Rosgen, D.L. (2008). Discussion – "Critical Evaluation of How the Rosgen Classification and Associated "Natural Channel Design" Methods Fail to Integrate and Quantify Fluvial Processes and Channel Responses" by A. Simon, M. Doyle, M. Kondolf, F.D. Shields Jr., B. Rhoads, and M. McPhillips. *Journal of the American Water Resources Association (JAWRA), 44*(3): 782–792.

DISCUSSION – "Critical Evaluation of How the Rosgen Classification and Associated "Natural Channel Design" Methods Fail to Integrate and Quantify Fluvial Processes and Channel Responses" by A. Simon, M. Doyle, M. Kondolf, F.D. Shields Jr., B. Rhoads, and M. McPhillips[1]

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I understand the effort that these authors have expended to meet their stated goals in their abstract to "*highlight inconsistencies and identify technical problems of Rosgen's "natural channel design" approach to stream restoration*" (p. 1117). It is appropriate to respond formally to the authors' assertions to present the facts of the methodologies rather than rely on the opinions of these authors. The statements made by these authors, in the absence of detailed investigation, point out an obvious problem that if individuals are not trained in the proper use of the classification system and natural channel design (NCD), then inappropriate applications and conclusions can and do occur. As with any tool, it is important to understand its proper use. If the authors had better investigated and become more familiar with the methods in NCD, the majority of their dialog and conclusions would not have necessitated this discussion. The procedures that are referenced to in this discussion counter the inaccuracies made and were *all* available to these authors for their study prior to the article under discussion. Unfortunately, none of these authors have attended any advanced formal training courses offered or contacted me to inquire about the details of the methods in NCD that have been implemented for over two decades. The unfamiliarity with the NCD method is exemplified in the following statement by the authors: "*empirical approaches such as those inherent in "natural channel design"…do not provide cause and effect solutions or means of predicting stable channel dimensions within unstable systems and represent only one possible alternative to evaluating stream types"* (p.1128). The multiple opinions expressed by the authors are not substantiated with facts and are addressed in the following discussion.

The authors correctly define and describe Level I and Level II stream classification although they do not label it as such. They then state that "*its use for engineering design or for predicting river behavior cannot be justified and that its use for designing mitigation projects in unstable fluvial systems seems beyond its technical scope"* (p. 1118). The Level I and Level II stream classification are not intended to meet the above objectives without conducting Level III and Level IV in the hierarchical assessment of channel morphology (Figure 1) (Rosgen, 1994, 1996, 1998, 2001a, c, 2006a, b, d, 2007) as stream classification does not substitute for a stability assessment. An excerpt from Rosgen (2006e, p. 2-31) about this matter reads: "The Rosgen classification system does not assess stability but rather describes various river types and quantifies their morphological parameters. When the values of these quantitative morphological variables depart from value ranges typical of a stable state in the same valley type, based on dimension, pattern, profile and materials, the channel may exceed a stability threshold, resulting in aggradation, degradation, accelerated lateral extension, avulsion and other instability consequences. The corresponding instability or disequilibrium often results in a morphological shift (evolution) to a new stream type." General statements, however, by various stream types are appropriate to summarize at level II stream classification dealing with sensitivity to disturbance, recovery potential, sediment supply, streambank erosion potential, and vegetation controlling influence (Rosgen, 1994, 1996, 2006e). These are general interpretations and do not substitute for the detailed level III (channel stability) prediction analysis as overlooked by the authors.

[1] A. Simon, M. Doyle, M. Kondolf, F.D. Shields Jr., B. Rhoads, & 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 (5), 1117–1131.

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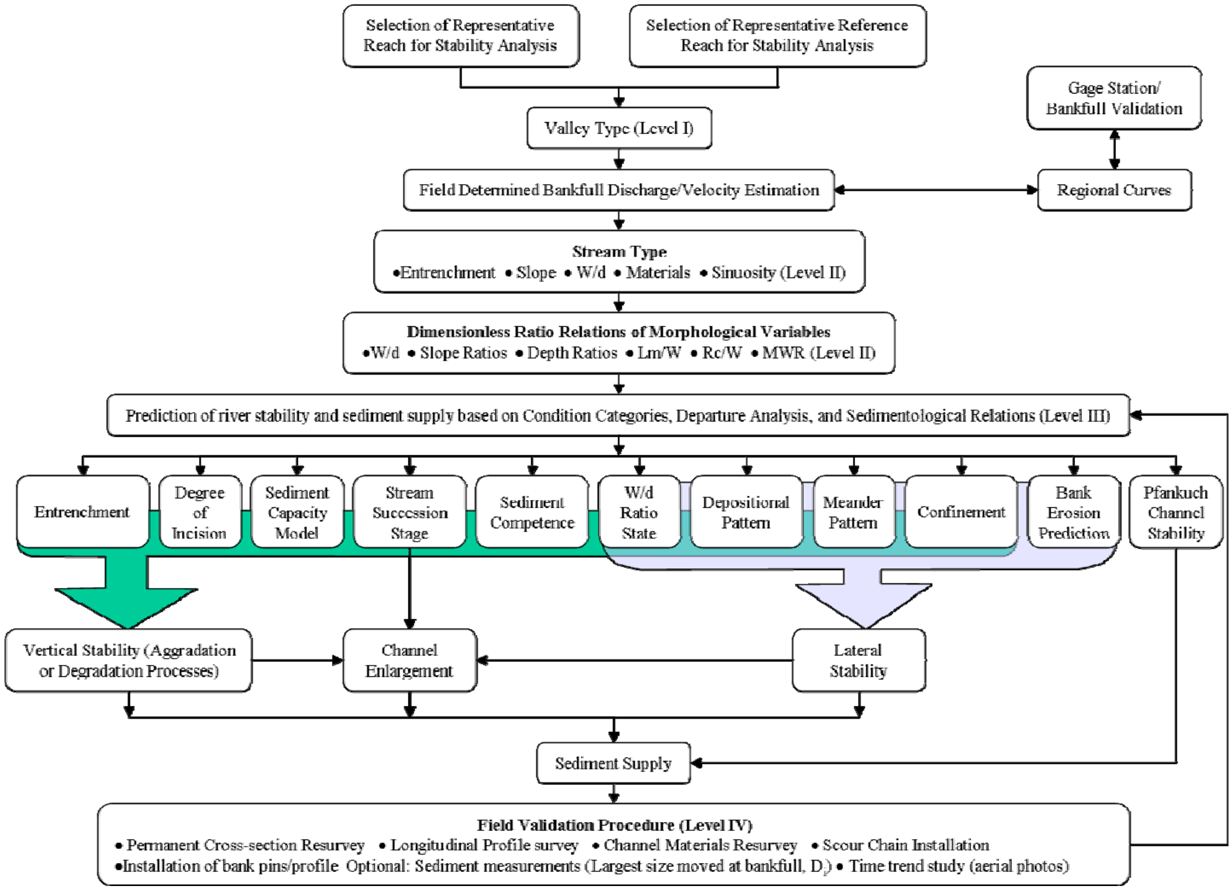

FIGURE 1. Generalized Flowchart of Application of the Four Assessment Levels of Channel Morphology, Stability Ratings, and Sediment Supply Used in Natural Channel Design (In Rosgen, 2004, 2006b, c, 2007).

