Using Stream Channel Reference Data to Guide Land Management Decisions

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In order to make informed land management decisions, managers concerned with aquatic resources need information at a variety of scales. "Project level" decisions require fine-scale information relating to specific small watersheds or stream reaches, while planning level decisions require a characterization of broad scale patterns that will influence allocation and scheduling of activities. Quantified reference data can provide a basis for decisions at both scales by defining conditions that would exist in stream channels under the present climate and tectonic regimes in the absence of land management. At smaller scales, data from undisturbed reaches can be directly compared with similar managed reaches to determine departures from reference conditions, while at larger scales reference data from a number of reaches can be use to define desired conditions across a region.

Keywords: *reference reach, TMDL, forest planning, sediment, channel morphology*

Physical Setting

Most of the data for this study were collected on the Beaverhead-Deerlodge National Forest (B-D), covering approximately 3.4 million acres (1.4 million hectares) in southwest Montana. The region is bordered by the continental divide on the west, and contains the headwaters of four major river systems (Big Hole, Beaverhead, Madison and Ruby). Wide valley bottoms are separated by isolated mountain ranges. The valley bottoms of the major rivers are mostly in private ownership, with public land located at higher elevations.

The dominant physical realities of this region are high elevation and low precipitation. Valley bottoms are semi-arid, averaging about 5800 feet (1769 m) in elevation and receiving an average of 13.6 inches (34.5 cm) of precipitation a year. The mountains receive more precipitation (27.2 inches [69.1 cm] per year), with most of that in the form of snow. Overall, annual precipitation has averaged 20.4 inches (51.8 cm) since 1980.

Livestock grazing is the land use that most affects aquatic values on the Beaverhead-Deerlodge National Forest. Seventy-eight percent of the forest is located in grazing allotments. Roadless and wilderness areas account for 62% of the forest, so some of the more common effects to aquatics from roads, timber harvest, and mining are either isolated or minimal. There is a wide range of suitable rangeland contained within the allotments. Some allotments, mainly on the eastern portion of the forest, are predominately suitable, while others are heavily timbered with little suitable range.

Additional data were collected throughout the Greater Yellowstone Ecosystem, which stretches south and west of the Beaverhead-Deerlodge into Wyoming and Idaho. Some of the Ecosystem mimics conditions on the B-D, although precipitation levels are often somewhat higher.

Methods

A comprehensive stream channel survey was initiated on the Beaverhead-Deerlodge National Forest in 1991. The survey was designed to collect stream channel data that would characterize physical channel attributes at the reach scale. Survey sites were chosen to: 1) identify reference conditions; 2) identify problem areas for restoration; and 3) portray the range of stream conditions throughout the forest. The following parameters were measured as part of the standard survey:

1. A monumented cross-section depicting floodplain, bankfull elevation, water surface, and thalweg. The cross section is used to compute entrenchment and width-to-depth ratio. (Rod and level)
2. Sinuosity (Pacing)
3. Gradient (Rod and level)
4. Stream substrate (Wolman pebble count, Wolman 1954)
5. Fifty bankfull widths and depths (measuring rod)
6. Channel Stability Evaluation (Pfankuch 1975)
7. Bank Erosion Hazard Index (Rosgen 1996)
8. Valley Bottom Width (pacing)
9. Reach photographs
10. Notes describing overall conditions with respect to previous and current management effects.

M Furniss, C Clifton, and K Ronnenberg, eds., 2007. *Advancing the Fundamental Sciences: Proceedings of the Forest Service National Earth Sciences Conference, San Diego, CA, 18-22 October 2004*, PNW-GTR-689, Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

The sites are permanently established with painted rebar and surveyed to local benchmarks, usually a nail in a tree. Where applicable, measurement protocols given in Harrelson et al. (1994) were used.

By 2002, a total of 682 stream reaches had been measured throughout the forest. Forty-four percent of the total streams on the forest have at least one survey, with many streams having multiple sites. On average, 3.3 survey sites were measured per 6th-code HUC (Hydrologic Unit, or watershed). Measured sites were considered to be a "representative reach" (Gordon et al. 1992), and depict conditions along a greater length of stream channel. The survey sites depict conditions on 3.7% of the stream length on the forest. Of the 682 sites, 137 were determined to be in reference condition. These have been combined with an additional 78 reference sites measured throughout the Greater Yellowstone Area (GYA) in the summer of 2002 to create a reference dataset of 215 reaches. The dataset includes stream reaches that represent watersheds of a variety of sizes, geologies, and precipitation ranges.

