10-614 (78)	1.2-2.7	**50**
	Region 4a	0.34	0.35	0.88	4	30-422 (155)	1.3-1.5	92
	Region 5	0.39	0.29	0.90	4	10-860 (91)	1.2-1.5	107
Moody *et al.* (2003)[8,13]	Basin and Range and Colorado Plateau (eastern AZ and western NM)	0.18	0.24	0.71	81	0.8-25,201 (168)	1.0-1.8	75
	Basin and Range (central and southeastern AZ)	0.29	0.22	0.73	58	2-12,973 (181)	1.0-1.8	61
Sweet and Geratz (2003)	Coastal Plain (NC)	0.42	0.36	0.92	22	2-471 (22)	<1	**48**
Chang *et al.* (2004)[8]	Appalachian Plateau (southeastern OH)	0.68	0.38	0.90	35	0.08-430 (6)	nd	**46**
Dudley (2004)	New England (southern ME)	0.25	0.34	0.76	15	8-772 (65)	<1.5	**65**
Lawlor (2004)	N. Rocky Mountains (northwestern MT)	0.28	0.22	0.37	41	3-1,054 (78)	1.0-4.4	88
Messinger and Wiley (2004)	Valley and Ridge and Blue Ridge (eastern WV)	0.27	0.41	0.72	11	122-1,773 (259)	1.5[9]	54
	Appalachian Plateau (western WV)	0.56	0.35	0.71	36	67-3,564 (518)	1.5[9]	56
Metcalf (2004)[8]	Coastal Plain (northeastern FL, southern GA)	0.31	0.43	0.84	12	3-513 (39)	1.0-1.4	**76**
	Coastal Plain (northwestern FL, southern AL)	0.63	0.25	0.86	14	4-1,228 (78)	1.0-1.2	**48**
Chaplin (2005)[14]	Piedmont, Valley and Ridge, and Appalachian Plateau (PA and MD): non-carbonate geology	0.36	0.33	0.72	35	14-554 (104)	1.0-1.9	49
	"……: carbonate geology	0.35	0.28	0.76	11	7-559 (65)	1.2-2.3	**53**
Keaton *et al.* (2005)	Valley and Ridge (MD, VA, and WV)	0.40	0.29	0.87	41	0.3-640 (17)	<1.1-2.3	**42**
Metcalf (2005)[8]	Coastal Plain (AL)	0.37	0.47	0.96	8	9-324 (65)	1.0-1.1	**37**
Mulvihill *et al.* (2005)	Appalachian Plateau (southwestern NY, Region 6)	0.40	0.24	0.64	14	3-751 (52)	1.0-2.4	61
Sherwood and Huitger (2005)[8]	Central Lowlands (southwestern OH, Region B)	0.80	0.27	0.88	5	1-1,002 (23)	1.3-5.6	**72**
	Appalachian Plateau and Central Lowlands (rest of OH, Region A)	0.60	0.27	0.88	45	0.8-1,774 (23)	1.0-9.7	**42**
Westergard *et al.* (2005)	Appalachian Plateau (south-central NY, Region 5)	0.35	0.37	0.91	16	2-860 (26)	1.1-3.4	**35**

TABLE 2. (Continued).

Source	Physiographic Province or Region[1]	c	f	R^2	n	A (km^2)[2]	BF RI (years)	95% PI (%)[3]
Mulvihill *et al.* (2006)	Central Lowland (northwestern NY, Region 7)	0.54	0.20	0.52	10	3-904 (65)	1.1-3.6	94
Glickauf *et al.* (2007)[8]	Coastal Plain (GA)	0.30	0.38	0.83	20	0.8-239 (17)	~1	**66**
Krstolic and Chaplin (2007)[15]	Coastal Plain (VA and MD)	0.45	0.27	0.87	22	0.7-293 (17)	<1-2.1	**50**
Mulvihill and Baldigo (2007)	Valley and Ridge (southeastern NY, Region 3)	0.62	0.21	0.77	12	1-852 (22)	1.2-3.4	**46**
Mulvihill *et al.* (2007)	Adirondack, Appalachian Plateau and St. Lawrence Valley (northern NY, Regions 1-2)	0.44	0.33	0.89	16	1-1,026 (23)	1.0-3.8	**47**
Magner and Brooks (2008)[7]	Superior Upland (Nemadji R. basin, northeastern MN)	0.35	0.33	0.79	14	0.3-329 (16)	~1-2	**70**
Mistak and Stille (2008)	Superior Upland (U. Menominee R. basin, MI)	0.42	0.20	0.76	4	44-900 (181)	1.0-1.8	83

Notes: $D = cA^f$, where D is bankfull depth (m), A is drainage area (km^2), c and f are empirical regression values, n is the number of observations, and R^2 is the correlation coefficient. BF RI, bankfull recurrence interval; PI, prediction interval; nd, no data.

[1] Physiographic regions are indicated, but not all authors regionalized their data by physiography (see summary provided by Wilkerson, 2008). Study-specific regionalizations, as reported by each source, are maintained here.

[2] Observed range, with median of the range given in parentheses.

[3] Average value over range of data, calculated for $\alpha = 0.05$ and two-tailed t-values (Zar, 1999). Bold values met the quality criteria of bankfull regressions having $n \geq 5$ and $R^2 \geq 0.75$ and were used in Figures 1 and 2.

[4] Ungaged.

[5] Maximum bankfull depth. Smoky Hill/Kansas R. data excluded because spatial variation of silt-clay content causes strongly variable channel geometry that overwhelms the downstream relationship with discharge and drainage area (Schumm, 1960).

[6] All data, with subsequent entries subdivisions of these data.

[7] Ungaged, but results calibrated to, or compared with, values for the one-year to two-year flood from local gages.

[8] Gaged and ungaged sites.

[9] Pre-determined recurrence interval, with channel geometry predicted for that value.

[10] Bankfull defined by level of valley flat.

[11] Average value.

[12] Regional differences better explained by ecoregion than physiography.

[13] Includes data of Odem and Moody (1999).

[14] Includes data of White (2001) and Cinotto (2003). Regional differences better explained by geology than physiography.

[15] Includes data of McCandless (2003b).

[16] Drainage area for Sturgeon R. corrected to 237 mi^2.

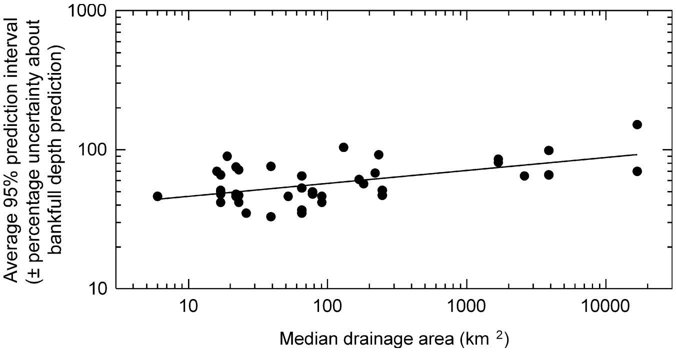

FIGURE 2. Average 95% Prediction Interval (±percentage uncertainty about the bankfull depth prediction across the range of a given regional regression) as a Function of Median Drainage Area (Table 2) for Datasets Used in Figure 1.

and standard procedures for calculating effective discharge have been developed (Biedenharn *et al.*, 2001).

