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TEMPORAL AND GEOMORPHIC VARIATIONS OF STREAM STABILITY AND MORPHOLOGY: MAHOGANY CREEK, NEVADA[1]

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ABSTRACT: Detailed studies of long-term management impacts on rangeland streams are few because of the cost of obtaining detailed data replicated in time. This study uses government agency aquatic habitat, stream morphologic, and ocular stability data to assess land management impacts over four years on three stream reaches of an important rangeland watershed in northwestern Nevada. Aquatic habitat improved as riparian vegetation reestablished itself with decreased and better controlled livestock grazing. However, sediment from livestock disturbances and road crossings and very low stream flows limited the rate of change. Stream type limited the change of pool variables and width/depth ratio, which are linked to gradient and entrenchment. Coarse woody debris removal due to previous management limited pool recovery. Various critical-element ocular stability estimates represented changes with time and differences among reaches very well. Ocular stability variables tracked the quantitative habitat and morphologic variables well enough to recommend that ocular surveys be used to monitor changes with time between more intensive aquatic surveys.

(KEY TERMS: watershed management/wildland hydrology; stream morphology; aquatic habitat; rangeland streams; grazing.)

INTRODUCTION

Studies have linked channel shape and form to bank stability (Millar and Quick, 1993), vegetation density (Smith, 1976; Graf, 1978; Rosgen, 1994), vegetation type (Zimmerman *et al.*, 1967; Murgatroyd and Ternan, 1983; Osterkamp and Hupp, 1984), and flow deflectors (Lisle, 1986). There is much evidence that livestock grazing affects all of these environmental factors and channel geometry (Gunderson, 1968; Platts and Nelson, 1985; Myers and Swanson, 1991 and 1992; Williamson *et al.*, 1992). As streams continue to degrade, public awareness of the need for healthy riparian zones continues to increase (Bren, 1993).

There has been much research devoted to measuring channel instability as represented by bank erosion (Lawlor, 1993), but much less devoted to indicators of conditions of stability. The U.S. Forest Service developed an ocular stream stability rating (SSR) system in 1975 (Pfankuch, 1978) to predict which streams were susceptible to perturbation. This methodology has been used by 60 percent of all national forests (Parrott *et al.*, 1989) and is still in common use (Kaplan-Henry *et al.*, 1994; USFS, 1992). This methodology rates overall stability by rating numerous individual indicators of stability. Several studies have used the SSR to establish stability conditions for aquatic resource study sites (Collier and Winterbourne, 1987; Murphy *et al.*, 1986; Newbold *et al.*, 1980). By applying this methodology on a large data base in Nevada, Myers and Swanson (1992) found that effects of ungulate damage on channel stability varied with stream type. However, their SSR data base was not replicated in time, and trend of and relationships with aquatic habitat variables were not tested.

The Summit Lake watershed in northwestern Nevada became a management priority to the U.S. Bureau of Land Management (BLM) because of the listing as threatened of the Lahonton cutthroat trout (USFWS, 1992) in the early 1970s. The BLM changed management by building a watershed exclosure on Mahogany Creek, a branch of the largest tributary to Summit Lake, in 1976. In 1988, the Summit Lake Indian Reservation built an exclosure on a long reach just above the lake. The remainder of the watershed, Summer Camp Creek, was grazed for several periods since 1976. Based on annual BLM aquatic habitat monitoring from 1976 to 1990, Myers and Swanson

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(1996) found that stability and tree cover increased overall, but that grazing periods decreased stability. They also found that pool area and quality decreased due to coarse woody debris removal. Fine sediment required about five years to move through the stream after the sources began to heal, but roads and drought increased sedimentation in certain reaches.

