WATER RESOURCES BULLETIN
VOL. 28, NO. 4 AMERICAN WATER RESOURCES ASSOCIATION AUGUST 1992

VARIATION OF STREAM STABILITY WITH STREAM TYPE AND LIVESTOCK BANK DAMAGE IN NORTHERN NEVADA[1]

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ABSTRACT: Many natural and anthropogenic factors contribute to the stability or erodibility of stream channels. Although a stream rating procedure used by more than 60 percent of the U.S. National Forests provides an estimate of overall stability, it does not identify the cause of instability or indicate corrective management. To better sort natural from livestock influences, stream stability rating indicator variables were related to stream types and levels of ungulate bank damage in a large data base for streams in northern Nevada. Stability and the range in stability varied naturally with stream type. Ungulate bank damage had different effects on different stream types and on different parts of their cross-sections. Vegetation is more important for stability on certain stream types than on other types. Streams with noncohesive sand and gravel banks are most sensitive to livestock grazing. Range managers should consider the stream type when setting local standards, writing management objectives, or determining riparian grazing strategies.

(KEY TERMS: livestock grazing impact; stream stability; sediment supply; riparian vegetation; aquatic ecosystems; watershed management; wildland hydrology; nonpoint source pollution.)

INTRODUCTION

The stability of stream channels and banks substantially affects the quality of riparian and aquatic habitats. Stream stability depends on stream morphology, basin geology, and channel material. Different sizes of stream channel materials vary in stability because of varying resistance to detachment (Simons and Senturk, 1976; Stelczer, 1981). Stream stability also depends on the type, density, and quality of riparian vegetation (Shen, 1971). Experiments in Alberta showed that a soil volume with 16 to 18 percent root volume had 20,000 times the resistance to erosion as did banks without roots (Smith, 1976). Soil samples with more than 3 mm/mm^3 of roots or rhizomes were essentially unerodible in a flume wall at a relatively high tractive stress (Kamyab, 1991). Livestock trampling and grazing has been shown to decrease bank stability by removing vegetation (Hubert *et al.*, 1985; Marlow and Pogacnik, 1985; Platts, 1981) and affect the stream bottom by adding finer grained materials from bank erosion (Myers and Swanson, 1991).

The U.S. Forest Service published a method for rating the stability of streambanks and channel bottoms in 1975 (Pfankuch, 1978). The procedure uses 15 somewhat subjective indicators to evaluate stability across a stream cross-section. The stated purpose of this procedure is "to systemize measurements and evaluations of the resistive capacity of mountain stream channels to the detachment of bed and bank materials and to provide information about the capacity of streams to adjust and recovery from potential changes in flow and/or increases in sediment production" (Pfankuch, 1978, pg. 1).

The Pfankuch (1978) stream stability rating (SSR) procedure is used by interagency stream survey crews in Nevada. SSR is also used by over 60 percent of all national forests for cumulative impact analysis (Parrott *et al.*, 1989). For example, the Eldorado National Forest in California uses the rating to determine a threshold of concern when evaluating the impact of management activities (Kaplan-Henry, 1987). The Bureau of Land Management also uses the procedure to study impacts of land use and potential for stream recovery (Gradek *et al.*, 1989). Despite its widespread agency use, no published study specifically evaluating the procedure or the individual indicators has been located. In the scientific literature, the rating has been used to explain variation in stream macroinvertebrate populations (Collier and

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[1] Paper No. 91106 of the *Water Resources Bulletin*. **Discussions are open until April 1, 1993.**

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Winterbourne, 1987; Newbold *et al.*, 1980), in the size of summer and winter Dolly Varden *Salvelinus malma*) parr populations affected by logging in Alaska (Murphy *et al.*, 1986), and in the stability differences between old growth and clear cut sites (Murphy *et al.*, 1986).

Rosgen (1985) introduced a stream classification method based on channel and floodplain morphology. Stream classification can be used to compare and contrast stream behavior from appearance among similar streams. The purpose of this research is to analyze the variation of the SSR indicator variables with respect to stream type (Rosgen, 1985) and level of ungulate bank damage (USFS, 1985) for data collected on northern Nevada rangeland streams. The results will aid range riparian managers by indicating which stream types and indicators of stream stability are more sensitive to grazing. This research also provides an overall critique of the rating system as applied to northern Nevada range streams.

METHOD OF ANALYSIS

Data Base

Survey crews supervised by the Nevada Department of Wildlife (NDOW) and including employees of the U.S. Bureau of Land Management and Forest Service (USFS) collected the data base analyzed in this study. It was collected from four northwestern Nevada mountain ranges: the Carson, Sweetwater, and Toiyabe Ranges from 1978 to 1981 and the Santa Rose Range from 1986 to 1988. The Carson and Sweetwater Ranges are eastern extensions of the Sierra Nevada Range. The Toiyabe and Santa Rosa Ranges are typical basin and range mountains of the Great Basin. The riparian community types occurring along these streams were classified by Manning and Padget (1992). The collection period covers climatic and streamflow extremes with record spring floods in 1983 and 1984 and severe drought in 1978 and 1988. Previous studies (Myers, 1990; Myers and Swanson, 1991) using different indices of stability from this data base did not find a major change in instability or aquatic habitat condition index between the 1978-81 and 1986-88 sampling periods.

The crews estimated SSR ratings, level of ungulate bank damage, and, since 1986, stream type along 724 200-foot stream reaches, or sampling units. The senior author revisited the units surveyed prior to 1986 to assign stream types and over 50 units surveyed after 1986 to spot check the surveyors' stream typing. Stream selection was not random because the crews chose all streams expected to contain trout. The selection of sampling units on each stream was nearly random. The precise locations depend on accessibility with the most downstream unit located at a canyon mouth or confluence and the upper end located near the upstream extent of fish populations. Separation between units varies from approximately one-half to one mile with more frequent sampling on rapidly changing streams.