THE CLASSIFICATION SYSTEM

Rosgen notes that many evaluators fail to incorporate the multiple levels of his classification hierarchy into their assessments, pointing to our focus on his Level II classification (Roper *et al.*, 2008, p. 419). While this may be true, if stream reach classification (Level II) is dependent upon valley segment type (Level I), then this dependency should be explicitly incorporated into the stream reach classification key [i.e., Rosgen's (1996) figure 5-3]. For our study, he suggests that "It is likely that West Fork Lick Creek is within a colluvial valley type II where a B stream type (not an F stream type) would typically be located" (Rosgen, this issue), which implies that the reach classification (Level II) should be modulated by the valley segment classification (Level I); but the rules for this are unclear.

REACH-SCALE CHANNEL TYPES

We disagree with Rosgen's assertion that nonunique solutions (i.e., multiple channel types) are "not possible" and "did not occur" in our analysis. The allowable variation of classification parameters (±0.2 units for both entrenchment ratio and sinuosity, and ±2.0 units for width-to-depth ratio) (Rosgen, 1996) causes overlap between channel types and the potential for nonunique solutions (Figure 3 and Table 3). At our study sites, this occurs for both the ensemble, average values (Table 4) and the individual crew observations (Table 5). For example, the Table 4 values for Big Creek indicate a C4 channel type as discussed by Rosgen, but the allowable variation of classification parameters can yield alternative solutions of both E4 and B4c. The allowable variation of both the width-to-depth ratio and sinuosity for E

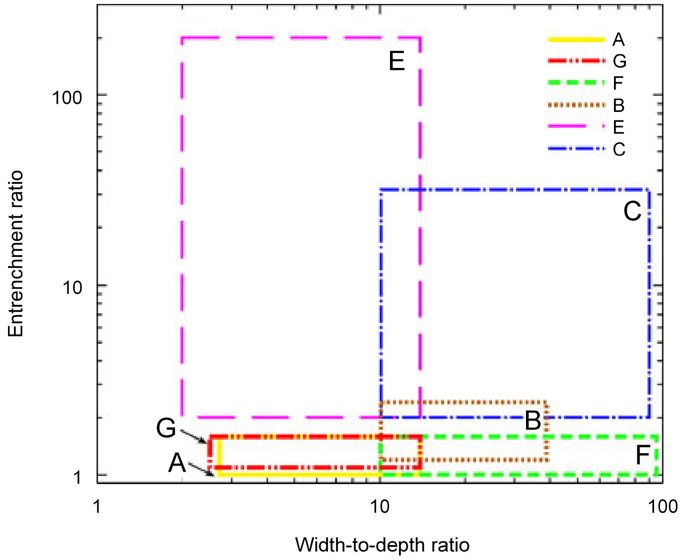

FIGURE 3. Overlap of Entrenchment and Bankfull Width-to-Depth Ratios for Single-Thread Rosgen Stream Types (A, G, F, B, E, and C) Due to the Allowed Variation of Classification Parameters (±0.2 units for entrenchment ratio and ±2.0 units for width-to-depth ratio) (Rosgen, 1996). Upper/lower parameter bounds that were not reported in Rosgen's (1996, figure 5-3) were determined from data reported for each channel type (pp. 5-35 to 5-189 of Rosgen, 1996). Nonunique channel classifications that can result from this overlap are shown in Table 3. Note that the overlap of entrenchment and width-to-depth ranges for A and G stream types does not result in nonunique solutions because these stream types have different slope ranges (Rosgen, 1996, figure 5-3). The same is true for A and F streams.

TABLE 3. Parameter Ranges for Which Nonunique Solutions (multiple stream types) Occur as a Result of Allowed Variation of Classification Parameters.

Channel Types	Entrenchment Ratio	Bankfull Width-to-Depth Ratio
Sinuosity ≥1.0, Slope ≤0.04		
C/B	2.01-2.4	>10
B/F	1.2-1.59	>10
B/F/G	1.2-1.59	10.1-13.9
F/G	<1.6	10.1-13.9
Sinuosity ≥1.3, Slope ≤0.04		
C/E	>2.0	10.1-13.9
C/E/B	2.01-2.4	10.1-13.9
Sinuosity = 1.01-1.39, Slope = 0.04-0.099		
B/A	1.2-1.59	10.1-13.9

TABLE 4. Average Channel Characteristics and Rosgen Stream Types.

Creek	Entrenchment Ratio	W/D	Sinuosity	Slope (m/m)	D_{50} (mm)	Stream Type
Big	2.33	13.8	1.44	0.0113	5	C4/E4/B4c
Bridge	1.57	18.7	1.28	0.0099	23	B4c/F4
Camus	1.61	29.4	1.04	0.0116	97	B3c*
Crane	2.72	21.1	1.47	0.0110	7	C4
Crawfish	1.35	17.5	1.15	0.0503	82	B3a*
Indian	1.75	23.0	1.17	0.0582	17	B4a*
Myrtle	1.61	17.6	1.13	0.0935	29	B4a*
Potamus	1.63	36.6	1.11	0.0242	75	B3*
Tinker	3.23	14.7	1.18	0.0272	18	C4b*
Trail	3.20	22.5	1.39	0.0176	47	C4
West Fork Lick	1.69	15.6	1.28	0.0330	26	B4
Whiskey	1.73	16.8	1.11	0.0688	41	B4a*

Notes: Values are crew averages per monitoring group averaged across all groups (i.e., double average). W/D, bankfull width-to-depth ratio; D_{50}, median surface grain size. Slashes indicate alternative classifications (nonunique solutions) due to the allowed variation of classification parameters (±0.2 units for entrenchment ratio and sinuosity and ±2.0 units for width-to-depth ratio; Rosgen, 1996). Asterisk means no stream type could have been determined without allowed variation of classification parameters.

channels ($W/D < 12 \pm 2.0$; sinuosity $>1.5 \pm 0.2$) allows Big Creek to be classified as an E4 stream, while the allowable variation of entrenchment ratio for B channels (1.4-2.2 ± 0.2) also allows it to be classified as a B4 stream. Big Creek plots in the parameter space shared by C, E, and B channels due to overlapping parameter ranges for these stream types (Figure 3, Tables 3 and 4), resulting in a nonunique classification of stream type. Nonunique solutions occur at 17% of our sites (2 out of 12) when one considers the average data (Table 4) and they occur for 25-36% of the crew observations across the three monitoring groups (Table 5). Note that the latter percentages differ slightly from values originally reported (Roper *et al.*, 2008, p. 422) due to minor classification errors that have been corrected in Table 5 (see Errata section).