The Level III assessment incorporates detailed procedures including time-trend aerial photography, detailed field measurements, sediment competence and sediment capacity prediction, hydraulic analysis, and field measurements to predict river stability–**not** the level II classification (USEPA, 2006; Rosgen, 2001a, c, 2004, 2006a, b, d, e, 2007). A two-week course is required to teach professionals (including individuals who have graduated from college with advanced degrees in engineering, geology, hydrology, fisheries, and geomorphology) how to conduct a watershed and stream channel stability analysis after having initial training in stream classification. Completion of 540 hours of study is required to learn the NCD method. The stability assessment procedure has been in use for over twenty years and is documented in Rosgen (1996, 1999, 2001a, b, c, 2004, 2006e) and is supported by the Environmental Protection Agency where the *Watershed Assessment for River Stability and Sediment Supply (WARSSS)* methodology was peer-reviewed for 13 months and was deemed an acceptable alternative to flat-rate, sediment standards for 303-D listed streams for "clean" sediment TMDL's (USEPA, 2006).

WARSSS (Rosgen, 2006e; USEPA, 2006) is used in NCD and is a three-phase methodology that identifies specific locations and processes adversely affected by various land uses; provides a consistent, quantitative analysis of sediment supply and channel stability; predicts hillslope, hydrologic, and channel processes contributing to sediment yield and river impairment; establishes a basis for site- and process-specific mitigation; and documents a better understanding of the cumulative effects of various land uses on the water resources. WARSSS is also used in river restoration by documenting the cause and consequence of impairment and establishing criteria for NCD. This stability assessment is mandatory to determine both spatial and temporal variability in channel and watershed conditions leading to the cause, extent, and consequence of disequilibrium. Classification is used in this Level as a stratification of morphological types that exist within the watershed, and for reference reach characterization to conduct departure analysis.

The Level IV validation of these quantitative prediction methods are implemented in NCD due to the complexity and uncertainty in predicting natural channel processes and function (Rosgen, 1996, 1999, 2001a, c, 2004, 2006d, e; USEPA, 2006). Because any model or prediction method may have limitations and uncertainties, it becomes necessary to validate predictions with actual measurements. The methods started since 1968 by the author have been continued, improved, and are documented in Rosgen (1996, 1999, 2001a, c, 2004, 2006d, e) and USEPA (2006). The most recent Level IV procedure has been implemented in large-scale river restoration projects since 1991. The Level IV data verifies predictions by field measurements of velocity, shear stress, stream power, bank erosion rates, bed stability, suspended and bedload sediment, entrainment (using scour chains), aggradation, degradation, lateral migration, avulsion, down-valley meander migration, and sediment supply changes. These methods have been taught and implemented in my classes since 1996 and are part of the NCD procedure (Phase VIII) (Rosgen, 2006b, c, d, 2007).

The authors state "*…using Rosgen stream types and "natural channel design," how would a practitioner determine the "correct" channel dimensions to design a restoration project?*" (p. 1123). If the authors had studied the NCD method, they would have been able to answer their own question. The authors fail to define the "*natural channel design methods*" of which they are referring. The authors cite my 1996 and 2001c work, but neither of these publications include my method for NCD.

The NCD methodology consists of *eight phases* (Rosgen, 2006b, c, d, 2007), including *Phase II* using stream classification and *Phase III*, the detailed watershed and channel stability assessment, including field data and analysis of flow resistance and sediment transport competency and capacity. This opposes the statement made that this procedure "*does not aim to quantify the specific variables and processes that control channel processes and morphology"* (p 1129). *Phase V* is the 40-step procedure used in NCD. Hey (2006) references these 40 steps in his article, which the authors of the article under discussion cite. <u>At minimum, the authors should have been aware of the eight phases and the 40-step procedure, but make no reference to either</u>. *Phase VIII* involves the validation of the physical process prediction methodologies used in *Phase III* of the procedure.

In science, a conclusion is reached following a rigorous investigation of the facts. The opinions expressed by these authors were not based on fact or any detailed investigation of my methods. The authors' opinions are compared to the facts with supporting references in Table 1. Additional discussion of key points is supplemented in the text.

The following excerpt is also astonishing: "*…the overriding emphasis on determining bankfull dimensions and Rosgen stream type may come at the expense of other important data-collection programs. It is estimated that between $28 million and $40 million (US$) has been spent for tuition and travel expenses for the roughly 14,000 students that have attended Rosgen 'natural channel design" courses. The 1990s in fact represent the first decadal period since inception that saw a decline in the number of gages in the U.S. Geological Survey (USGS) stream-gaging program. Although a direct causal relation cannot be substantiated, a recent survey of active stream gages operated by the USGS from 1989 to present, also shows this disturbing trend"* (p 1125). Are the authors actually implying that a possible reason the number of USGS gaging stations declined from 1989 to present is because funding was instead being applied to attend the courses I started teaching in the 1990s? To even infer such a relationship is contrary to responsible scientific reporting without any supporting evidence to infer such a claim.

TABLE 1. Various Opinions Expressed by Authors Compared to Supported Facts.