The stream type procedure (Rosgen, 1985) uses hydraulic gradient, sinuosity, width/depth ratio, bed material size, valley confinement, and landform feature erodibility to classify streams. The analyzed data base includes nine different stream types commonly found in northern Nevada (Table 1 and Figure 1).

The level of ungulate (predominantly cattle) bank damage (Table 1) is a subjective rating based on observed signs of current grazing, trampling, and trailing (USFS, 1985). The bank damage level does not represent previous damage indicated by increased channel width and downcutting caused by historic grazing. No attempt was made to correlate these ratings to actual numbers of animals or other grazing management practices because of the impossibility of obtaining meaningful data. While actual dates vary, grazing seasons are generally in summer due to the harsh winter climate. To a limited degree, wildlife, such as deer, could have made some of the bank damage; however, elk are rare or absent in these ranges. The number of sampling units in each category generally decreases from Level 4 (no or light damage) to Level 1 (excessive damage; Figure 1).

The stream stability rating consists of 15 individual indicator variables from the upper and lower channel banks and the channel bottom, respectively. The survey crews rate each indicator excellent, good, fair, and poor based on Pfankuch's (1978) methodology. Numerical values assigned to each rating reflect the weight of their importance assumed by Pfankuch (1978). The numerical values are summed to determine ratings for the upper and lower channel banks, the channel bottom and the overall rating (Table 2).

Contingency Table Analysis

Data collected define the observations for a cross-classification, or contingency table, of stream type, level of ungulate damage, and SSR condition. Because the categories are both exhaustive and mutually exclusive, the data represents a multinomial distribution. The analysis assumes that observed SSR conditions (are response classifications and) result from stream type and level of ungulate bank damage (which are explanatory categories; Fienberg, 1980).

TABLE 1. Stream Types[1] and Levels of Ungulate Bank Damage[2] Used in This Study.

Type	General Description of Stream Type
A2	Stable, steep (≥0.04) boulder and cobble channel in depositional landforms with steep side slopes, very deep and very well confined.
A3	Erodible, steep (≥0.04), coarse-grained channel with some fines in coarse depositional landforms with steep side slopes, very deep and very well confined.
A4	Erodible, steep (≥0.04) fine-grained channel in very steep depositional landforms, very deep and very well confined.
B1	Stable moderate-gradient (0.025-0.04) small boulder channel in stable coarse-grained landforms, moderately entrenched and confined.
B2	Stable moderate-gradient (0.015-0.04) cobble and coarse gravel channel in moderately steep coarse depositional landforms, moderately entrenched and confined.
B3	Unstable moderate-gradient (0.015-0.04) cobble-bed channel with a mixture of gravel, sand, and small boulders in coarse depositional landforms with unstable banks, moderately entrenched and well confined.
B4	Unstable moderate-gradient (0.015-0.04) gravel, sand, and silt channel in fine-textured noncohesive depositional landforms, deeply entrenched and well confined.
C3	Low-gradient (0.005-0.01) gravel-bed channel with low terraces and fine-textured unstable banks, moderately entrenched and slightly confined.
C4	Low- gradient (0.001-0.005) sand-bed channel with low terraces and depositional fine-grained banks, moderately entrenched and slightly confined.

Level	General Description of Ungulate Bank Damage
1	Excessive damage – 76-100 percent bank damage, severe erosion and sloughing over entire bank because of completely damaged vegetation, no recovery, erosion constant.
2	High damage – 51-75 percent from heavy ungulate use, moderate to high bank erosion and sloughing, grazing does not allow plant biomass recovery to 50 percent bank stability.
3	Moderate damage – 26-50 percent ungulate damage, some erosion and sloughing, < 1/2 of potential plant biomass remains.
4	Light to no damage – partial or no evidence of bank damage, 0-25 percent ungulate use, little or no erosion or sloughing, near natural vegetation.

[1] After Rosgen (1985).
[2] After USFS (1985).

Various models of independence and interaction are fit to a three-way contingency table (Everitt, 1977; Fienberg, 1980). This analysis determines the interactions of the categories (T for stream type, L for level of ungulate bank damage, and S for SSR) for explaining the number of observations fitting the given cross-classification. The hierarchy analyzed is complete independence of categories ([T] [L] [S]) interaction of just one pair of categories ([TL] [S]), interaction of two pairs of categories ([TL] [TS]) or [TL] [LS]), interaction of all three possible pairs ([TL] [TS] [LS]), and interaction of all three variables ([TLS]). The best model was chosen from the hierarchy using the likelihood test statistic (Fienberg, 1980) at a level of significance equal to or greater than 10 percent. The minimum level of significance between hierarchic levels is 1 percent. The likelihood test statistic (Equation 1) was chosen because it is more conservative for this data base.

$$G^2 = 2 \sum (Observed) \ln \left(\frac{Observed}{Expected} \right) \qquad (1)$$

Two-way analysis tests the hypothesis of independence between stream type and SSR variables for natural variation without ungulate damage (Level 4). Also, two-way analysis tests the hypothesis of independence between SSR variables and levels of ungulate bank damage for each stream type to show which stream types are most susceptible to damage. The independence hypothesis is rejected at less than the