THE USE OF REFERENCE REACH DATA IN PROJECT PLANNING (NEPA ANALYSIS)

Under the National Environmental Policy Act (NEPA), federal agencies initiating land management activities must complete an analysis to determine the effect of the project on the natural environment. The Affected Environment section of the NEPA analysis requires a determination of the existing condition before the effect of the proposed project is evaluated. One way to evaluate existing condition is to compare current conditions with reference data for similar sites (Frissell et al. 1986). The stream surveys enabled us to do this for the Beaverhead-Deerlodge National Forest.

The concept of using minimally disturbed sites as references has appeared in the literature in recent years (Dissmeyer 1994; Minshall 1994; Maxwell et al. 1995). Recent methodologies for analyzing watershed conditions (USDA et al. 1994, 1995; McCammon et al. 1998) recommend the use of reference watersheds as a means of determining the effects of land management

Reference reaches are matched with project reaches on the basis of the similarity of their valley bottom widths, valley bottom gradient, and the drainage area above the reach. Rosgen (1996) demonstrated that valley types provide an indication of stream channel morphology. Bengeyfield (1999) showed the relationship between valley features and drainage area to stream types for southwest Montana. Using a Classification and Regression Tree procedure (Brieman et al. 1984) and an earlier version of this data set, he used valley bottom width, valley bottom gradient, and drainage area to predict Level One stream types. A cross-validation procedure showed that E stream types, for example, were correctly predicted 89% of the time. Analyzing the data from the reference data set and project reach stream surveys produces a comparison table (Table 1).

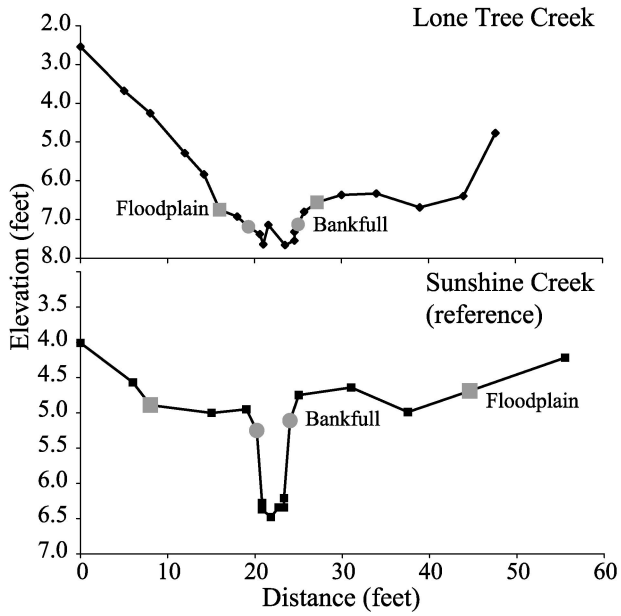
Table 1. Comparison of stream survey parameters between project reach (Lone Tree Creek) and reference reach (Sunshine Creek). * indicates data not collected.

Parameter	Lone Tree Creek	Sunshine Creek
Valley Bottom Width (VBW) (ft)	25	75
Valley Bottom Gradient (VBG) (%)	2.53	2.75
Area (acres)	1500	704
Stream Type	B4	E4
Entrenchment	1.96	9.63
Width/Depth Ratio	28.5	3.3
Sinuosity	1.05	1.8
Gradient (%)	2.41	1.53
D_{50} (mm)	30	13
W_{50} (ft)	3.7	5.9
Channel Stability	64 - Fair	48 - Good
BEHI	*	24.8

A comparison of the data for Lone Tree Creek (project) and Sunshine Creek (reference) shows that both valley bottoms are narrow and moderately steep, and their watersheds are small (Table 1). However, they contain different stream types (B4 vs. E4). Lone Tree Creek is more entrenched (1.96 vs. 9.63), wider and shallower (width-to-depth ratio = 28.5 vs. 3.3), straighter (sinuosity = 1.1 vs. 1.8), and steeper (gradient = 2.4 vs. 1.5) than the reference. It is not only wider at the cross section, but along the entire reach (W_{50} = 5.9 vs. 3.7). Lone Tree Creek is not as stable as Sunshine Creek. (Channel Stability = 64 vs. 48), and is more susceptible to streambank erosion (Bank Erosion Hazard Index [BEHI] = 30.5 vs. 24.8). The relationships between the project and reference reaches can be displayed graphically as shown in Figures 1 and 2.