Beginning in 1989, the Summit Lake Indian Tribe and the Nevada Department of Wildlife began a more intensive aquatic habitat inventory regime based on USFS (1985) and Pfankuch (1978). We used this more intensive data to assess changes of the SSR and stream morphologic and aquatic habitat variables in relation to management, low flows, and differences between geomorphically different stream reaches. Specifically, we examined and tested whether SSR stream morphologic and aquatic habitat variables varied with time, stream reach geomorphology, and ungulate damage. We also determined relationships between measured and ocular variables to test whether ocular methods of Pfankuch (1978) could be a rapid assessment technique for use between more detailed measurements.

STUDY AREA

Environmental Setting

The Mahogany Creek watershed drains 34.4 km^2, evenly divided between Mahogany Creek and Summer Camp Creek, westward from the Black Rock Mountains in northwestern Nevada. The geologic substrate of the watershed is predominately rhyolitic and basaltic flows (Stewart and Carlson, 1978). This watershed drains into Summit Lake, a terminal lake formed by landslide dam from the Black Rock Mountains about 7840 years BP (Curry and Melhorn, 1990). Climate ranges from moist steppe to dry subhumid continental with 15 to 65 centimeters of precipitation depending on elevation (Houghton *et al.*, 1975). Woody riparian vegetation consists mostly of aspen (*Populus tremuloides*) and willow (*Salix* sp.).

We divided the streams on the watershed into three study reaches (Figure 1). The downstream Reach 1 (six sampling stations) is on the Summit Lake Indian Reservation. This reach is flat (<1 percent), sinuous (>2), and slightly entrenched (floodable area exceeds 2.2 times the channel width) with moderate width/depth ratio (>12), and has a sandy substrate. Reach 2 (six sampling stations) combines a reach on Mahogany Creek between the confluence and reservation with Summer Camp Creek because of similar size and management. Reach 3 (five sampling stations) is the exclosed Mahogany Creek branch. Both Reaches 2 and 3 have moderate channel width/depth ratio (>12), sinuosity (1.2 to 1.4), entrenchment (floodable area less than 2.2 times the channel width), and gradient (2 to 4 percent) with predominately gravel substrate. Reach 1 is type C5, although near the lake it is narrower and is almost type E5, and Reaches 2 and 3 are type B4 in the Rosgen (1994) stream classification.

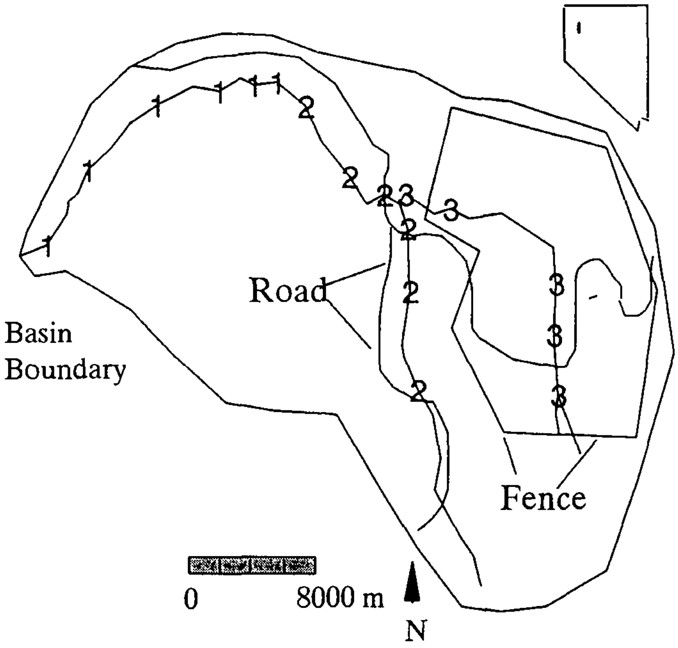

Figure 1. Site Map Showing Watershed, Study Sites With Number Representing the Reach Number, Roads, and Exclosure Fencing.