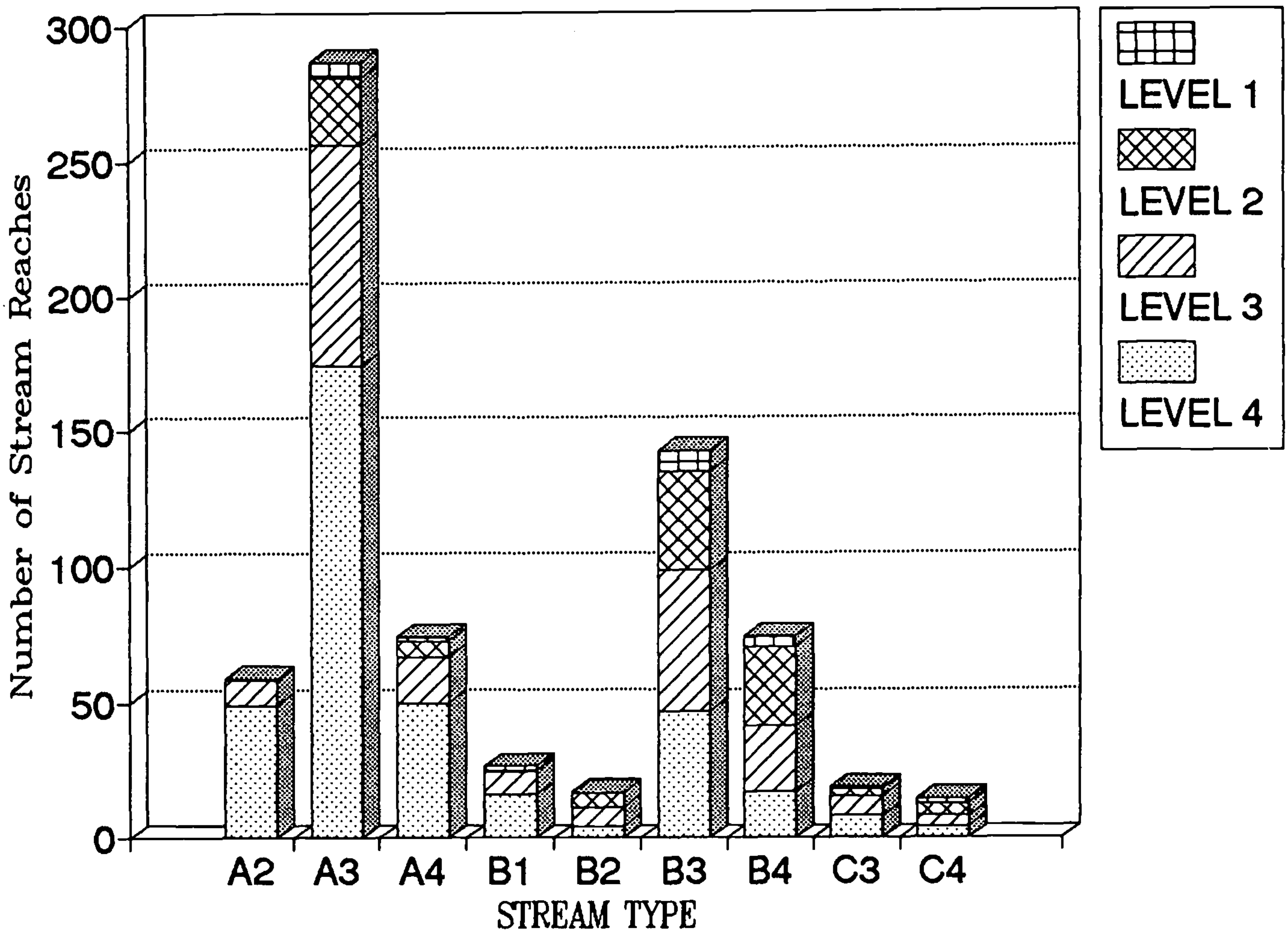

Figure 1. Distribution of Stream Types and Ungulate Bank Damage Levels Among the 721 Analyzed Stream Reaches.

TABLE 2. Stream Stability Rating Indicator Variables.

Number	Indicator Variable	Rating of Indicator Variables			
		Excellent	Good	Fair	Poor
1	Landform Slope	1-2	3-4	5-6	7-8
2	Mass Wasting or Failure	1-3	4-6	7-9	10-12
3	Debris Jam Potential	1-2	3-4	5-6	7-8
4	Vegetative Bank Protection	1-3	4-6	7-9	10-12
5	Channel Capacity	1	2	3	4
6	Bank Rock Content	1-2	3-4	5-6	7-8
7	Obstructions and Flow Deflectors	1-2	3-4	5-6	7-8
8	Cutting	1-4	5-8	9-12	13-16
9	Deposition	1-4	5-8	9-12	13-16
10	Rock Angularity	1	2	3	4
11	Brightness	1	2	3	4
12	Consolidation or Particle Packing	1-2	3-4	5-6	7-8
13	Bottom Size Dist. and Percent Stable Materials	1-4	5-8	9-12	13-16
14	Scouring and Deposition	1-6	7-12	13-18	19-24
15	Clinging Aquatic Vegetation	1	2	3	4
16	Upper Banks (Sum of 1-4)	4-10	11-20	21-30	31-40
17	Lower Banks (Sum of 5-9)	5-12	13-24	25-36	37-48
18	Channel Bottom (Sum of 10-15)	6-15	16-30	31-45	46-60
19	Total SSR (Sum of 1-15)	15-38	39-76	77-114	115-148

10 percent level of significance. The tables are collapsed around zero-sum marginal totals to eliminate expected values less than 1.0 thereby improving the precision of the test statistic (Fienberg, 1980).

Observer Variation

Precision of the individual indicator variable estimate of streambank stability from a narrative description may be low (Platts *et al.*, 1983). Platts *et al.* indicate that subjective estimates vary because of changes in observers, observers' thinking, applicability of the procedure, weather conditions, stream size, experience, training, and the degree of instability.

An attempt to quantify the variation among observers was made by traveling with the interagency crew for one week in August of 1989 in the Trout Creek mountains of northern Nevada. During this week, most of the five crew members and the senior author rated a total of six sampling units resulting in six individual ratings for four units, five ratings for a fifth unit, and four ratings for a sixth unit. Experience of the crew members varied from novice to several years of inventory.

To estimate variation among observers, transect ratings were combined for analysis of each indicator variable. Because the sampling units varied in stability, the mode of the ratings varied among units, and a simple multinomial distribution of the categories was not possible. The mode for an indicator variable is the rating at each unit selected most frequently. The analysis, therefore, determined the number of individual ratings that selected the mode for each observation as well as the number of ratings that differed by one, two, and three categories. For example, if the mode for a unit is a good rating, all excellent and fair ratings count as a variation of one category from the mode.