Opinion by Authors (page numbers referenced)	**Correct/ Incorrect**	**Fact with Literature Cited**
"A large part of the "natural channel design" approach is the heavy reliance of artificial structures within the newly designed channel." (p. 1118)	**Incorrect**	The heavy reliance is based on a detailed watershed and river stability assessment and the proper design of a dimension, pattern, and profile that matches the independent variables of the valley type, materials, boundary conditions, and the streamflow and sediment regime (Rosgen, 2006b, d, 2007). Structures are used for grade control, diversions, fish habitat, and near-bank stress reduction to buy time for streambank vegetation.
"The bankfull level in unstable streams can be exceedingly difficult to identify particularly in erosional channels (such as F and G types) because of a lack of depositional features and because channel dimensions…are changing with time." (p. 1118-1119)	**Correct**	This is precisely why USGS gages must be used to develop regional curves for bankfull discharge versus drainage area for given hydro-physiographic provinces (Phase II in NCD) (Rosgen, 1998, 2006e, 2007; USEPA, 2006)
Natural channel design using stream classification does not separate bank and bed material (p. 1119 and 1124) and therefore cannot be used in entrainment analysis	**Incorrect**	The active bed particle size on riffles is used to obtain relative roughness (velocity prediction) and for entrainment calculations (USEPA, 2006; Rosgen, 2001c, 2006e, 2007).
A gravel-bed channel with silt-clay banks might have a median diameter in the sand range and would classify as a C5 (p. 1119)	**Incorrect**	"In some bi-modal particle distributions the indexed D-50 particle may not even be present. In this case, the *dominant* particle size should be determined as that particle size which has provided the largest number of observations" (Rosgen, 1996, p. 5-26). Therefore, the channel would classify as a C4.
"C channel having bedrock banks…would be classified as C1." (p. 1119)	**Incorrect**	Cannot classify a channel without knowing bed material (Rosgen, 1994, 1996).
"When analyzing channel width as a function of discharge, a classification approach suggests that the variation in width is the result of a change in stream type." (p. 1120)	**Incorrect**	The delineation of stream types uses width/depth ratio, not width (Rosgen, 1994, 1996). There are many additional morphological variables that must change in addition to width/depth ratio to change stream type.
"Channel form…can be used in combination with other diagnostic characteristics of a stream system…to infer dominant trends in channel processes and response." (p. 1120)	**Correct**	This is what my methods entail in the four levels in the hierarchical assessment of channel morphology (Rosgen, 1994, 1996, 1998, 2001a, c, 2006a, b, d, 2007). Prediction and measurements of sediment and hydraulics are compared with form/processes. **See next row.**
Rosgen methods to "quantitatively predict channel adjustments" do not include rigorous analysis of channel processes and are flawed. (p. 1120)	**Incorrect**	Level II (morphological description of "form") is used in the <u>rigorous analysis of channel process in the Level III</u> stability assessment. A main objective of WARSSS (Rosgen, 2006e; USEPA, 2006) is to identify processes and land uses responsible for erosion, channel instability, and disproportionate sediment supply. The evaluation of the process and form interrelations are performed on both the reference reach and the impaired reach as standard procedure in NCD (Rosgen, 2006b, d, 2007).
The Goodwin Creek, Mississippi is an example of how using a reference reach in natural channel design would be untenable shown in Figure 3 (p. 1120)	**Incorrect**	*A Geomorphological Approach to Restoration of Incised Rivers* (Rosgen, 1997) involves a priority system that can be used in this example. Rosgen (1997) discusses the key information needed to restore natural stability and function in incised rivers, which includes understanding the watershed processes and causes of incision.
Using Rosgen stream classification, "channels are often forced to fit into *some*	**Incorrect**	The Rosgen stream classification was developed from morphological measurements of hundreds of rivers from

category of the scheme whether it is appropriate or not." (p. 1123)		1969 through 1994, indicating a trend of variables and their ranges that were then grouped into discrete channel types; they were not "force-fit" into arbitrary units. Rather, these stream types were derived through the integration of the boundary conditions and flow processes from which they were formed (Rosgen, 1996, 2006c). The morphological variables are **measured** to determine the stream type. A dual stream type (e.g., B4→G4) is designated when selected delineative variables overlap between types rather than "force" a classification category.
"The natural channel design approach bestows knowledge to the practitioner of how a given stream type will respond to a disturbance…[and is] flawed" (p. 1123). The authors support this claim by posing the question "For example, how would a stable C5 channel adjust to a disturbance?" and they present a model simulation.	**Incorrect**	In natural channel design, it is necessary to predict and understand how a channel responds to disturbance (Rosgen, 2007). The predicted response of an increase in streamflow on a C5 stream type requires an understanding of boundary conditions and analysis of shear stress, unit stream power, entrainment, the BANCS streambank erosion model where bank materials are explicitly considered, and the FLOWSED/POWERSED models (level III assessment) (Rosgen, 2006e; USEPA, 2006). Following this analysis, the channel evolution (successional scenario and stage) is predicted. Sufficient information is not presented in the authors' example to predict the channel response; however, it is not surprising to see the results of the model simulation where the resulting stream types would be classified as G5 and F5 (Table 2). Contrary to what the authors state, these channels would **not** be associated with an equilibrium condition as the streams are most likely shifting their dimension, pattern and profile to eventually reach a stable C5 stream type condition.
The Bank Erosion Hazard Index (BEHI) "is used only to qualitatively evaluate bank stability and does not enter into the design approach" (p. 1124)	**Incorrect**	The Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) quantitatively predicts streambank erosion rate in feet per year (Rosgen, 1996, 2001b, c, 2006e; USEPA, 2006). BEHI and NBS are used in NCD in Phase III and Phase V, step 8 of the 40-step procedure (Rosgen, 2006b, d, 2007). The BEHI and NBS variables are accounted for in NCD by intentionally designing a channel that has low BEHI and NBS ratings.
"Natural channel design methodology encourages the collection of field data, much of it centered on describing channel form at the bankfull stage." (p. 1125)	**Incorrect**	A review of the 40-steps in phase V in NCD reveals the inaccuracy of this statement (Rosgen, 2007, pp. 11-29 through 11-53). For example, sediment competence (entrainment) and transport capacity are assessed in Steps 23 through 27, which include measurements of bar sample, riffle bed material, and sediment size and load. The channel form at all flow stages is designed.
"the data required for evaluation of channel processes and stability does not provide all the information required to perform analyses of channel response and behavior. Instead, the data is used to make only qualitative evaluation of relative stability" (p. 1125)	**Incorrect**	Data requirements are listed in Rosgen (2006e, Table 5-1, p. 5-6) and USEPA (2006) to evaluate channel processes. The data is used in a quantitative evaluation of relative stability as depicted in the channel stability ratings in Rosgen (1996, 2001c, 2004, 2006e, pp. 5-145 through 5-152) and USEPA (2006). See Table 3 (Rosgen, 2003, 2006c, e; USEPA, 2006).
"The physics of erosion, transport, and deposition are the same regardless of what hydro-physiographic province one is in or what the stream type may be, because of the uniformity of physical laws" (p. 1129)	**Correct**	However, the rates, extent and consequence of erosion, transport, and deposition vary by stream type and the resultant stability predicted in the methods developed by Rosgen (2001a, b, 2006a, e; USEPA, 2006)