Nonunique solutions are particularly problematic when stream type cannot be determined without using the allowed variation of classification parameters. For example, it is unclear whether Crawfish Creek should be classified as an A3 or B3a channel using the data reported by AREMP Crew 1 (Table 5); both alternatives require using allowable variation of classification parameters that follow different paths through Rosgen's (1996) classification key. This situation occurs for 13% of the crew observations in our study (Table 5). As suggested by Rosgen, selection between alternative channel types might be resolved by considering Level I of the classification scheme (i.e., considering what channel types are typically associated with a given valley type and landform) (Rosgen, 1996). However, the procedure for using Level I information to inform and adjust the Level II classification is unclear, as discussed in the previous section. Furthermore, it seems potentially dangerous to decide between alternative solutions based on "what should occur" for a given valley type and landform, rather than what is observed to occur through Level II field measurements. This is comparable to the danger of inferring channel condition based on stream type, rather than documenting it through historical analysis (Kondolf, 1995; Juracek and Fitzpatrick, 2003); however, use of Levels III and IV of the Rosgen system are intended to provide this historical analysis and assess cause-and-effect relationships.

The issue of multiple channel types (nonunique solutions) was recently recognized and accepted by Rosgen (2008), despite his objection to it here. Rosgen (2008) indicates that dual stream types are acceptable "when delineative variables overlap between types" (Rosgen, 2008, p. 785, right column, last sentence). This seems like a reasonable solution, given the overlap of Rosgen stream types (Figure 3 and Table 3) and the recognition that any channel classification scheme can impose artificial boundaries across the range of channel characteristics that occur within a river network (Kondolf, 1995). Hence, one might expect occasional hybrid, or dual, channel types (Rosgen, 2008), particularly when a channel is evolving from one state to another in response to disturbance (Rosgen, 2003, pp. 23-24).

In addition to nonunique solutions, we also noted that many of our study sites do not fall into primary stream classes without the allowed variation of classification parameters. This is true for 7 out of 12 (58%) of the sites when one considers the ensemble, average data (Table 4, asterisks) and 61 out of 99 (62%) of the crew observations (Table 5, NC values). We described these channels as falling in the gray zone between primary stream types, while Rosgen refers to them as being at the tails of typical parameter distributions for a given channel type. This is a matter of semantics, with the main point being that many of our study sites are on the fringes of Rosgen's (1996) parameter ranges, suggesting that the classification

TABLE 5. Data Used to Determine Rosgen Stream Types by Roper *et al.* (2008).

Creek	**Monitoring Group**	**Crew**	**Entrenchment Ratio**	***W/D***	**Sinuosity**	**Slope (m/m)**	**D_{50} (mm)**	**Stream Type**
Big	AREMP	1	2.50	11.3	1.43	0.010	3	E4/C4 (NC)
	AREMP	2	5.58	9.0	1.49	0.010	5	E4 (NC)
	AREMP	3	1.44	14.7	1.37	0.011	6	B4c/F4 (B4c)
	PIBO	1	1.4	14	1.43	0.010	6	B4c/F4 (B4c)
	PIBO	2	>3.0	8	1.50	0.010	8	E4 (E4)
	UC	1	1.70	19.2	1.32	0.012	2	B4c (B4c)
	UC	2	1.58	17.3	1.72	0.016	4	B4c/F4 (B4c)
	UC	3	1.57	19.2	1.24	0.013	3	B4c/F4 (B4c)
Bridge	AREMP	1	1.39	15.4	1.22	0.009	22	B4c/F4 (F4)
	AREMP	2	1.71	11.5	1.23	0.009	19	B4c (NC)
	AREMP	3	1.90	11.9	1.21	0.009	28	B4c (NC)
	PIBO	1	1.5	15	1.20	0.010	24	B4c/F4 (B4c)
	PIBO	2	1.5	15	1.24	0.010	37	B4c/F4 (B4c)
	UC	1	1.58	22.0	1.33	0.014	10	B4c/F4 (B4c)
	UC	2	1.46	20.6	1.55	0.011	17	B4c/F4 (B4c)
	UC	3	1.60	22.5	1.23	0.010	22	B4c (B4c)
Camas	AREMP	1	1.43	20.0	1.03	0.011	90	B3c/F3 (NC)
	AREMP	2	1.68	19.6	1.01	0.009	80	B3c (NC)
	AREMP	3	1.43	23.6	1.04	0.011	77	B3c/F3 (NC)
	PIBO	1	1.7	21	1.07	0.011	102	B3c (NC)
	PIBO	2	1.6	23	1.02	0.011	130	B3c (NC)
	PIBO	3	2.2	26	1.16	0.011	96	B3c/C3 (NC)
	UC	1	1.71	35.5	1.01	0.012	100	B3c (NC)
	UC	2	1.62	44.1	1.00	0.014	74	B3c (NC)
	UC	3	1.14	51.9	1.02	0.015	119	F3 (NC)
Crane	AREMP	1	3.75	14.0	1.54	0.009	2	C4 (C4)
	AREMP	2	5.28	16.1	1.39	0.012	5	C4 (C4)
	AREMP	3	1.68	14.9	1.46	0.009	13	B4c (B4c)
	PIBO	1	2.5	16	1.58	0.009	10	C4 (C4)
	PIBO	2	1.6	20	1.52	0.009	15	B4c (B4c)
	UC	1	4.02	15.1	1.47	0.014	2	C4 (C4)
	UC	2	1.55	18.8	1.78	0.014	2	B4c/F4 (B4c)
	UC	3	2.01	57.0	1.39	0.013	1	B5c/C5c (B5c)
Crawfish	AREMP	1	1.24	13.6	1.10	0.051	89	A3/B3a (NC)
	AREMP	2	1.19	13.4	1.10	0.052	118	A3 (NC)
	AREMP	3	1.15	12.6	1.18	0.058	24	A4 (NC)
	PIBO	1	1.4	18	1.17	0.048	119	B3a (NC)
	PIBO	2	1.5	14	1.17	0.047	134	B3a (NC)
	UC	1	1.40	24.0	1.13	0.054	53	B4a (NC)
	UC	2	1.51	22.8	1.19	0.052	35	B4a (NC)
	UC	3	1.31	23.4	1.08	0.053	82	B3a (NC)
Indian	AREMP	1	1.62	27.3	1.20	0.057	7	B4a (B4a)
	AREMP	2	1.85	18.5	1.11	0.055	24	B4a (NC)
	AREMP	3	2.21	17.3	1.15	0.059	9	B4a (NC)
	PIBO	1	2.1	14	1.27	0.058	28	B4a (B4a)
	PIBO	2	1.6	26	1.15	0.056	40	B4a (NC)
	PIBO	3	1.7	16	1.15	0.059	25	B4a (NC)
	UC	1	1.81	24.7	1.16	0.050	10	B4a (NC)
	UC	2	1.34	35.7	1.13	0.067	11	B4a (NC)
	UC	3	1.55	27.3	1.17	0.063	1	B5a (NC)
Myrtle	AREMP	1	1.23	13.8	1.09	0.094	52	B4a/A4 (NC)
	AREMP	2	1.26	17.6	1.12	0.095	23	B4a (NC)
	AREMP	3	1.41	19.9	1.17	0.091	23	B4a (NC)
	PIBO	1	1.7	17	1.11	0.091	47	B4a (NC)
	PIBO	2	2.3	14	1.30	0.082	40	B4a (NC)
	UC	1	1.46	23.1	1.09	0.097	22	B4a (NC)
	UC	2	1.60	19.3	1.08	0.098	4	B4a (NC)
	UC	3	1.53	18.2	1.07	0.100	26	B4a (NC)
Potamus	AREMP	1	1.19	19.6	1.20	0.020	83	F3b (F3b)
	AREMP	2	1.14	27.7	1.17	0.023	116	F3b (NC)
	AREMP	3	1.10	26.0	1.16	0.023	65	F3b (NC)