RESULTS AND DISCUSSION

Of the individual indicators, the channel capacity showed the highest observer variation followed by brightness and cutting (Table 3). These indicators are the most nebulous and evidently have the least precision. The least variation occurred on vegetative bank protection, bank rock content, bottom size distribution, and clinging aquatic vegetation. These all require observing the existence or estimating the percent of something obvious. Variation decreases when several indicator variables (numbers 16, 17, 18, and 19) are summed.

TABLE 3. Observer Variation[1] for the SSR Indicator Variables.

Indicator Variable[2]	Categories from the Mode			
	Mode	1	2	3
1	60.6	21.2	15.2	3.0
2	60.6	33.3	6.1	0
3	60.6	39.4	0	0
4	69.7	30.3	0	0
5	48.5	45.5	6.1	0
6	75.8	21.2	3.0	0
7	63.6	33.3	3.0	0
8	57.6	39.4	3.0	0
9	63.6	36.4	0	0
10	66.7	27.3	6.1	0
11	54.5	36.4	9.1	0
12	66.7	30.3	3.0	0
13	75.8	15.2	9.1	0
14	63.6	27.3	9.1	0
15	75.8	21.2	3.0	0
16	72.7	27.3	0	0
17	81.8	18.2	0	0
18	72.7	27.3	0	0
19	87.9	12.1	0	0

[1] Values are the percentage of observers who chose the most frequent category (mode) or categories away from the mode.

[2] Table 2 provides definitions of the indicator variable numbers.

Lower test statistics (G^2) indicate better fits of the chosen models for the three-way contingency table analysis of SSR indicator variables (Table 4). The presence of the interaction [TL] for every indicator variable indicates a relation between stream type and ungulate damage. This is explained by the fact that many A-type streams are too steep for access by domestic livestock. Given the stream type, seven stability variables were independent of damage: debris jam potential, bank rock content, obstructions, deposition, percent stable materials, scouring and deposition, and lower banks SSR. Thus, management of grazing activities might have no on-site effect on these stability indices on some stream types. Note that many of these variables have relatively large "weights" associated with them.

In the two-way analysis, higher test statistics (G^2) suggest dependence between SSR ratings and stream type for units not showing much evidence of ungulate bank damage (Table 5). The probability indicates the chance that the categories are independent. Note the independence with stream type for cutting, rock angularity, scouring and deposition, and channel bottom SSR. Similarly, low probabilities suggest dependence of an SSR indicator variable and ungulate bank damage for individual stream types (Table 6). All indicator variable ratings for the highly erodible, sandy bottom type B4, the stable, boulder bottom A2 and the stable, boulder/cobble bottom B2 channels are independent of ungulate bank damage.

TABLE 4. Results of Three-Way Contingency Table Analysis.

Indicator[1] Variable	Model[2,3]	df	G^2	Probability
1	[TL] [TS] [LS]	72	76.4	0.34
2	[TLS]	0	0.0	1.00
3	[TL] [TS]	81	84.7	0.37
4	[TL] [LS]	96	109.0	0.17
5	[TL] [TS] [LS]	72	71.1	0.51
6	[TL] [TS]	81	78.4	0.56
7	[TL] [TS]	81	94.3	0.15
8	[TL] [TS] [LS]	72	88.2	0.10
9	[TL] [TS]	81	79.3	0.53
10	[TL] [S]	105	104.7	0.44
11	[TL] [TS] [LS]	72	68.1	0.61
12	[TL] [TS] [LS]	72	69.4	0.56
13	[TL] [TS]	81	88.4	0.27
14	[TL] [TS]	81	86.9	0.31
15	[TL] [TS] [LS]	72	64.8	0.72
16	[TLS]	0	0.0	1.00
17	[TL] [TS] [LS]	54	65.4	0.14
18	[TL] [TS] [LS]	48	41.2	0.75
19	[TL] [TS] [LS]	48	52.2	0.31

[1] Table 2 provides definitions of the indicator variable numbers.

[2] T = stream type; L = ungulate damage level; S = indicator variable rating.

[3] The specified model is the chosen significant model for each indicator variable.

TABLE 5. Maximum Likelihood Statistic for the Variation of Indicator Variables with Stream Type.

Indicator Variable[1]	G^2	Probability[2]
1	70.9	0.00
2	41.5	0.01
3	40.1	0.02
4	44.3	0.01
5	53.0	0.00
6	77.8	0.00
7	43.4	0.01
8	27.4	0.39
9	49.0	0.01
10	29.8	0.19
11	39.4	0.02
12	52.0	0.00
13	46.1	0.00
14	32.5	0.12
15	42.7	0.01
16	25.8	0.06
17	34.4	0.01
18	23.4	0.10
19	30.2	0.02

[1] Table 2 provides definitions of the indicator variable numbers.

[2] Underlined probabilities indicate significant variation of the indicator variable with stream type.

TABLE 6. Probabilities[1] for the Variation of Stream Stability Indicator Variables with Ungulate Bank Damage.

Indicator Variables[2]	Stream Type								
	A2	A3	A4	B1	B2	B3	B4	C3	C4
1	0.84	0.02	0.07	0.47	0.37	0.33	0.33	0.21	0.22
2	0.34	0.00	0.45	0.06	0.71	0.90	0.30	0.06	0.01
3	0.94	0.01	0.59	0.40	0.17	0.52	0.50	0.82	0.43
4	0.60	0.00	0.02	0.24	0.44	0.04	0.11	0.08	0.53
5	0.36	0.02	0.37	0.27	0.58	0.14	0.49	0.34	0.70
6	0.79	0.07	0.03	0.82	0.95	0.42	0.61	0.45	0.85
7	0.15	0.08	0.34	0.07	0.97	0.16	0.50	0.80	0.34
8	0.69	0.15	0.01	0.80	0.92	0.09	0.44	0.14	0.02
9	0.86	0.64	0.55	0.18	0.76	0.30	0.12	0.63	0.39
10	0.99	0.52	0.87	0.64	0.91	0.18	0.80	0.84	0.06
11	0.19	0.01	0.19	0.70	0.96	0.01	0.24	0.20	0.42
12	0.82	0.22	0.44	0.87	0.66	0.01	0.12	0.19	0.60
13	0.86	0.10	0.06	0.83	0.81	0.08	0.31	0.93	0.16
14	0.79	0.44	0.59	0.06	0.48	0.39	0.34	0.37	0.28
15	0.72	0.03	0.39	0.68	0.27	0.34	0.49	0.55	0.05
16	0.44	0.01	0.26	0.52	0.80	0.76	0.33	0.08	0.01
17	0.22	0.28	0.04	0.25	0.93	0.67	0.14	0.24	0.58
18	0.91	0.12	0.18	0.78	0.73	0.47	0.13	0.41	0.08
19	0.92	0.22	0.02	0.45	0.89	0.23	0.18	0.03	0.34