CHANNEL WIDTH VERSUS STREAM POWER

The authors argue that "*it is not entirely clear that classification systems are needed, or are misleading, as typical geomorphic analysis is sufficient to provide necessary information for quantifying geomorphic processes*" (p 1120). The authors support their argument by showing a relation between channel width and stream power from New Zealand streams for single and braided channels. For widths greater than approximately 300 meters and a corresponding stream power of 11,000 W/m, the streams become braided, which in Figure 1 in the article under discussion is titled "the continuum of channel width with stream power."

To address the relation presented, 45 river reaches spanning widths from 3m to 603m and slopes from 0.0001 to 0.251 located in New Zealand, Canada, and the United States were selected (Rosgen, 2006c). These data were plotted first using only width and corresponding stream power at high flows. A second relation was developed with the same data set by stratifying the streams into broad groupings (Level I) of A, B, C, and D stream types. Contrary to the inference presented by the authors, width was **not** the determinate relationship for stream power, as no relationships appeared (Figure 2; Rosgen, 2006c). Stratifying the streams into their respective morphological types, however, helped explain the scatter in the data (Figure 3; Rosgen, 2006c) by revealing trends within stream types. Thus, stream type can further explain variability within a large population. The A stream types that are steep with low width/depth ratios have the highest stream power for comparable widths of the other types. The B, C, and D stream types have subsequently lower values of stream power for similar widths. In the example used by the authors, stream power increased with width up to a threshold, then the morphology was braided at the greatest of both width and stream power values. This result might exist in a unique situation, but would not necessarily be a reasonable general relation as indicated in the contrast between Figure 2 and Figure 3. Without stratification by stream type, there is no relation between width and stream power in this data set.

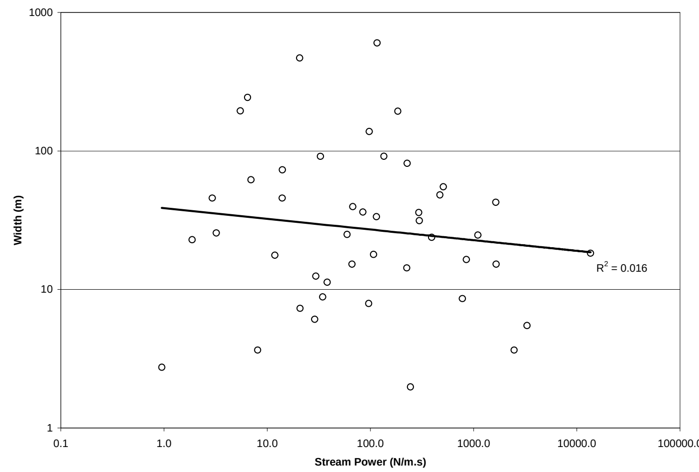

FIGURE 2. The Relationship of Width Versus Stream Power for a Variety of River Sizes at High Flows. Data from Barnes, 1967; Hicks and Mason, 1991; Annable, 1994; and Williams and Rosgen, 1989. From Rosgen (2006c; reprinted with permission of ASCE).

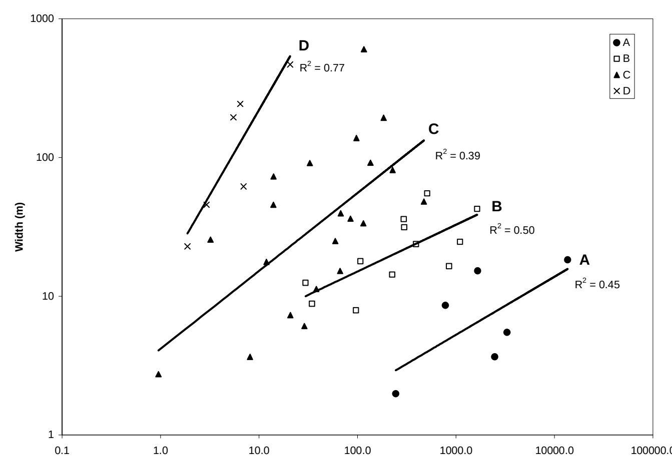

FIGURE 3. A Stratification of the Data in FIGURE 2 by Major Stream Type Showing Relationship of Width Versus Stream Power. From Rosgen (2006c; reprinted with permission from ASCE).

Furthermore, when willow spraying occurred on Weminuche Creek in Colorado, the stream widened due to increased streambank erosion (Rosgen, 2006c, e; USEPA, 2006). The stream width *increased* three-fold. The width/depth ratio increased from 22 to 233 and the stream type changed from a single-thread channel, C4, to a multiple-thread, braided D4 stream type. The stream power, however, *decreased* from 491 N/m to 348 N/m with unit power changing (power per unit width) 40.6 N/m/s to 5.5 N/m/s (Table 3). The *decrease* in stream power due to the *increase* in width at this reach caused the stream to aggrade. Following aggradation, the stream avulsed by cutting off 640 m of its length causing major incision. This change caused the stream to *decrease* width from 63.1 m to 5.5 m with a corresponding decrease in width/depth ratio of 233 to 5. The stream power *increased* with the corresponding width *decrease* from 348 N/m (5.5 N/m/s) to 1,651 N/m (300.2 N/m/s). The increased power resulted in a stream type change from a D4 (braided channel) to G4 stream type (incised gulley). The stratification and eventual change in stream type helps explain the relation between width and stream power as well as other hydraulic, sedimentological, and morphological variables (Table 3).

A quote from Kellerhals *et al.* (1976) is particularly appropriate here: "*Consistent river channel classification with emphasis on those aspects of river behavior that are most important in practical river engineering problems, is a pre-requisite to the study of river processes…any analysis of river behavior or publication of river data should be qualified by river type*" (Rosgen, 2006c).