TABLE 5. (Continued).

Creek	Monitoring Group	Crew	Entrenchment Ratio	*W/D*	Sinuosity	Slope (m/m)	D_{50} (mm)	Stream Type
	PIBO	1	2.1	29	1.11	0.023	95	B3/C3b (NC)
	PIBO	2	1.4	35	1.11	0.023	66	B3/F3b (NC)
	UC	1	1.30	48.8	1.06	0.029	86	B3/F3b (NC)
	UC	2	1.96	54.2	1.05	0.023	33	B4 (NC)
	UC	3	2.70	57.3	1.06	0.031	40	C4b (NC)
Tinker	AREMP	1	4.33	15.0	1.14	0.025	9	C4b (NC)
	AREMP	2	5.19	11.6	1.17	0.026	25	C4b (NC)
	AREMP	3	4.25	11.1	1.18	0.026	8	C4b (NC)
	PIBO	1	>3	16	1.17	0.026	34	C4b (NC)
	PIBO	2	>3	17	1.21	0.026	26	C4b (C4b)
	PIBO	3	>3	12	1.41	0.028	29	C4b/E4b (NC)
	UC	1	2.55	13.1	1.11	0.028	9	C4b (NC)
	UC	2	2.28	22.1	1.12	0.028	3	C4b/B4 (NC)
	UC	3	1.46	14.7	1.13	0.033	21	B4/F4b (NC)
Trail	AREMP	1	4.55	17.9	1.37	0.017	31	C4 (C4)
	AREMP	2	9.60	11.0	1.36	0.017	64	C4/E4 (NC)
	AREMP	3	3.52	12.8	1.41	0.017	67	C3/E3 (C3)
	PIBO	1	>3	20	1.40	0.016	58	C4 (C4)
	PIBO	2	1.3	30	1.38	0.017	55	F4/B4c (F4)
	UC	1	1.73	32.3	1.36	0.019	37	B4c (B4c)
	UC	2	1.47	27.6	1.40	0.019	38	B4c/F4 (B4c)
	UC	3	1.52	26.3	1.45	0.020	25	B4/F4b (B4)
WF Lick	AREMP	1	0.98	10.0	1.30	0.032	28	G4 (G4)
	AREMP	2	1.49	9.4	1.29	0.030	24	G4 (NC)
	AREMP	3	1.85	6.2	1.23	0.031	22	B4 (NP)
	PIBO	1	1.5	18	1.32	0.033	30	B4/F4b (B4)
	PIBO	2	>3	14	1.29	0.032	26	C4b (C4b)
	UC	1	1.64	19.3	1.29	0.033	12	B4 (B4)
	UC	2	1.31	20.5	1.32	0.035	26	B4/F4b (F4b)
	UC	3	1.21	27.0	1.22	0.039	18	B4/F4b (F4b)
Whiskey	AREMP	1	2.21	11.3	1.08	0.061	48	B4a (NC)
	AREMP	2	1.64	15.2	1.09	0.069	55	B4a (NC)
	AREMP	3	1.66	15.6	1.10	0.070	49	B4a (NC)
	PIBO	1	1.2	20	1.13	0.072	64	B4a (NC)
	PIBO	2	1.9	15	1.17	0.064	26	B4a (NC)
	UC	1	1.74	14.9	1.07	0.064	21	B4a (NC)
	UC	2	1.93	16.7	1.04	0.073	28	B4a (NC)
	UC	3	1.71	25.2	1.07	0.079	8	B4a (NC)

Notes: AREMP, Aquatic and Riparian Effectiveness Monitoring Program; D_{50}, median surface grain size; PIBO, PACFISH/INFISH Biological Opinion Monitoring Program; UC, Upper Columbia Monitoring Program; *W/D*, bankfull width-to-depth ratio. The first stream type for each crew is based on Roper *et al.*'s (2008) rule set for consistency. Slashes indicate alternative classifications (nonunique solutions) due to the allowed variation of classification parameters (±0.2 units for entrenchment ratio and sinuosity and ±2.0 units for width-to-depth ratio; Rosgen, 1996). The value in parentheses is the stream type without allowing for variation of the above classification parameters and without applying our consistency rule. NC means no stream type could have been determined without allowed variation of classification parameters. NP means not possible to classify even with allowed variation of parameters (Roper *et al.*, 2008, pp. 420-421).

may not be representative for our study sites (Roper *et al.*, 2008, p. 424). Alternatively, this result may partially stem from not adhering to Rosgen's (1996) measurement techniques, as discussed above.

VISUAL APPEARANCE *VS.* CLASSIFIED STREAM TYPE

Our discussion of the discrepancy between visual appearance and classified stream type (Roper *et al.*, 2008, p. 424) was based on Rosgen's descriptions of major stream types, which indicate that A and G streams can exhibit a step-pool morphology, while B streams are riffle-dominated channels (Rosgen, 1994, table 2; Rosgen, 1996, table 4-1). When we found that visually identified step-pool channels were classified 91% of the time by observer measurements as B streams (riffle dominated), we considered them to have been misclassified (the observed morphology did not match Rosgen's description of the primary channel type). However, Rosgen notes an addendum to his description of primary channel types, which indicates that B channels can also have a step-pool morphology

(Rosgen, 1996, pp. 4-24). Consequently, the apparent misclassification that we identified is incorrect when one considers this addendum. To avoid future errors of this sort, we recommend that the description of B channels be revised; the current description for these channels as being "riffle dominated…with occasional (infrequently spaced) pools" (Rosgen, 1994, table 2; Rosgen, 1996, table 4-1) does not suggest the possibility of a step-pool morphology.