An analysis of the data and graphs shows Lone Tree Creek differing from the reference for most of the stream parameters measured. The largest differences are in channel dimension, with somewhat smaller differences in pattern and profile. Lone Tree Creek is wider, straighter, and steeper than Sunshine Creek. Channel Stability and Bank Erosion Hazard reflect similar patterns. Notes taken onsite at the time of the survey indicate heavy trampling by livestock, willows that are in poor condition, and a species of sedge that increases with grazing pressure.

Figure 1. Cross-sections of Sunshine Creek (reference) and Lone Tree Creek (project).



By comparing onsite data from Lone Tree Creek to reference conditions, the departure from expected channel dimensions can be quantified and displayed graphically. In this case, the notes describe a disturbance (livestock grazing) that would logically produce the channel conditions measured, suggesting a cause/effect relationship for the existing condition. Similar effects due to grazing have been documented by Clifton (1989), Clary and Webster (1990), and Kovalchik and Elmore (1992). The data and analysis suggest there is considerable difference between the existing and desired conditions in Lone Tree Creek, necessitating a change in grazing management in order to restore reference conditions.

Lone Tree Creek is one of five reaches surveyed for the Antelope Creek Grazing Allotment. Employing reference data, site specific conditions were described for individual reaches and then compared to the reference data. This allowed departure from desired conditions to be displayed. By including these data in Chapter 3 of the NEPA document, the need for change was established, and an alternative was generated that prescribed more stringent standards for livestock management.

The Use of Reference Reach Data in a Regulatory Framework (TMDL Analysis)

In recent years, states have identified Water Quality Limited Segments (WQLS) as impaired water bodies that are in need of restoration in order to meet the requirements of the Clean Water Act. This process is designed to be quantitative, and specific levels of a pollutant are required to be met before the stream can be removed from the impaired list. The use of reference conditions is considered to be an acceptable concept for determining target levels of pollutants (EPA 1999). Furthermore, it is recommended that reference conditions be measured across a region to define variability (Frissel et al. 1986; Minshall 1994).

Data from the measurement of 215 reference reaches throughout southwest Montana and the Greater Yellowstone Ecosystem provides information that can be used to establish acceptable target levels for specific Rosgen stream types (Rosgen 1996). Figures 3 through 5 display cumulative distribution curves for substrate size and width/depth ratio derived from the reference data set for stream types B, C, and E.

For example, if a stream were placed on a state's 303(d) list as being impaired for sediment, and the impaired reach were a B4 stream type, then Figure 3 could be used to establish target levels for substrate distribution. If fine sediment were a concern, the target might be that only 16% of the substrate could be below 6 mm in size. If bedload transport were a concern, the D_{84} of the impaired reach might be targeted at 160 mm. Confidence intervals define acceptable range of variability for monitoring purposes.

If an E stream were placed on the 303(d) list for habitat alteration as a result of streambank alteration due

Figure 2. Cumulative distribution curve for bankfull stream widths for Sunshine Creek (reference) and Lone Tree Creek (project).