The authors also state within their width versus stream power example that "*Classification approaches may even suggest that the D type channel "should" be "restored" to a C type channel*." Certainly not every braided (D) channel should be converted to a C type stream. In many cases, the D type is the stable form in Valley Types III (alluvial fans), IX (glacial outwash) and XI (Deltas) (Rosgen, 1994, 1996). One common landscape setting where this distinction is critical to recognize is where steep gradient tributary channels drop their coarse bedload as they enter a lower gradient valley floor. In these systems, an A3a stream type exists upstream of the fan in a Valley Type I, and the D channel immediately downstream in a Valley Type III induces deposition of the large boulders on a debris fan or cone. The deposition in this transition region between the steep-gradient tributary and the lower-gradient trunk stream (i.e., Valley Type II, colluvial; Type VIII, terraced/alluvial; or Type X, lacustrine) is necessary to maintain stability of the drainage networks. It is often practical to construct a D channel (which I have done) to match the stable form within a certain valley type to induce deposition of naturally occurring flood debris or excess sediment supply upstream from channels that would be negatively impacted or destabilized by the frequent addition of excess coarse bedload material and debris.

TABLE 3. Morphological, Hydraulic, and Sedimentological Data for Various Stream Type changes, Weminuche Creek, Colorado (Rosgen, 2003, 2006c, e; USEPA, 2006).

Stream Type	**C4 (stable)**	**C4 (unstable)**	**D4 (unstable)**	**G4 (unstable)**	**F4 (unstable)**
Bankfull discharge	11.3 m^3s^{-1}	11.3 m^3s^{-1}	11.3 m^3s^{-1}	11.3 m^3s^{-1}	11.3 m^3s^{-1}
Bankfull width	12.1 m	16.7 m	63.1 m	5.5 m	28.3 m
Bankfull mean depth	0.54 m	0.55 m	0.27 m	1.1 m	0.35 m
Width/depth ratio	22.4	30.4	233	5	81
Bankfull XS area	6.5 m^2	9.3 m^2	17.0 m^2	6.1 m^2	9.9 m^2
Bankfull max depth	0.88 m	0.82 m	0.70 m	1.8 m	0.73 m
Width flood-prone area	152 m	152 m	152 m	8.2 m	31.4 m
Entrenchment ratio	12.6	9.1	2.4	1.5	1.1
D_{15}	10.6 mm	9.4 mm	0.1 mm	20.0 mm	0.1 mm
D_{35}	19.7 mm	15.0 mm	0.1 mm	40.0 mm	6.0 mm
D_{50}	26.9 mm	19.8 mm	6.9 mm	52.0 mm	15.8 mm
D_{84}	52.5 mm	48.2 mm	28.8 mm	70.0 mm	38.2 mm
D_{95}	68.8 mm	61.3 mm	50.0 mm	95.0 mm	59.7 mm
Water surface slope	.0045	.0050	.0032	.0150	.0051
Bankfull mean velocity	1.7 m/s	1.2 m/s	0.64 m/s	1.86 m/s	1.2 m/s
Shear stress	23.9 N/m^2	26.8 N/m^2	8.6 N/m^2	161.4 N/m^2	14.4 N/m^2
Unit Stream Power	40.6 N/m/s	32.2 N/m/s	5.51 N/m/s	300.2 N/m/s	17.3 N/m/s
D_{50} bar	20 mm	12 mm	7 mm	n/a	7 mm
Largest particle on bar	75 mm	75 mm	10 mm	100 mm	16 mm
Relative roughness (D/D_{84})	10.4	11.4	9.4	15.7	9.2
Darcy-Weisbach friction factor (f)	0.0659	0.1067	0.3739	0.0972	0.1653
Friction factor (u/u*)	11.04	7.3	6.9	4.6	9.1
Roughness coefficient (n)	0.027	0.039	0.037	0.067	0.031
Sediment competence (largest size)	75 mm	24 mm	12 mm	400 mm	18 mm
Bedload transport rate (bankfull)	1.5 kg/s	1.3 kg/s	0.25 kg/s	4.2 kg/s	3.0 kg/s
Bedload yield (bankfull)	129.6 tonnes/day	112.3 tonnes/day	21.6 tonnes/day	363 tonnes/day	259 tonnes/day
Suspended sediment concentration (bankfull)	400 mg/l	500 mg/l	520 mg/l	750 mg/l	720 mg/l
Suspended sediment yield (bankfull)	476 tonnes/day	595 tonnes/day	619 tonnes/day	893 tonnes/day	869 tonnes/day
Total sediment yield (bankfull)	605 tonnes/day	707 tonnes/day	641 tonnes/day	1256 tonnes/day	1128 tonnes/day
Streambank erosion rate	0.03 tonnes/m/yr	0.04 tonnes/m/yr	0.9 tonnes/m/yr	3.5 tonnes/m/yr	1.8 tonnes/m/yr
Vertical stability process	**Stable**	**Slight Aggradation**	**Aggradation**	**Degradation**	**Aggradation**

UVAS CREEK, CALIFORNIA EXAMPLE

The authors use the failure of Uvas Creek, California to support their claim that "natural channel design" is flawed (p. 1120). However, the failure of Uvas Creek, California (Kondolf *et al*., 2001) cannot be attributed to natural channel design (Rosgen, 2006c). The river restoration designer was a landscape architect with no formal training or experience in NCD, and who chose to disregard the advice of trained peer-reviewers. The constructed channel had a width/depth ratio twice the value of the stable form of a C4 stream type, a flat gradient point bar, and a uniform grade (no differential between riffles/pools) (Rosgen, 2006c). No sediment competence or transport capacity was calculated, and the as-built channel differed substantially than what was even designed. This design violated the fundamental tenets of the NCD procedure, yet its failure was blamed on stream classification. Phase VIII in NCD (Rosgen, 2006b, d, 2007) involves designing a plan for effectiveness, validation, and implementation monitoring to ensure stated objectives are met, prediction methods are appropriate, and the construction is implemented as designed. This phase was also violated in the Uvas Creek project. Documentation was sent to the author M. Kondolf explaining how the failure cannot be attributed to the concept of a single-thread stable channel on March 15th, 2000 and May 3rd, 2000 by Steve Zembsch, involved in the project, who stated "This concept was never properly studied, designed, or installed." A letter sent to the City of Gilroy dated July 6, 1995 states specific concerns of the design plan and "that the drawings represent a project that will fail." Furthermore, Kondolf *et al*. (2001) noted that an underestimate of bankfull discharge might also have contributed to the failure. Given the history of assessment of this project, with which one of the authors (M. Kondolf) is intimately acquainted, and the long list of obvious design and construction errors, it is unconscionable for Simon *et al*. (2007) to assert that natural channel design or stream classification is to blame for project failure. Their discussion is one-sided and misleading.
When projects fail to meet stated objectives, I encourage reviewers to obtain and present all the facts and to make in-depth technical suggestions for improvement rather than <u>incorrectly assessing blame to a procedure that was not followed</u> (Rosgen, 2006c).