[1] Underlined probabilities indicate significance at 10 percent.

[2] Table 2 provides definitions of the indicator variable numbers.

Individual Indicator Variables

The following discussion of individual indicator variables is based on the significant relations in Tables 4, 5, and 6. The paragraph numbers refer to variable numbers described in Table 2.

1. Landform slope classifies the slope of the upper banks with steep slopes rating poor based on the fact that steep slopes should experience more erosion. Landform slope varied significantly with stream type because confinement and, therefore, landform slope, is a determinant of stream type. Landform slope varied significantly with ungulate bank damage for stream types A3, A4, C3, and C4 and also in the three-way model. Observed data for stream type A3 indicates an improvement in the indicator variable (slope decreases) as ungulate damage increases (Figure 2). Livestock trampling may contribute to decreased slope; however, livestock are better able to graze on streambanks with naturally mild slopes. The same pattern is observed on types C3 and C4; however, the sampling units with no ungulate bank damage, but steep upper bank slopes, suggest recovering downcut streams (Swanson, 1989).

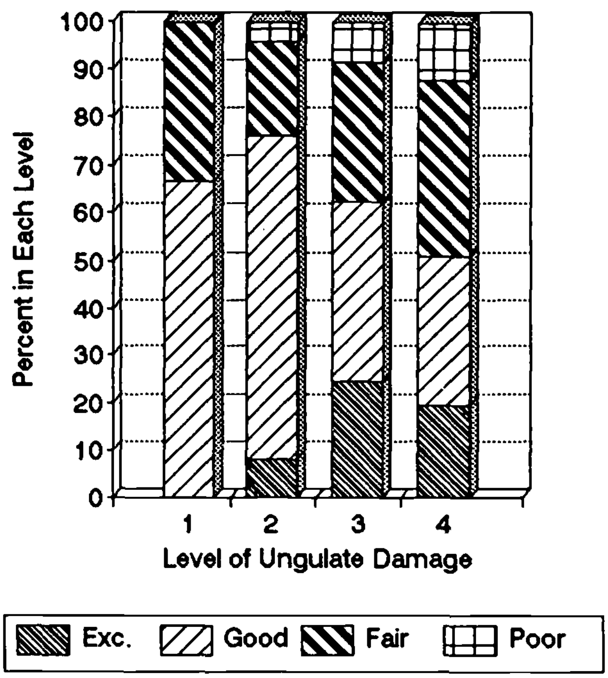

Figure 2. Variation of the Condition of Landform Slope Over Levels of Ungulate Bank Damage for Stream Type A3.

2. Mass wasting hazard, the potential and tendency for mass soil movements on the upper channel banks, depended on the interaction among all three variables. Mass wasting varied significantly with stream type because streams confined in erodible materials (A3 and A4 and, to a lesser extent, B3 and B4) are naturally subject to mass wasting, usually at long return intervals (Cooke and Warren, 1973). Ungulate damage decreases natural stability as suggested by the significant variation for stream types A3, B1, C3, and C4. Type A3 has steep, unstable upper banks. Types C3 and C4 have unstable, low, upper banks with broad floodplains. Type B1 is significant because, in the data base, there is an excellent observation for damage level 2 which caused a high test statistic that should be rejected. This analysis suggests that mass wasting depends on natural instability and increases due to disturbance by livestock grazing on susceptible stream types. On naturally unstable stream types (A4, B3, and B4), bank damage may not significantly increase instability.

3. Debris jam potential rates the amount of and tendency for debris on the upper banks to float into the main channel and cause jams. It varied significantly with stream type because natural debris depends on vegetation type which varied with stream type (Myers and Swanson, 1991). Debris jam potential varied significantly and negatively with ungulate bank damage on type A3. This suggests that livestock grazing removes the source of the debris or that excess debris discourages cattle from grazing some reaches.

4. Vegetative bank protection rates the amount of vegetation and other nonerodible cover on the upper banks. It varied with stream type in the two-way analysis, but is independent of stream type in the three-way analysis. This implies a relationship with stream type in the absence of ungulate damage. It also related to the observed variation of vegetation type with stream type (Myers and Swanson, 1991). Ungulate damage probably magnified the high natural instability of vegetation on the upper banks of stream types A3, A4, B3, and C3, and apparently masked the effect of stream type in the three-way analysis.

5. Channel capacity rates the ability of the stream to contain flood flows and depends on the width/depth ratio. The significant variation with stream type reflects the width/depth ratio of the stream which is a classification parameter for stream type. The significant variation with respect to ungulate damage for A3 streams is curious because the width/depth ratio for this stream type is less than 10, an excellent or good rating. Observations reveal a distinct shift from excellent ratings for level 4 to fair and good ratings for levels 1-3, which explains the statistic (Figure 3). This

result indicates that ungulate damage increases the width, and that not all streams with steep gradient have a low width/depth ratio.