CLOSURE

Our analysis assessed the "in practice" variability in Rosgen classification between and within several monitoring groups that are active in the western U.S. Results may have differed if the underlying data were collected in strict accordance with Rosgen's (1996) field methods; an issue that warrants further investigation. However, this does not invalidate our analysis and the intended study goal of evaluating classification consistency and sources of observed differences. We found that channel classification was inconsistent both between and within monitoring groups, with the former due to differences in methods and training between groups, and the latter due to differences in observer measurements within a given monitoring protocol. Our study did not address accuracy, so we do not know whether the observed channel types are correct as defined by strict adherence to Rosgen's methods; nor do we know whether the observed range of variability in classified stream types is representative of his methods. Nevertheless, our analysis quantifies the variability present in the data collected by the monitoring groups examined in our study and has implications for whether these groups can effectively share such data and whether these data allow effective communication of stream type.

Furthermore, it should be recognized that Rosgen's (1994, 1996) method is a means to classify, but the accuracy of these measurements in terms of their ability to describe the mean and variance of channel conditions within a given stream reach has not been demonstrated. The requirements for making accurate measurements of most channel characteristics are open questions in fluvial geomorphology. For example, we can statistically assess how many particles one should sample in conducting grain size analyses (Church *et al.*, 1987; Rice and Church, 1996), but similar rules have not been developed for determining requisite sample sizes for accurately representing the mean and variance of other channel characteristics (width, depth, etc.) in any one channel type, let alone across different channel morphologies. Rosgen asserts accuracy of his methods by statements such as "the best locations for determining bankfull channel dimensions are at the riffle or 'cross-over' reach of C, E, and F streams" and that these are "the most representative, appropriate locations to determine bankfull channel dimensions." These recommended methods provide consistency of measurement locations, which is valuable for reducing observer variability, but there is no demonstration that the advocated methods provide the "best" or "most representative" values. For example, riffles are a subset of the channel units present within pool-riffle streams (Bisson *et al.*, 1982), so they describe a subset of the actual channel conditions, hydraulic geometry, and aquatic habitat within these channels (Church, 1992).

Many of Rosgen's comments focus on criticizing our methods of data collection, but there is no discussion of the larger issue of the sensitivity of his classification to bankfull identification (Johnson and Heil, 1996; Roper *et al.*, 2008) and advice on how to deal with this issue. For example, could the classification be reformulated to make it more robust by removing its bankfull dependence?

ERRATA

1. p. 422 of Roper *et al.* (2008) should read "The data indicate that 25% of AREMP, 33% of PIBO, and 36% of UC determinations could have been placed in another stream type (i.e., nonunique solutions)." Crew observations yielding nonunique solutions (multiple channel types) are shown in Table 5 of the Reply.
2. p. 424 of Roper *et al.* (2008) should read "…without the allowable variation of classification parameters, the overall mean values of 5 of the 12 evaluated streams (>40%) did not fall into a primary stream type because they had entrenchment ratios between 1.4 and 2.2 and sinuosity less than 1.2 (Table 1)." Furthermore, two other sites (Crawfish and Tinker) could not be classified without the allowed variation of parameters, bringing the total to 7 out of 12 (58%) (Table 4, this issue).
3. Several classification errors in Table 3 of Roper *et al.* (2008) have been corrected here (Table 5): (a) observations for UC Crews 1 and 2 at Crawfish Creek are (NC), as are observations for PIBO Crews 1 and 3 at Tinker Creek; and (b) the channel type for UC Crew 3 at Camas Creek is F3, reducing the number of streams to three (25%) for which measurements from all crews in all monitoring groups yielded the same stream type.

4. Some of the protocols for measuring channel attributes were incorrectly reported in Table 2 of Roper *et al.* (2008) and have been corrected here, with further information about methods also provided (Table 1). Note that UCs width-to-depth ratio is not based on the thalweg depth as originally described and as criticized by Rosgen, but is based on the reach-average mean bankfull depth derived from thalweg measurements using Kaufmann *et al.*'s (1999) method. Also note that AREMP generally followed Rosgen's (1996) recommended measurement procedures, thereby providing perhaps the best indication of within-group consistency that might result from adherence to Rosgen's recommended methods, at least for this study.

ACKNOWLEDGMENTS

We thank two anonymous reviewers and an Associate Editor for comments that improved the manuscript.

LITERATURE CITED

Andrews, E.D., 1980. Effective and Bankfull Discharges of Streams in the Yampa River Basin, Colorado and Wyoming. Journal of Hydrology 46:311-330.

Andrews, E.D., 1984. Bed-Material Entrainment and Hydraulic Geometry of Gravel-Bed Rivers in Colorado. Geological Society of America Bulletin 95:371-378.

Andrews, E.D. and J.M. Nankervis, 1995. Effective Discharge and the Design of Channel Maintenance Flows for Gravel-Bed Rivers. *In*: Natural and Anthropogenic Influences in Fluvial Geomorphology, J.E. Costa, A.J. Miller, K.W. Potter, and P.R. Wilcock (Editors). Geophysical Monograph 89. American Geophysical Union, Washington, D.C., pp. 151-164.

AREMP, 2005. Field Protocol Manual. Aquatic and Riparian Effectiveness Monitoring Program, Interagency Monitoring Program, Northwest Forest Plan, USDA Forest Service Pacific Northwest Regional Office and Bureau of Land Management Oregon State Office, Corvallis, Oregon, unpublished manual, 53 pp., http://www.reo.gov/monitoring/reports/watershed/aremp/aremp.htm, *accessed* August 2009.

Azary, I., 1999. Application of the Rosgen Stream Classification System to Southern California Wilderness Streams. *In*: Wildland Hydrology, TPS-99-3, D.S. Olsen and J.P. Potyondy (Editors). American Water Resources Association, Herndon, Virginia, pp. 237-244.

Barry, J.J., J.M. Buffington, P. Goodwin, J.G. King, and W.W. Emmett, 2008. Performance of Bed Load Transport Equations Relative to Geomorphic Significance: Predicting Effective Discharge and Its Transport Rate. Journal of Hydraulic Engineering 134:601-615.

Biedenharn, D.S., C.R. Thorne, P.J. Soar, R.D. Hey, and C.C. Watson, 2001. Effective Discharge Calculation Guide. International Journal of Sediment Research 16:445-459.