FORM VERSUS PROCESS

The authors state, "*Using channel form to quantitatively predict channel adjustments…is flawed*" (p. 1120). It is confusing to me how these authors can make such a statement then on the other hand say that the Simon and Hupp classification (1986) and other "*process-based classifications allow assessing likely future geomorphic conditions based on <u>current form</u>"* (p. 1121). Statements that stream restoration should avoid using form-based methods and instead use process-based approaches may confuse the issue. Form and process are not mutually exclusive; they are critically linked and must be used interchangeably (Rosgen, 2006c). "*The dimension, pattern, and profile of the river reflect the combined processes of adjustment which are presently responsible for the form and function of the river*" (Rosgen, 1996, p. 6-7). River morphology (form) reflects boundary conditions and flow processes (Rosgen, 2006c). Rivers having similar boundary and flow processes will have similar morphology, whereas variation in either boundary condition or flow process will alter channel morphology (Schumm, 2005). If boundary conditions change, such as willow spraying, the frictional resistance and stability of streambanks is reduced and channel adjustments occur as shown in Table 2 (Rosgen, 2006c). The example shown in Table 2 reflects the combined influence of boundary conditions on river morphology (form), which in turn effects the controlling processes and channel change consequences (Rosgen, 2006c).

The relations measured in Table 2 are just a few of many different examples of the interaction between stream classification (form) and process. <u>To accomplish NCD, one must use both form- and process-based approaches</u> (Rosgen, 2006b, d, 2007). For example, to my knowledge, no available analytical or process-based model predicts the depth and slope of runs and glides, transverse bar features, point bar slope, and other features of riffle/pool stream types such as a C4 (Rosgen, 2006c). To design and construct such features, dimensionless ratios and morphological relations of these bed features of similar stream types are used. This is a *form-based* calculation using analog methods from reference reach data by stream type and valley type. However, the final design is checked for hydraulic and sedimentological response using analytical approaches as part of the NCD procedure. There is currently no alternative to these form-based calculations in the design and construction of these features. For example, none of the existing "process-based" equations account for the effect of meandering, which can lead to major errors in slope and planform (Hey, 2004, 2006). Unfortunately, critics such as Simon *et al*. (2007) do not go beyond theory; they do not field test alternate design strategies that would improve the current state of the science of river restoration implementation.

NCD utilizes analog, empirical, and analytical methods to accomplish river restoration (Rosgen, 2006b, d, 2007). Regime equations became a logical alternative to rational approaches for design (Hey and Thorne, 1986). However, without a morphological stratification, regime equations can result in significant errors (Hey, 2004, 2006). Hydraulic relations stratified by stream type (Rosgen 1994, 1996, 2006c) depict the differences amongst streams to help minimize the variance for applications in design. In fact, a morphological stratification using width/depth ratio effectively explained variability in width versus discharge in Kansas streams (Osterkamp *et al*., 1983).

TABLE 2. Relation of Form and Process Variables and Consequence of Adjustment to Imposed Change in Stream Type (Morphology) (Rosgen, 2006c).

Stream Type Change Due to Disturbance	**Morphological (Form) Variable Change**	**Process Relations**	**Consequence of Adjustment And Channel Change**
1. C4 to D4 from willow spraying (boundary condition change)	• Width/Depth Ratio (*increased*) • Sinuosity (*decreased*) • Slope (*increased*) • Particle sizes of channel (*decreased*)	• Streambank erosion/lateral accretion *(accelerated)* • Relative roughness (*increased*) • Stream power (*decreased)* • Sediment competence (entrainment) (*decreased)* • Sediment transport capacity (*decreased*) • Aggradation • Channel Enlargement	• Land loss (*increased)* • Mean velocity *(decreased)* • Dissolved oxygen (*decrease*) • Flood risk (increase) • Aquatic habitat (*decrease)* • Stream stability *(decrease*)
2. C4 to G4 due to advancing headcut	• Width/Depth Ratio *(decreased*) • Sinuosity (*decreased*) • Slope (in*creased*) • Entrenchment ratio (vertical containment) (*decreased*) • Particle sizes of channel (increased) • Bank height ratio (incision ratio) (*increased*)	• Streambed and streambank erosion rate *(increased*) • Incision/degradation (*increased/ accelerated*) • Relative roughness *(decreased)* • Shear stress *(increased*) • Stream power (*increased)* • Sediment competence – critical depth computation (*increased/ exceeded)* • Sediment transport capacity (*increased in excess)*	• Land loss (*increased*) • Mean velocity *(increased*) • Lowering local baselevel/ abandoning floodplain • Land productivity • *(decreased*) • Aquatic habitat loss *(increased*) • Riparian vegetation (*decreased*)

STREAM SUCCESSION AND TEMPORAL AND SPATIAL SCALES

The authors do not appear to understand the objectives and use of the channel evolution scenarios (Figure 4) as they state that the approach "*does not quantify channel response and does not explain how and why these sequences of forms occur*" (p. 1123). Stream succession or channel evolution is part of the level III stability assessment where processes must be understood (Rosgen, 1996, 2001c, 2006e; USEPA, 2006). In regards to stream succession, "*the cause of the instability is as important to understand as well as the* *consequence*" (Rosgen, 2001c). Predicting the channel succession scenarios and associated stages follow the Level III stability indices, including streambank erosion prediction, sediment capacity, and sediment competence calculations (Rosgen, 2006e; USEPA, 2006). Stream channel succession is the result of adverse consequences of accelerated sediment supply, accelerated bank erosion rates, degradation, aggradation from channel disturbance, streamflow changes, and/or sediment budget changes that lead to channel change (Rosgen, 2006e, p. 2-44; USEPA, 2006). These changes result in stability shifts and adjustments leading to stream channel morphological changes and eventual stream type changes over time. Each stage of individual sequence in Figure 4 is associated with unique, quantitative relations of morphological, hydrological, and sedimentological functions (Table 3) (Rosgen, 2001a, 2003, 2006c, e; USEPA, 2006).