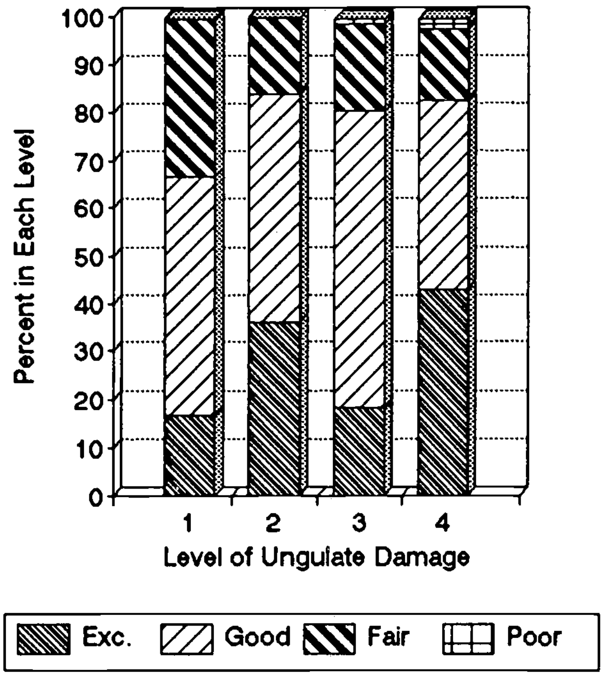

Figure 2. Variation of the Condition of Channel Capacity Over Levels of Ungulate Bank Damage for Stream Type A3.

6. Bank rock content is a qualitative estimate of the size and quantity of rock in the lower banks. The variation of this indicator variable with stream type was highly significant because bank material is a criteria for stream type. The three-way model shows independence from ungulate bank damage; however, variation is significant with ungulate bank damage for types A3 and A4 in the two-way model. Many sampling units on stream types A3 and A4 rated excellent because they are in decomposed granitic landforms (in the Carson Range), which contain much avalanche and landslide debris. The banks contain boulders and rocks which lead to the excellent ratings even though they mostly disintegrate when they reach the channel bottom. Also, these units were not grazed; therefore, the excellent ratings coincided with damage level 4. This resulted in a significant relation not caused by, but merely coincidental to, ungulate bank damage.

7. Obstructions and flow deflectors, the amount of and tendency for deflectors to cause erosion or sedimentation, varied significantly with stream type in the two-way model and is independent from ungulate damage in the three-way model. The rating apparently depends on the source of material, boulders, and vegetation, which varies with stream type (Knighton, 1984; Myers, 1990).

8. Cutting rates the amount of scour on the lower banks and varied significantly with ungulate damage for types A4, B3, and C4. Observer variation was high, which may mask the expected variation with stream type. The effect of grazing overcame observer variation on only the most fine-grained stream types with naturally unstable banks. High, natural instability of type B4 apparently was not increased by grazing.

9. Deposition of sediment on the lower channel banks, which may accompany upstream cutting, varied significantly with stream type. This is presumably due to the stream gradient and width/depth ratio differences among stream types. The increased frequency in the data of fair and poor ratings of type C3 and C4 streams (which have low gradient and high width/depth ratios) supports this presumption. These results suggest that deposition depends on sediment transport conditions on site, as well as sediment supply conditions throughout the entire watershed.

10. Rock angularity estimates the amount of wear as represented by the amount of rounding and smoothing on the stream bottom particles. The premise is that, as rocks move, the angularity of particles decreases, which decreases their ability to interlock. There is no indication of the time since rock movement. The only significant variation was with ungulate damage for stream type C4, which is a spurious result because type C4 is a sand bed channel and there should be few rocks to rate.

11. Brightness of the stream bottom indicates movement of the stream bottom by the absence of algal and other staining agents when the bottom appears bright. Brightness varied with stream type and with ungulate damage level for stream types A3 and B3. Disturbance of A3 and B3 streams, which have coarse but unstable and confining upper banks, is likely to add fresh (bright) bedload sediment.

12. Consolidation is a measure of particle packing which is due, in part, to particle shape, sediment load, and time since bedload moving flood events. The significant variation among stream types may have resulted from differing channel materials, gradient, width/depth ratio, and channel roughness which relate to sediment supply and deposition. Inclusion of the [LS] term in the three-way model suggests slight livestock effects over the whole data base.

13. Bottom size distribution requires estimation of shifts from the natural variation of size distribution of the channel bottom materials. The significant variation with stream type resulted from types A4, B4, and C4 having had a majority of fair ratings while

other types rate good. This suggests observer error because they may have associated sand and small gravel (the dominant bed material for these types) with shifts in material distribution. Bottom size distribution varied with ungulate bank damage for types with naturally unstable banks (A3, A4, and B3) indicating that livestock use increased sedimentation in the unit.

14. Scouring and deposition rates the amount of these processes occurring on the unit. Presence of both is a poor rating; the absence of both is an excellent rating. Scouring and deposition was not independent from stream type. The significant variation with ungulate damage of type B1 resulted from an anomalous excellent observation with level equal to 2 and should be rejected.

All of the streams in the data base are small, and most of the surveys occurred after the spring snowmelt period. Small streams in baseflow do not move much sediment; hence, streams that were unstable during high flow conditions may appear stable when observed in the summer. Scour holes are not obvious in a gravel bed. Frequently, holes scoured during a rising hydrograph fill during recession; therefore, the surveyor never sees evidence of scour. Deposition may not be observed on steep streams when the bed material is of the same size. Apparently, seasonality of scour and the difficulty of identifying new deposition prevents this indicator variable from being a useful indicator of stability.

15. Clinging aquatic vegetation indicates stability because of the time required for vegetation to establish. The indicator varied significantly with stream type and with ungulate bank damage for stream types A3, B2, and C4. Fine grained streams (B4 and C3) with few surfaces (cobble and boulders) exhibited mostly fair and poor ratings and did not vary with ungulate damage. Stable streams with large material (A2, B1, and B2) mostly rated good and excellent. Type A3 contains some large surfaces and the ratings tend toward fair with increasing damage. The trend on C4 streams was toward increased clinging vegetation with damage which may be due to increased algae due to the lower gradient.