Bisson, P.A., J.L. Nielsen, R.A. Palmason, and L.E. Grove, 1982. A System of Naming Habitat Types in Small Streams, With Examples of Habitat Utilization by Salmonids During Low Streamflow. *In*: Acquisition and Utilization of Aquatic Habitat Inventory Information, N.B. Armantrout (Editor). Western Division of the American Fisheries Society, Bethesda, Maryland, pp. 62-73.

Brush, L., 1961. Drainage Basins, Channels, and Flow Characteristics of Selected Streams in Central Pennsylvania. U.S. Geological Survey Professional Paper 282-F, United States Government Printing Office, Washington, D.C., 35 pp.

Castro, J.M. and P.L. Jackson, 2001. Bankfull Discharge Recurrence Intervals and Regional Hydraulic Geometry Relationships: Patterns in the Pacific Northwest. Journal of the American Water Resources Association 37:1249-1262.

Chang, T.J., Y.Y. Fang, H. Wu, and D.E. Mecklenburg, 2004. Bankfull Channel Dimensions in Southeast Ohio. *In*: Self-Sustaining Solutions for Streams, Wetlands and Watersheds, J.L. D'Ambrosio (Editor). American Society of Agricultural Engineers Publication 701P0504, St. Joseph, Michigan, pp. 347-355.

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. U.S. Geological Survey Scientific Investigations Report 2005-5147, Reston, Virginia, 34 pp.

Church, M., 1992. Channel Morphology and Typology. *In*: The Rivers Handbook, P. Carlow and G.E. Petts (Editors). Blackwell Scientific Publications, Oxford, United Kingdom, pp. 126-143.

Church, M.A., D.G. McLean, and J.F. Wolcott, 1987. River Bed Gravels: Sampling and Analysis. *In*: Sediment Transport in Gravel-Bed Rivers, C.R. Thorne, J.C. Bathurst, and R.D. Hey (Editors). Wiley, Chichester, United Kingdom, pp. 43-88.

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. U.S. Geological Survey Water-Resources Investigation Report 03-4014, New Cumberland, Pennsylvania, 27 pp.

Doll, B.A., A.D. Dobbins, J. Spooner, D.R. Clinton, and D.A. Bidelspach, 2003. Hydraulic Geometry Relationships for Rural North Carolina Coastal Plain Streams. Unpublished report to North Carolina Division of Water Quality for 319 Grant, Project No. EW20011, North Carolina Stream Restoration Institute, Raleigh, North Carolina, 11 pp. http://www.bae.ncsu.edu/programs/extension/wqg/srp/techresources.html, *accessed* August 2009.

Dudley, R.W., 2004. Hydraulic-Geometry Relations for Rivers in Coastal and Central Maine. U.S. Geological Survey Scientific Investigations Report 2004-5042, Augusta, Maine, 30 pp.

Dugaw, D.D., J.D. Heitke, E.K. Archer, R.C. Henderson, and J.L. Kershner, 2005. Effectiveness Monitoring for Streams and Riparian Areas: Sampling Protocol for Stream Channel Attributes. PACFISH/INFISH Biological Opinion (PIBO) Effectiveness Monitoring Program, Logan, Utah, unpublished manual, 72 pp. http://www.fs.fed.us/biology/fishecology/emp, *accessed* April 2009.

Dunne, T. and L.B. Leopold, 1978. Water in Environmental Planning. Freeman, San Francisco, California.

Elliott, J.G. and K.D. Cartier, 1986. Hydraulic Geometry and Streamflow of Channels in the Piceance Basin, Rio Blanco and Garfield Counties, Colorado. U.S. Geological Survey Water-Resources Investigations Report 85-4118, Denver, Colorado, 28 pp.

Emmett, W.W., 1972. The Hydraulic Geometry of Some Alaskan Streams South of the Yukon River. U.S. Geological Survey Open-File Report 72-108, 102 pp.

Emmett, W.W., 1975. The Channels and Waters of the Upper Salmon River Area, Idaho. U.S. Geological Survey Professional Paper 870-A, United States Government Printing Office, Washington, D.C., 116 pp.

Glickauf, S., W. Harman, S. Bevington, and K. Gilland, 2007. The Development of Bankfull Hydraulic Geometry Relationships for Streams of the Georgia Coastal Plain. *In*: Proceedings of the 2007 Georgia Water Resources Conference, Athens, Georgia, 3 pp. http://www.gwri.gatech.edu/conferences/previous-gwrc-conferences/gwrc-2007/, *accessed* April 2009.

Hack, J.T., 1957. Studies of Longitudinal Stream Profiles in Virginia and Maryland. U.S. Geological Survey Professional Paper 294-B, United States Government Printing Office, Washington, D.C., pp. 45-97.

Harman, W.A., G.D. Jennings, J.M. Patterson, D.R. Clinton, L.O. Slate, A.G. Jessup, J.R. Everhart, and R.E. Smith, 1999. Bankfull Hydraulic Geometry Relationships for North Carolina Streams. *In*: Wildland Hydrology, TPS-99-3, D.S. Olsen and J.P. Potyondy (Editors). American Water Resources Association, Herndon, Virginia, pp. 401-408.

Harman, W.A., D.E. Wise, M.A. Walker, R. Morris, M.A. Cantrell, M. Clemmons, G.D. Jennings, D. Clinton, and J. Patterson, 2000. Bankfull Regional Curves for North Carolina Mountain Streams. *In*: Water Resources in Extreme Environments, TPS-00-1, D.L. Kane (Editor). American Water Resources Association, Middleburg, Virginia, pp. 185-190.

Harrelson, C.C., C.L. Rawlins, and J.P. Potyondy, 1994. Stream Channel Reference Sites: An Illustrated Guide to Field Technique. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station General Technical Report GTR-RM-245, Fort Collins, Colorado, 61 pp.

Hillman, T.W., 2004. Monitoring Strategy for the Upper Columbia Basins. Unpublished report prepared by BioAnalysts (Eagle, ID) for the Upper Columbia Salmon Recovery Board, Wenatchee, Washington, 103 pp.

Jaquith, S. and M. Kline, 2001. Vermont Regional Hydraulic Geometry Curves. Unpublished report prepared for the Vermont Department of Environmental Conservation, Water Quality Division, Waterbury, Vermont, 11 pp. http://www.anr.state.vt.us/dec/waterq/rivers/docs/rv_hydraulicgeocurves.pdf, *accessed* April 2009.

Johnson, P.A. and B.J. Fecko, 2008. Regional Channel Geometry Equations: A Statistical Comparison for Physiographic Provinces in the Eastern US. River Research and Applications 24:823-834.

Johnson, P.A. and T.M. Heil, 1996. Uncertainty in Estimating Bankfull Conditions. Water Resources Bulletin 32:1283-1291.

Juracek, K.E. and F.A. Fitzpatrick, 2003. Limitations and Implications of Stream Classification. Journal of the American Water Resources Association 39:659-670.