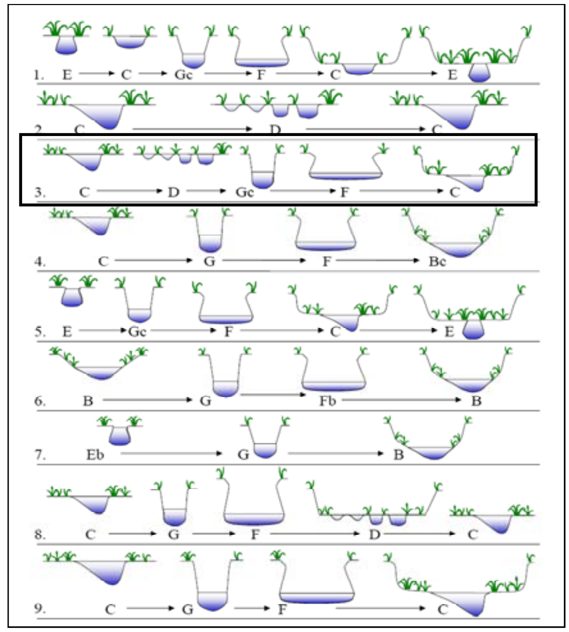

FIGURE 4. Various Successional Stage Scenarios Highlighting Scenario #3 for the Weminuche Creek Example (Rosgen, 2001a, 2003, 2006c, e, 2007; USEPA, 2006).

The authors cite Rosgen (1996, p. 6-8 to 6-9) who shows different evolutionary sequences for a disturbed E4 channel as an example of how channel evolution *"does not quantify channel response and does not explain how and why these sequences of form occur"* (p.1123). The evolutionary models of Rosgen (1996) were constructed from observations of real streams, just as were the models of Simon and Hupp (1986). Despite the contention to the contrary, the details of post-disturbance evolution of an E4 channel are detailed in Rosgen (1996, p. 6-7 to 6-9).

The authors also inaccurately state that "*Field data collected under the "natural channel design" methodology represents a single snapshot in time and utilizes a plethora of dimensionless ratios to describe relative channel stability with insufficient consideration for the spatial and temporal distribution of processes that control channel response in disturbed stream systems*" (p 1125). The sequences of stream succession depicted in Figure 4 (Rosgen, 2001a, 2003, 2006c, e, 2007; USEPA, 2006) are based upon observations of the temporal and spatial evolution of actual streams. Because these sequences of stream change have been seen repeatedly in the field, they represent an empirical basis for predicting the probable future states of a stream, much like Simon and Hupp (1986). However, the prediction of future stream types and condition cannot be made without investigating and understanding the landscape context of the stream in question.

The Weminuche Creek example documented in Rosgen (2006e, pp 2-76 to 2-93) and USEPA (2006) is indicative of channel change over a 12-year period and changes in major stream types at specific locations along its length. A wide range of stream type succession scenarios, noting the Weminuche example (scenario #3) is shown in Figure 4. These changes in stream type following disturbance represent the proper use of stream classification, knowing that channels have changed over time, as the data collected by stream type reflects the dynamic adjustment of the morphological, hydraulic, and sedimentological data (Table 2 and Table 3). A snapshot indeed only references the condition at that location in time, which is why a stability examination is completed as part of NCD. Using time-space substitution (Schumm *et al*., 1984), the data collected both upstream and downstream allows for an understanding of channel adjustment as stream types change over time and space. In the Weminuche Creek example, the C4 to D4 conversion created aggradation in the downstream direction, whereas the avulsion 600 m downstream created an incising gulley (G4 stream type) advancing headward. Over time, the G4 stream type widened to create an F4 stream type (entrenched, high width/depth ratio channel). Further downstream, and over several years, the channel is rebuilding a new C4 stream type and floodplain at a lower elevation than the pre-disturbance floodplain (now a terrace).

The interpretations of channel response based on morphological character (form) are appropriate as actual channel response is used to forecast changes spatially (upstream and downstream) and over time (based on similar time-trend rates). The change in form is predicted due to the anticipation of similar processes responsible for the change. I would *not* say this approach has "*insufficient consideration for the spatial and temporal distribution of processes that control channel response in disturbed stream systems,"* as stated by the authors.

Last, the authors provide aerial photos of Hotophia Creek in Mississippi and come to the conclusion that "*A "reference" reach, "natural channel design" approach would probably not be successful here*" (p. 1126). What scientific evidence and investigation did the authors use to make such a claim? If NCD "probably" wouldn't work, what method was evaluated that may "probably" work? Not enough evidence is presented on Hotophia Creek to even respond to the authors' claim. I am surprised to see such unsubstantiated statements published.

DISCUSSION AND SUMMARY

"*In modern science there is always some tension between the theoretical and the practical application of basic knowledge*" –Luna B. Leopold (In Rosgen, 1996, p. v). The extensive amount of untrue statements put forward by these authors as documented in Table 1, and throughout this discussion, is disturbing. Many of the statements, claims, and conclusions are inaccurate. The authors did not provide a thorough investigation of the methodology that they are claiming to have critically evaluated. The authors incorrectly concluded that the natural channel design method largely ignores that alluvial systems are open systems that adjust to altered inputs of energy and materials. Furthermore, the authors did not substantiate how the Rosgen classification and associated "natural channel design" methods fail to integrate and quantify fluvial processes and channel response. The results of this article are not responsible or reproducible, and did not result from a thorough investigation of the details in the methods published by Rosgen (1996, 1999, 2001a, b, c, 2004, 2006a, b, d, e, 2007) and USEPA (2006). The lack of proper scientific investigation into the method and the conversion of their opinions into formal statements without supporting data provide minimal benefit to improve the science of river restoration.

ACKNOWLEDGEMENTS

The author would like to thank Darcie Frantila for her contributions in the research of existing publications and the technical editing of this discussion paper and to Dr. Douglas Smith for his technical review of the manuscript.

LITERATURE CITED

Annable, E.D., 1994. *Morphological Relations of Rural Watercourses in Southeastern Ontario for Use in Natural Channel Design*. Master thesis, Univ Guelph, School of Engineering, Guelph, Ontario, Canada.