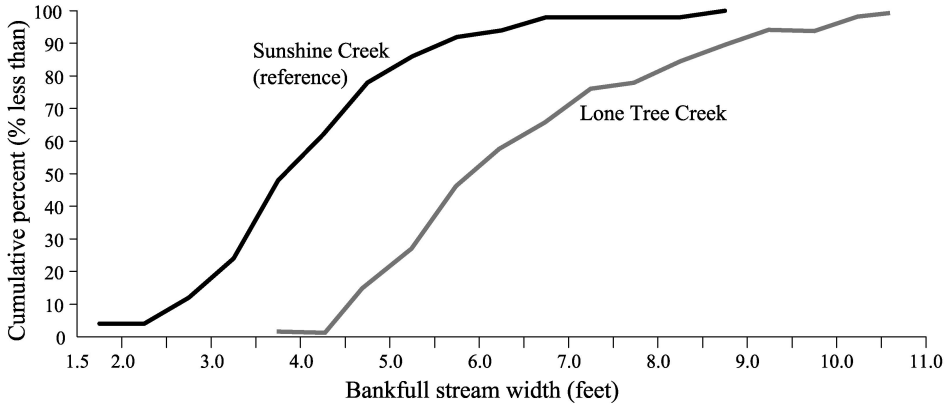
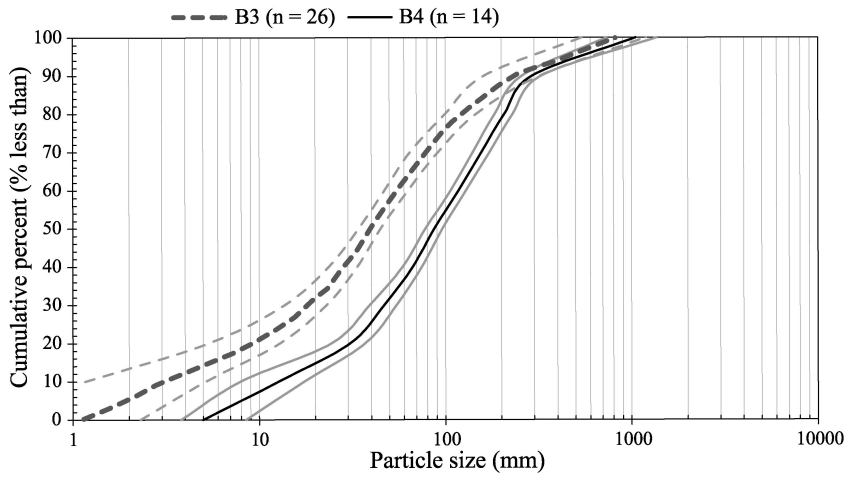


Figure 3. Particle size distribution, B stream types, with 95% confidence limits.



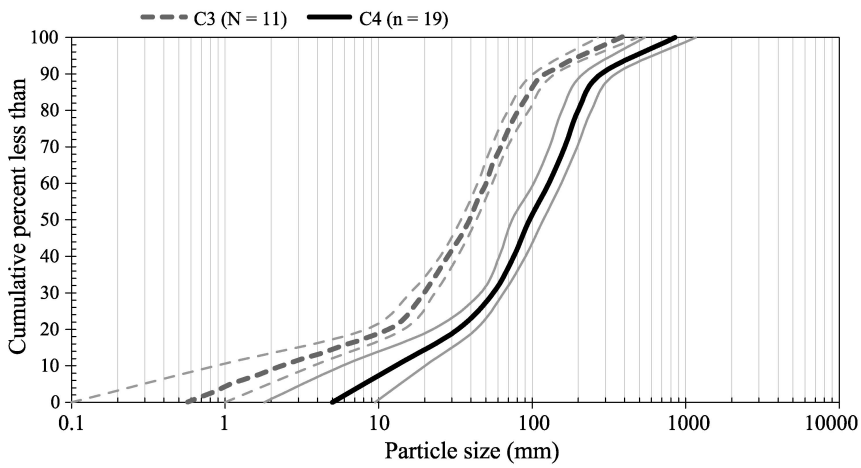


Figure 4. Particle size distribution, C stream types, with 95% confidence limits.

Figure 5. Particle size distribution, E stream types, with 95% confidence limits.