Summation Indicator Variables

16. Upper bank is the sum of the four upper bank indicator variables. The second order interaction among all variables is significant, which parallels the result for mass wasting. The significance with ungulate damage for unstable types A3, C3, and C4 emphasizes their sensitivity. The significant variation with ungulate damage was due to a slight improvement from level 3 to level 4 that was not attributable to any one of the individual indicators. The stability of the upper banks should vary with stream type (Rosgen, 1985). The naturally unstable types, A4 and B3, rated mostly fair or poor without ungulate bank damage so that, overall, the level of ungulate bank damage did not influence this summation indicator variable. Debris jam potential and upper bank slope had good or excellent observations for these stream types with heavy ungulate bank damage. Because the relations for any given variable could not explain the variation of the entire upper bank, instability apparently results from different upper bank variables for different stream types.

17. Lower bank is the summation of the five indicator variables for the lower banks. It varied significantly with stream type, but with ungulate damage only on stream type A4. This suggests that, although livestock apparently affect individual SSR indicator variables (channel capacity and cutting), morphologic parameters represented by stream type such as steepness, soil type, and vegetation type control the overall stability rating of the lower banks.

18. Channel bottom is the summation of the six indicator variables for the channel bottom. It varied significantly with ungulate bank damage only on stream type C4 in the two-way analysis. The three-way analysis shows all interactions are significant. The majority of sampling units without ungulate bank damage (206 of 376 units) rated fair. Over all units, 419 of the 724 sampling units rated fair. The proportion rating fair or poor increased less than 20 percent with increasing ungulate damage (Figure 4). All indicator variables in this summation variable, except clinging aquatic vegetation, show the majority of observations in the good range. As the indicator variables are summed, the final conclusions about the stream tend toward poorer conditions (see the next subsection).

19. The overall SSR was significant for stream type and for ungulate damage for types A4 and C3. The majority of observations tended to be fair (63 percent over the total data base) with a small increase in poor and decrease in good ratings with increasing ungulate damage (Figure 5). This tendency toward fair ratings indicates a bias in the method. The procedure tends to rate the total SSR poorer than indicated by the ratings of individual indicator variables (Figure 6). For example, if 14 indicator variables rate good and just one rates fair, the overall rating is fair because the scores on the field survey form represent the lower end of the category. An example that holds for all categories and indicators is mass wasting. The category for excellent is a score of 1 to 3. The field form shows excellent equals a value of 3. The observer must cross out 3 and rate the indicator variable 2 to obtain a rating in the middle of the category. While

this is encouraged in the manual for the procedure (Pfankuch, 1978), it was rarely done by field crews on this study.

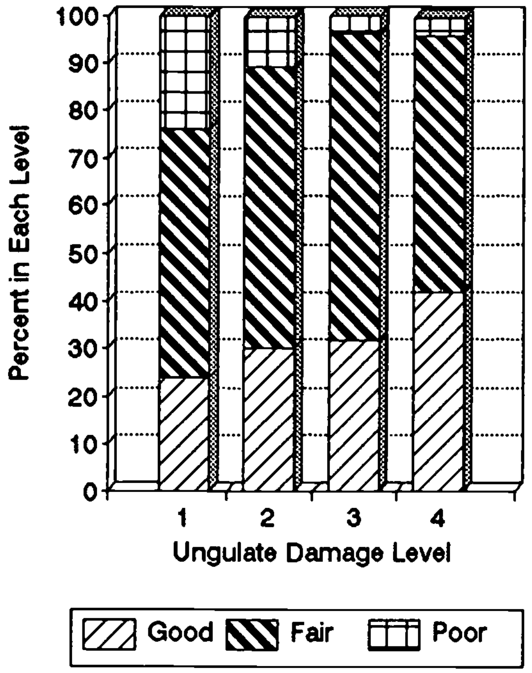

Figure 4. Variation of the Condition of Channel Bottom Over Levels of Ungulate Bank Damage for the Entire Data Base..

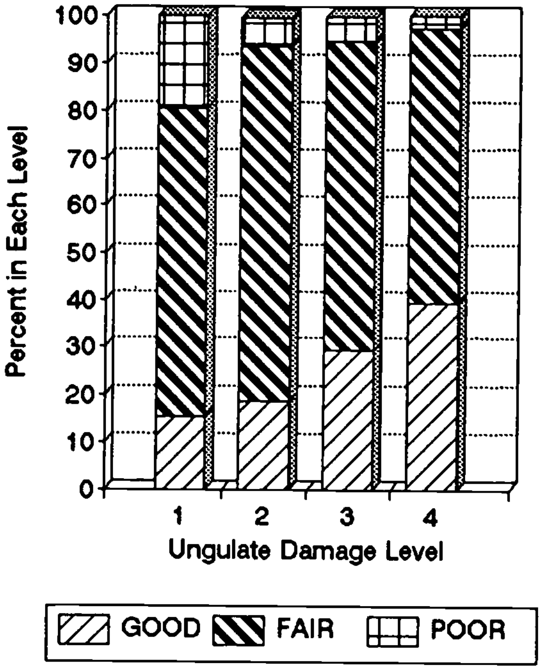

Figure 5. Variation of the Condition of the Total SSR Over Levels of Ungulate Bank Damage for the Entire Data Base.

CONCLUSION

Overall, stream type was the most significant determinant of stability, and livestock affected certain stream types much more than others. Stream types A3, A4, B3, C3, and C4 were the most sensitive to ungulate bank damage of the types studied. Stream types A2, B1, and B2 were less sensitive. Stream type B4 is already so unstable that grazing did not significantly worsen the conditions.

The decrease in significance of summation indicator variables with ungulate bank damage indicates that different indicator variables were important for different stream types. Improved management for individual indicator variables among specific stream types and reaches should improve the overall rating on site and downstream.