Barnes, H.H., 1967. *Roughness Characteristics of Natural Channels*. U.S. Geological Survey, Water Supply Paper 1849, 213 pp.

Hey, R.D., 2004. Evaluation of Natural Stable Channel Design Procedures. Presented at *ASAE Conference on Self Sustaining Solutions for Streams, Wetlands and Watercourses*, St. Paul, Minnesota.

Hey, R.D., 2006. Fluvial Geomorphological Methodology for Natural Stable Channel Design. *Journal of the American Water Resources Association* 42(2):357-374.

Hey, R.D. and C.R. Thorne, 1986. Stable Rivers with Mobile Gravel Beds. *Journal of Hydraulic Engineering*, ASCE, 112(8):671-689.

Hicks, D.M. and P.D. Mason, 1991. *Roughness Characteristics of New Zealand Rivers*. New Zealand Dept. of Scientific and Industrial Research, Marine and Freshwater, Natural Resources Survey, Wellington, New Zealand, 329 pp.

Kellerhals, R., M. Church, and D.I. Bray, 1976. Classification and Analysis of River Processes. *Journal Hydraulic Div. ASCE 102* (HY7): 813-829.

Kondolf, G.M., M.W. Smeltzer, and S. Railsback, 2001. Design and Performance of a Channel Reconstruction Project in a Coastal California Gravel-Bed Stream. *Environmental Management* 28(6):761-776.
Malakoff, D., 2004. The River Doctor. *Science* 305:937-939.
Osterkamp, W., L.J. Lane, and G.R. Foster, 1983. An Analytical Treatment of Channel Morphology Relations. U.S. Geol. Survey, Prof. Paper 1288, 21 pp.
Rosgen, D.L., 1994. A Classification of Natural Rivers. *Catena* 22:169-199.
Rosgen, D.L., 1996. *Applied River Morphology.* Wildland Hydrology Books, Pagosa Springs, Colorado.
Rosgen, D.L., 1997. A Geomorphological Approach to Restoration of Incised Rivers. In: *Proceedings of the Conference on Management of landscapes Disturbed by Channel Incision*, S.S.Y Wang, E.J. Langendoen, & F.D. Shields (Editors). University of Mississippi. Oxford.
Rosgen, D.L., 1998. The Reference Reach-A Blueprint for Natural Channel Design. In: *Engineering Approaches to Ecosystem Restoration (Proceedings of the Wetlands Engineering and River Restoration Conference)*, D.F. Hayes (Editor). American Society of Civil Engineers, Reston, Virginia.
Rosgen, D.L., 1999. Development of a River Stability Index for Clean Sediment TMDL's. In: *Proceedings of Wildland Hydrology*, D.S. Olsen & J.P. Potyondy (Editors), pp.25-36. American Water Resources Association, Herndon, Virginia.
Rosgen, D.L., 2001a. A Hierarchical River Stability/Watershed-Based Sediment Assessment Methodology. In: *Proceedings of the Seventh Federal Interagency Sedimentation Conference,* 2(2):97-106.
Rosgen, D.L., 2001b. A Practical Method of Computing Streambank Erosion Rate. In: *Proceedings of the Seventh Federal Interagency Sedimentation Conference,* 2(2):9-15.
Rosgen, D.L., 2001c. A Stream Channel Stability Assessment Methodology. In: *Proceedings of the Seventh Federal Interagency Sedimentation Conference*, 2(2):18-26.
Rosgen, D.L., 2003. A Critical Review of Stream Classification, Ph.D. Dissertation, Univ. East Anglia, Norwich, England.
Rosgen, D.L., 2004. Restoration WARSSS. In: *Self-Sustaining Solutions for Streams, Wetlands, and Watersheds, September 12-15, 2004.* American Society of Agricultural and Biological Engineers, St. Joseph, Michigan.
Rosgen, D.L., 2006a. FLOWSED/POWERSED: Prediction Models for Suspended and Bedload Transport. In: *Proceedings of the Eighth Federal Interagency Sediment Conference.* Subcommittee on Sedimentation, Reno, Nevada.
Rosgen, D.L., 2006b. River Restoration Using a Geomorphic Approach for Natural Channel Design. In: *Proceedings of the Eighth Federal Interagency Sedimentation Conference*, 1:394-401. Subcommittee on Sedimentation, Reno, Nevada.
Rosgen, D.L., 2006c. The Application of Stream Classification Using the Fluvial Geomorphology Approach for Natural Channel Design: The Rest of the Story. In: *Proceedings of the 2006 World Environmental and Water Resources Congress, May 21-25, 2006.* American Society of Civil Engineers, Omaha, Nebraska.
Rosgen, D.L., 2006d. The Natural Channel Design Method for River Restoration. In *Proceedings of the 2006 World Environmental and Water Resources Congress, May 21-25, 2006.* American Society of Civil Engineers, Omaha, Nebraska.
Rosgen, D.L., 2006e. *Watershed Assessment and River Stability for Sediment Supply (WARSSS).* Wildland Hydrology Books, Fort Collins, Colorado.
Rosgen, D.L., 2007. Chapter 11: Rosgen Geomorphic Channel Design. In: *Part 654 Stream Restoration Design National Engineering Handbook (210-VI-NEH)*, J. Bernard, J.F. Fripp & K.R. Robinson (Editors). USDA Natural Resources Conservation Service, Washington, D.C..
Schumm, S.A., 2005, River Variability and Complexity, Cambridge University Press, New York, 220 pp.
Schumm, S.A., M.D. Harvey, C.C. Watson, 1984. *Incised Channels: Morphology, Dynamics and Control*. Water Resources Publications, Littleton, Colorado.
Simon, A. and C.R. Hupp, 1986. *Channel Evolution in Modified Tennessee Channels.* Proceedings of the Fourth Interagency Sedimentation Conference, Las Vegas, Nevada, pp.2, 5-71 to 5-82.
U.S. Environmental Protection Agency (EPA), 2006. *WARSSS–Watershed Assessment of River Stability & Sediment Supply | EPA.* http://www.epa.gov/warsss/. Accessed 2006.
Williams, G.P., and Rosgen, 1989. Measured Total Sediment Loads (Suspended and Bedloads) for 93 United States Streams. U.S. Geol. Survey, Open File Report 89-67, Denver, Colorado, 128 pp.