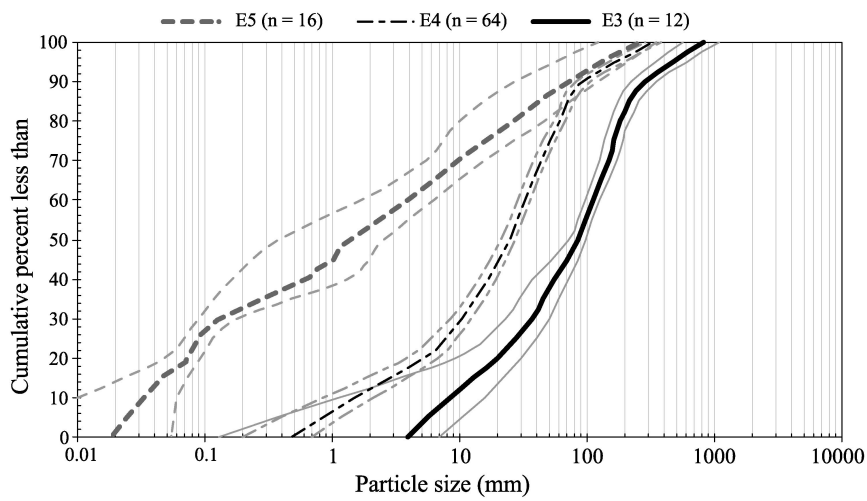


Table 2. Distribution of stream types in Beaverhead/Greater Yellowstone Area dataset.

Level 2 Stream Type	B Streams	C Streams	E Streams
2	1		
3	26	12	10
4	16	22	65
5		2	18
Ea			25

to livestock grazing, then a target might be established for width/depth ratio in order to restore overhanging banks. The distribution throughout the reach should be such that the average width/depth ratio should be about 3 to 3.5.

THE USE OF REFERENCE REACH DATA AT THE LANDSCAPE SCALE (FOREST PLANNING)

National Forests throughout the country are presently going through a revision of Forest Plans that were first completed in the 1980s. As part of that process, the Desired Future Condition (DFC) for individual resources must be described (CFR 219). For stream channels, a logical DFC would be to maintain the dimension, pattern, and profile that have been developed by natural flow regimes under the present climate and tectonic regimes. Reference reach data can help in describing these conditions and establishing goals for management.

The reference reach dataset for the Beaverhead-Deerlodge and Greater Yellowstone Ecosystem contains 215 reaches. These were stratified by stream type, with results summarized in Table 2. The B2 and C5 strata were dropped from further analysis because their sample size was too small. This left a reference dataset of 213 reaches. The remaining strata were subject to statistical analysis for mean, standard deviation, and 90% confidence interval (Table 3).

These data localize the Rosgen classification and can form the basis for describing DFC for each of the stream types. For example, for E stream types to maintain stable channels given the natural flow regime, they should have a width/depth ratio close to the mean for E stream types, in this case, 6. If the width/depth ratio of a given reach fell between 5.5 and 6.5, a manager could be 90%

Table 3. Statistics for reference reach strata representing various stream types. Confidence Intervals are all $\alpha = 0.1$. W/D ratio is width to depth ratio; % < 6mm is the percent of the substrate smaller than 6 mm in diameter; D_{50} is median particle size; D_{84} is the particle size 84% of the substrate is smaller than; W_{50} is average channel width; CS is the channel stability rating (Pfankuch 1975) ; BEHI is the Bank Erosion Hazard Index (Rosgen 1996).

Stream Type	Statistic	Entrenchment	W/D ratio	Sinuosity	Gradient	% < 6mm	D_{50}	D_{84}	W_{50}	CS	BEHI
B3	Mean					6	107	306			
N=26	SD						41	195			
	90% CI					3 - 8	120-94	369-243			
B4	Mean					17	41	148			
N=16	SD						18	70			
	90% CI					12 - 22	48-34	177-119			
Total B	Mean	1.7	13.3	1.22	0.039				13.4	64.7	25.5
N=42	SD	0.3	5.9	0.14	0.026				6.5	16.1	7.4
	90% CI	1.78 - 1.62	14.8 - 11.8	1.26 - 1.18	0.049-0.029				15.5-11.3	69.6-59.8	27.9-24.1
C3	Mean					5	91	206			
N=12	SD						29	84			
	90% CI					0 - 10	104-78	244-168			
C4	Mean					16	39	104			
N=22	SD						14	53			
	90% CI					13 - 18	44 - 34	133 - 85			
Total C	Mean	18.2	23	1.48	0.013				29.4	71.1	24.3
N=34	SD	16.6	11.9	0.35	0.014				19.5	18.8	6.8
	90% CI	22.8 - 13.6	26.2 - 19.8	1.57 - 1.39	0.017-0.009				41.4-17.4	82.5-59.7	28.5-20.1
E3	Mean					8	82	201			
N=10	SD						22	79			
	90% CI					0 - 18	93 - 71	160			
E4	Mean					22	25	70			
N=65	SD						16	45			
	90% CI					19 - 25	28 - 22	79 - 61			
E5	Mean					64		38.5			
N=18	SD						0.48	73.8			
	90% CI					60 - 71	0.54	67.1- 9.9			
Ea	Mean			1.25	0.062		0.69-0.27				
N=25	SD			0.21	0.022						
	90% CI			1.32 - 1.18	0.069-0.055						
Total E	Mean	11.1	6	1.6	0.017				6.6	62.5	20.9
N=118	SD	14.4	3.4	0.4	0.01				6.1	15.3	4.9
	90% CI	13.3 - 8.9	6.5 - 5.5	1.66 - 1.54	0.019-0.015				8.6-4.6	67.6-57.4	22.7-19.1