Kaufmann, P.R., J.M. Faustini, D.P. Larsen, and M.A. Shirazi, 2008. A Roughness-Corrected Index of Relative Bed Stability for Regional Stream Surveys. Geomorphology 99:150-170.

Kaufmann, P.R., P. Levine, E.G. Robison, C. Seeliger, and D.V. Peck, 1999. Quantifying Physical Habitat in Wadeable Streams. U.S. Environmental Protection Agency EPA/620/R-99/003, Washington, D.C., 102 pp.

Keaton, J.N., T. Messinger, and E.J. Doheny, 2005. Development and Analysis of Regional Curves for Streams in the Non-Urban Valley and Ridge Physiographic Province, Maryland, Virginia, and West Virginia. U.S. Geological Survey Scientific Investigations Report 2005-5076, Reston, Virginia, 109 pp.

Kellerhals, R., C.R. Neill, and D.I. Bray, 1972. Hydraulic and Geomorphic Characteristics of Rivers in Alberta. Research Council of Alberta, River Engineering and Surface Hydrology Report 72-1, Edmonton, Alberta, 52 pp.

Kilpatrick, F.A. and H.H. Barnes, 1964. Channel Geometry of Piedmont Streams as Related to Frequency of Floods. U.S. Geological Survey Professional Paper 422-E, United States Government Printing Office, Washington, D.C., 10 pp.

Kondolf, G.M., 1995. Geomorphological Stream Channel Classification in Aquatic Habitat Restoration: Uses and Limitations Aquatic Conservation. Marine and Freshwater Ecosystems 5:127-141.

Krstolic, J.L. and J.J. Chaplin, 2007. Bankfull Regional Curves for Streams in the Non-Urban Non-Tidal Coastal Plain Physiographic Province, Virginia and Maryland. U.S. Geological Survey Scientific Investigations Report 2007-5162, Reston, Virginia, 48 pp.

Kuck, T.D., 2000. Regional Hydraulic Geometry Curves of the South Umpqua Area in Southwestern Oregon. *Stream Notes*, January:6-8.

Lawlor, S.M., 2004. Determination of Channel-Morphology Characteristics, Bankfull Discharge, and Various Design-Peak Discharges in Western Montana. U.S. Geological Survey Scientific Investigations Report 2004-5263, Reston, Virginia, 19 pp.

Leopold, L.B., 1994. A View of the River. Harvard University Press, Cambridge, Massachusetts.

Leopold, L.B. and H.E. Skibitzke, 1967. Observations on Unmeasured Rivers. Geografiska Annaler 49A:247-255.

Leopold, L.B., M.G. Wolman, and J.P. Miller, 1964. Fluvial Processes in Geomorphology. Freeman, San Francisco, California.

Magner, J.A. and K.N. Brooks, 2008. Predicting Stream Channel Erosion in the Lacustrine Core of the Upper Nemadji River, Minnesota (USA) Using Stream Geomorphology Metrics. Environmental Geology 54:1423-1434.

Maner, M., 1999. Regional Stream Geometry Curves for Ozark Upland Streams. *In*: Wildland Hydrology, TPS-99-3, D.S. Olsen and J.P. Potyondy (Editors). American Water Resources Association, Herndon, Virginia, pp. 385-391.

McCandless, T.L., 2003a. Maryland Stream Survey: Bankfull Discharge and Channel Characteristics of Streams in the Allegheny Plateau and Valley and Ridge Hydrologic Regions. U.S. Fish and Wildlife Service CBFO-S03-01, Annapolis, Maryland, 33 pp.

McCandless, T.L., 2003b. Maryland Stream Survey: Bankfull Discharge and Channel Characteristics in the Coastal Plain Hydrologic Region. U.S. Fish and Wildlife Service CBFO-S03-02, Annapolis, Maryland, 29 pp.

McCandless, T.L. and R.A. Everett, 2002. Maryland Stream Survey: Bankfull Discharge and Channel Characteristics of Streams in the Piedmont Hydrologic Region. U.S. Fish and Wildlife Service CBFO-S02-01, Annapolis, Maryland, 40 pp.

Messinger, T. and J.B. Wiley, 2004. Regional Relations in Bankfull Channel Characteristics Determined From Flow Measurements at Selected Stream-Gaging Stations in West Virginia, 1911-2002. U.S. Geological Survey Water-Resources Investigations Report 03-4276, Reston, Virginia, 43 pp.

Metcalf, C., 2004. Regional Channel Characteristics for Maintaining Natural Fluvial Geomorphology in Florida Streams. U.S. Fish and Wildlife Service unpublished report prepared for the Florida Department of Transportation, Panama City, Florida, 41 pp. http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_EMO/FDOT_BD470_final.pdf, *accessed* April 2009.

Metcalf, C., 2005. Alabama Riparian Reference Reach and Regional Curve Study. U.S. Fish and Wildlife Service unpublished report prepared for the Alabama Department of Environmental Management, Panama City, Florida, 34 pp. http://www.fws.gov/panamacity/, *accessed* April 2009.

Miller, J.P., 1958. High Mountain Streams: Effects of Geology on Channel Characteristics and Bed Material. State Bureau of Mines and Mineral Resources, New Mexico Institute of Mining and Technology Memoir 4, 53 pp.

Miller, S.J. and D. Davis, 2003. Optimizing Catskill Mountain Regional Bankfull Discharge and Hydraulic Geometry Relationships. *In*: Watershed Management for Water Supply Systems, TPS-03-2, M.J. Pfeffer, D.J. Van Abs, and K.N. Brooks (Editors). American Water Resources Association, Middleburg, Virginia, pp. 10.

Miller, A., J. Troxell, and L.B. Leopold, 1971. Hydrology of Two Small River Basins in Pennsylvania Before Urbanization. U.S. Geological Survey Professional Paper, United States Government Printing Office, Washington, D.C., 701-A, 57 pp.

Mistak, J.L. and D.A. Stille, 2008. Regional Hydraulic Geometry Curve for the Upper Menominee River, Michigan Department of Natural Resources, Fisheries Technical Report 2008-1, Ann Arbor, Michigan, 19 pp.

Moody, T., M. Wirtanen, and S.N. Yard, 2003. Regional Relationships for Bankfull Stage in Natural Channels of the Arid Southwest. Natural Channel Design, unpublished report, Flagstaff, Arizona, 36 pp. http://www.naturalchanneldesign.com/, *accessed* April 2009.

Mulvihill, C.I. and B.P. Baldigo, 2007. Regionalized Equations for Bankfull Discharge and Channel Characteristics of Streams in New York State: Hydrologic Region 3 East of the Hudson River. U.S. Geological Survey Scientific Investigations Report 2007-5227, Reston, Virginia, 15 pp.