This research suggests three possible changes in the rating procedure. First, the indicator rock angularity should be eliminated because of its variation with basin parameters that do not influence stream stability. Second, scouring and deposition should be separated as in cutting and deposition. A stream rarely scours and deposits in the same short reach. Third, the scores indicated should reflect the middle of the category. As an example, the scores for mass wasting should be 2, 5, 8, and 11 instead of 3, 6, 9, and 12. Also, the observers should be encouraged to rate streams more flexibly by scoring between the values on the form.

Management based on the results of the total stream stability rating may be missing significant problem areas. Because the majority of streams in this study area rate fair overall without regard to ungulate bank damage, the rating system is insensitive to problems of rangeland streams. The proposed changes may alleviate some of these problems. However, a complete tool should be developed for the purposes this one is being used for, inventory and allocation of various management inputs.

Variation among stream types is highly significant for the vast majority of the stream stability rating indicator variables. Stream type is therefore important for estimating potential response to management of a stream reach. It could also be used as the tool for comparing reaches along a stream or within a watershed or other management unit. Comparison of streams or stream reaches is necessary to allocate scarce funds to achieve maximum effort through land management. A means for optimizing management is to apply different management practices with specific objectives to priority stream reaches.

Management objectives should be derived after first understanding the potential of the stream reach to respond to alternative management practices or

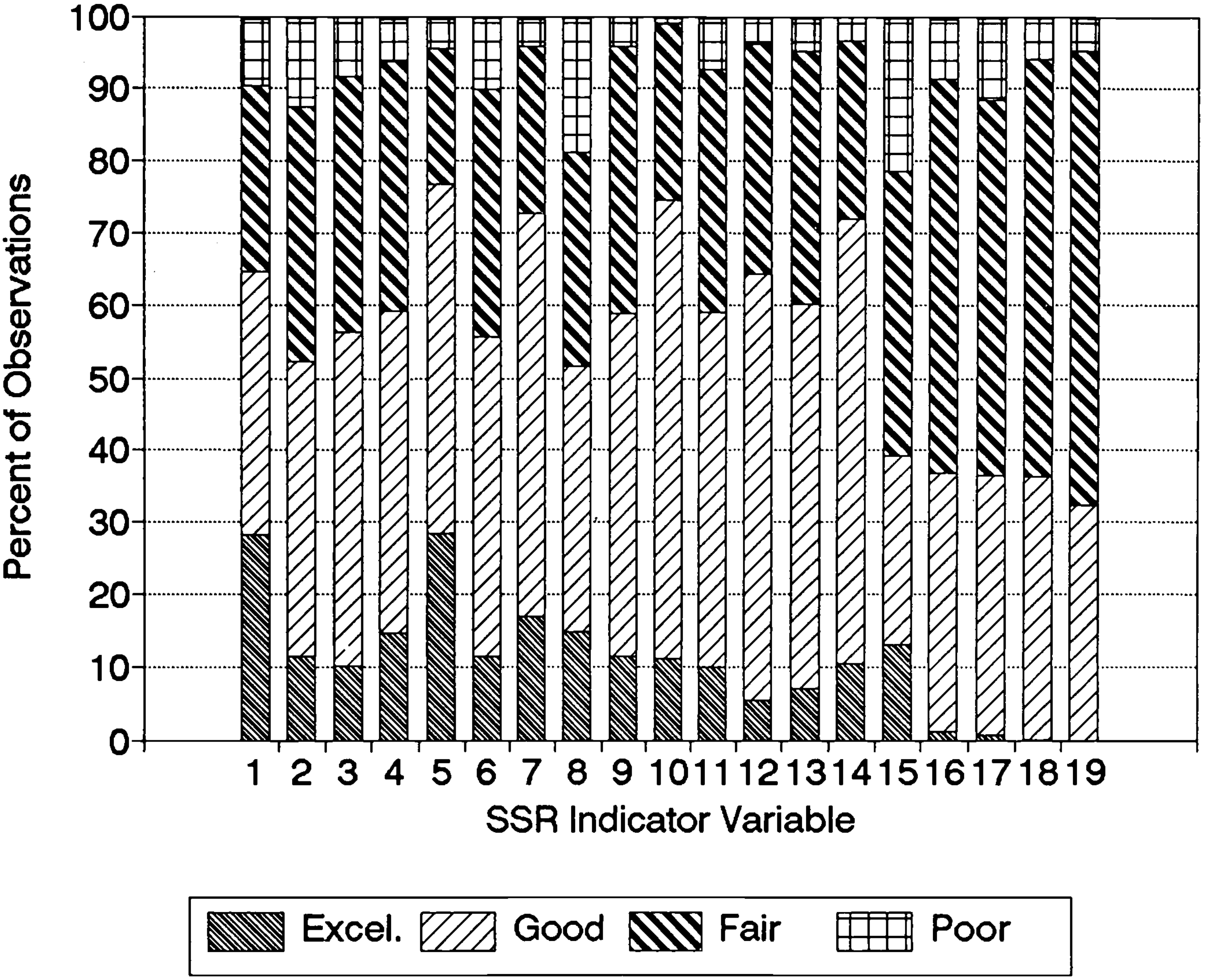

Figure 6. Distribution of Condition Over All SSR Indicator Variables for the Entire Data Base (see Table 2 for the definition of the indicator variables).

standards. Analyses of existing data, such as this study, should provide good insight for understanding streams in specific geologic and/or climatic regions. Additional studies of the vast SSR data base should aid land managers in writing management objectives. These objectives should be worded so that it is clear what changes to expect. Individual SSR indicator variables may be appropriate examples, but the total SSR does not suggest specific desirable changes.

ACKNOWLEDGMENTS

This research was made possible by a grant of Wallop-Breaux funds from the Nevada Department of Wildlife supplemented with funds from the Intermountain Region of the USDA Forest Service and the Nevada Agricultural Experiment Station Project No. 635. Special thanks are due to Pat Coffin, Leroy McClelland, Ralph Phenix, Don Duff, Elizabeth Jacobson, and G. Fred Gifford for assistance or review.

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