certain it was representing that mean. By describing each of the parameters in these terms, the DFC for that particular stream type can be described. How these data are eventually displayed in the Forest Plan will be determined in an interdisciplinary mode. For example, in the Rosgen classification, reaches that are slightly entrenched really have no upper limit on entrenchment ratio. Therefore, establishing a range of 13.6 to 22.8 for C reach entrenchment would be unrealistic and unnecessarily constraining. In this case, the DFC for C reach entrenchment might be better expressed as > 13.6.

Discussion

The measurement of a variety of physical parameters in watersheds that are undisturbed or minimally disturbed can be used to define physical stream conditions that reflect the present climate and tectonic regime of a region. If these measurements are used as references, land managers can estimate the dimension, pattern, and profile that would be the result of natural processes for stream channels within their area. By measuring the parameters that are used as delineative criteria in the Rosgen classification, stream types can be locally defined. For example, E stream types are defined in the classification system as having a width/depth ratio of less than 12. In the Greater Yellowstone Ecosystem/southwest Montana area, measurements of 118 E stream reaches show an average width/depth ratio of 6. Consequently, if a given E reach had a width/depth ratio of 10, and the stream banks were trampled by livestock, that reach might be determined to be trending away from stability as a result of getting wider and shallower.

These data can be used at various scales depending on the situation. For NEPA documents, where very site specific data is required to characterize stream conditions, reference and project reaches may be matched based on valley bottom characteristics. Demonstrating the difference between reference and project conditions will give the manager an idea of the status and trend of streams in the project area and how they may respond to a proposed action. On the Beaverhead-Deerlodge National Forest, NEPA documents have incorporated this approach since 1997.

In the TMDL arena, targets for parameters that define the condition of a stream with respect to beneficial uses must be established. Reference data, sampled throughout the area, can help define the conditions whereby beneficial uses can be expected to be self-maintaining. In Montana, the Ruby River and Yaak River TMDLs are presently using reference data to help establish targets for sediment and channel dimensions. At the Forest Planning scale, Desired Future Conditions define the hoped for end result of a suite of management operations over the entire forest. In past planning efforts, the DFCs for streams were often simple narratives that were neither quantitative nor measurable. The ability to gather reference data over a wide geographic area and a variety of stream types allows the DFC for each stream type to be described in a manner that provides the land manager a picture of the conditions that should exist regardless of the suite of management activities applied to the land. In the Forest Plan Revision process, the Beaverhead-Deerlodge National Forest is basing its DFCs for aquatics on local reference data. Across all scales, the ability to quantify standards, targets, and DFCs, makes any subsequent monitoring program more effective.

Reference data can provide land managers timely and excellent information with which to make decisions. However, they are not a panacea, and should not be applied in a vacuum. The need for professional interpretation at all levels of analysis is paramount. Choosing individual reference reaches, setting confidence limits, establishing acceptable risk, and determining the relative importance of different types of reference data, all require field-based knowledge of the watersheds in question. Rather than dogmatically establishing limits to management, reference data should be looked on as a tool that enables specialists to make better recommendations, and allows managers to gain a better understanding of how aquatic systems work.

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