Mulvihill, C.I., A.G. Ernst, and B.P. Baldigo, 2005. Regionalized Equations for Bankfull Discharge and Channel Characteristics of Streams in New York State: Hydrologic Region 6 in the Southern Tier of New York. U.S. Geological Survey Scientific Investigations Report 2005-5100, Reston, Virginia, 14 pp.

Mulvihill, C.I., A.G. Ernst, and B.P. Baldigo, 2006. Regionalized Equations for Bankfull-Discharge and Channel Characteristics of Streams in New York State: Hydrologic Region 7 in Western New York. U.S. Geological Survey Scientific Investigations Report 2006-5075, Reston, Virginia, 14 pp.

Mulvihill, C.I., A. Filopowicz, A. Coleman, and B.P. Baldigo, 2007. Regionalized Equations for Bankfull Discharge and Channel Characteristics of Streams in New York State: Hydrologic Regions 1 and 2 in the Adirondack Region of Northern New York. U.S. Geological Survey Scientific Investigations 2007-5189, Reston, Virginia, 18 pp.

Nash, D.B., 1994. Effective Sediment-Transporting Discharge From Magnitude-Frequency Analysis. Journal of Geology 102:79-95.

Nixon, M., 1959. A Study of Bank-Full Discharges of the Rivers of England and Wales. Proceedings of the Institution of Civil Engineers 12:157-174.

Nolan, K.M., T.E. Lisle, and H.M. Kelsey, 1987. Bankfull Discharge and Sediment Transport in Northwestern California. *In*: Erosion and Sedimentation in the Pacific Rim, R.L. Beschta, T. Blinn, G.E. Grant, F.J. Swanson and G.G. Ice (Editors). International Association of Hydrological Sciences, Publication no. 165, Wallingford, UK, pp. 439-449.

Odem, W.I. and T.O. Moody, 1999. Channel Geometry Relationships in the Southwest U.S. *In*: Wildland Hydrology, TPS-99-3, D.S. Olsen and J.P. Potyondy (Editors). American Water Resources Association, Herndon, Virginia, pp. 409-416.

Pruitt, B.A., W.L. Nutter, and W.B. Ainslie, 1999. Estimating Flood Frequency in Gaged and Ungaged Watersheds. *In*: Proceedings of the 1999 Georgia Water Resources Conference, K.J. Hatcher (Editor). University of Georgia, Athens, Georgia, pp. 520-523.

Rice, S. and M. Church, 1996. Sampling Surficial Fluvial Gravels: The Precision of Size Distribution Percentile Estimates. Journal of Sedimentary Research 66:654-665.

Roper, B.B., J.M. Buffington, E. Archer, C. Moyer, and M. Ward, 2008. The Role of Observer Variation in Determining Rosgen Stream Types in Northeastern Oregon Mountain Streams. Journal of the American Water Resources Association 44:417-427.

Roper, B.B., J.L. Kershner, E Archer, R. Henderson, and N. Bouwes, 2002. An Evaluation of Physical Stream Habitat Attributes Used to Monitor Streams. Journal of the American Water Resources Association 38:1637-1646.

Rosgen, D.L., 1994. A Classification of Natural Rivers. Catena 22:169-199.

Rosgen, D.L. 1996. Applied River Morphology (Second Edition). Wildland Hydrology, Pagosa Springs, Colorado.

Rosgen, D.L., 2003. Applied River Morphology. PhD dissertation. University of East Anglia, Norwich, Norfolk, United Kingdom, 27 pp. and appendices.

Rosgen, D.L., 2008. Discussion of "Critical Evaluation of How the Rosgen Classification and Associated 'Natural Channel Design' Methods Fail to Integrate and Quantify Fluvial Processes and Channel Responses." Journal of the American Water Resources Association 44:782-792.

Schumm, S.A., 1960. The Shape of Alluvial Channels in Relation to Sediment Type. U.S. Geological Survey Professional Paper 352-B, United States Government Printing Office, Washington, D.C., pp. 17-30.

Sherwood, J.M. and C.A. Huitger, 2005. Bankfull Characteristics of Ohio Streams and Their Relation to Peak Streamflows. U.S. Geological Survey Scientific Investigations Report 2005-5153, Reston, Virginia, 38 pp.

Simon, A., M. Doyle, M. Kondolf, F.D. Shields, B. Rhoads, and M. McPhillips, 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.

Smartt, P.F.M. and J.E.A. Grainger, 1974. Sampling for Vegetation Survey: Some Aspects of the Behaviour of Unrestricted, Restricted, and Stratified Techniques. Journal of Biogeography 1:193-206.

Smith, D.P. and L. Turrini-Smith, 1999. Western Tennessee Fluvial Geomorphic Regional Curves. Unpublished report submitted to the U.S. Environmental Protection Agency, Region IV, Nashville, Tennessee, 38 pp. http://hydro.csumb.edu/Doug/html/tn_reg_crv_1999.pdf, *accessed* April 2009.

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.

Westergard, B.E., C.I. Mulvihill, A.G. Ernst, and B.P. Baldigo, 2005. Regionalized Equations for Bankfull Discharge and Channel Characteristics of Streams in New York State: Hydrologic Region 5 in Central New York. U.S. Geological Survey Scientific Investigations Report 2004-5247, Reston, Virginia, 16 pp.

White, K.E., 2001. Regional Curve Development and Selection of a Reference Reach in the Non-Urban, Lowland Sections of the Piedmont Physiographic Province, Pennsylvania and Maryland. U.S. Geological Survey Water-Resources Investigations Report 01-4146, New Cumberland, Pennsylvania, 20 pp.

Whiting, P.J., J.F. Stamm, D.B. Moog, and R.L. Orndorff, 1999. Sediment Transporting Flows in Headwater Streams. Geological Society of America Bulletin 111:450-466.

Wilkerson, G.V., 2008. Improved Bankfull Discharge Prediction Using 2-Year Recurrence-Period Discharge. Journal of the American Water Resources Association 44:243-258.

Williams, G.P., 1978. Bank-Full Discharge of Rivers. Water Resources Research 14:1141-1154.

Wohl, E.E., D.J. Anthony, S.W. Madsen, and D.M. Thompson, 1996. A Comparison of Surface Sampling Methods for Coarse Fluvial Sediments. Water Resources Research 32:3219-3226.

Wolman, M.G., 1954. A Method of Sampling Coarse Bed Material. Transactions, American Geophysical Union 35:951-956.

Wolman, M.G., 1955. The Natural Channel of Brandywine Creek Pennsylvania. U.S. Geological Survey Professional Paper 271, United States Government Printing Office, Washington, D.C., 56 pp.

Wolman, M.G. and J.P. Miller, 1960. Magnitude and Frequency of Forces in Geomorphic Processes. Journal of Geology 68:54-74.

Zar, J.H., 1999. Biostatistical Analysis. Prentice-Hall, Upper Saddle River, New Jersey, 663 pp.