A U.S. Geological Survey gaging station has operated since 1987 below the confluence of Mahogany Creek and Summer Camp Creek and about 4 km above Summit Lake. Average monthly streamflow is 0.08 cms. Random streamflow measurements indicated that baseflow on Summer Camp Creek is 25 percent higher than on Mahogany Creek. Based on records extension back to 1976 (Myers and Swanson, 1996), this study period (1989-92) coincided with the last four years of a seven-year drought with flows in 1992 being the lowest on record. Flows in 1990 were approximately normal.

Land Management

The BLM built an exclosure around the Mahogany Creek watershed (Figure 1) in 1976 to eliminate livestock grazing. Annual grazing occurred on Reach 1 on the reservation until 1988 when a riparian exclosure was built. At the beginning of this study, Reach 1 had been grazed annually for many years but rested for one, Reach 2 had been rested for two years (Myers and Swanson, 1996), and Reach 3 had been rested for 14 years. During the study period, Reach 1 and 3 were rested, while the pasture containing Reach 2, with approximately 5 km of stream, was grazed from July 1 to August 30, 1990, by 730 cattle. Riparian utilization was approximately 40 percent of the year's new growth, with utilization at individual sites classified as moderate to heavy (BLM, 1993). There were approximately 300 wild horses in the pasture containing Summer Camp Creek in 1990 (BLM, 1993). The exclosure limited but did not eliminate horse usage of Mahogany Creek (Myers and Swanson, 1996).

Other management activities affected these watersheds. There are approximately 2 km/km^2 of road in both basins with two at grade crossings per reach within the study reach (Figure 1). These roads serve as a source of sediment to the stream (Myers and Swanson, in press). Also, managers cleared the streams of coarse woody debris in the 1970s to clear fish passages (Jack Piccolo, Summit Lake Tribal Fisheries Biologist, personal communication, 1993). This coarse woody debris removal decreased pool area and quality and will probably limit pool recovery until the riparian vegetation recovers (Myers and Swanson, 1996).

METHOD OF ANALYSIS

Field Methods

Surveyors randomly established 17 inventory stations distributed within predetermined reaches. An inventory station has five systematic transects with 15 m spacing resulting in a 75 m subreach being inventoried. Spacing between stations averages less than 1 km (Figure 1), which results in an inventory of 8 percent of total stream length. Ocular estimates on each bank integrate 7.5 meters up- and downstream from each transect. Parameters measured across transects are averaged over the entire station and expressed as a percent of water width.

Surveyors measured the water width and fraction of that width which are pools, the fraction consisting of various substrate types, and depths. They estimated bank stabilities, Pfankuch (1978) stability variables, and vegetation cover types. From these data, we calculated aquatic habitat and stream morphologic variables (Table 1) and used Pfankuch SSR variables (Table 2). We split all SSR variables into binary indicators of good or fair at their median value for analysis as an indicator variable. Myers and Swanson (1992) found that channel capacity, cutting, and brightness were least often properly identified by surveyors. The splitting of variables into binary indicators should eliminate much of this variability. The methods also provided estimates of ungulate damage due to grazing, which we reduced to a binary indicator of damaged or undamaged.

Statistical Methods

We analyzed SSR variables for variation among reach and change with time by using three-way (reach (R), year (Y), and SSR variable level (S)) log-linear models (Fienberg, 1980). We chose to test the hierarchy of complete independence ([R][Y][S]), interaction of reach and SSR variable ([RS][Y]), interaction of reach and SSR variable and of year and SSR variables ([RS][YS]), and interaction of each pair of terms ([RS][YS][RY]). We determined expected cell counts for each model according to Fienberg (1980) and their corresponding test statistic:

$$\chi^2 = \sum \frac{(Obs - Exp)^2}{Exp} \tag{1}$$

Here, Obs is observed and Exp is expected count of each cell. If the fitted model is correct and the sample size is large, χ^2 have chi-square distributions where the degrees of freedom equals the difference between number of cells (3x3x2=18) and number of parameters fit. When [RS][YS][RY] is significant (high χ^2, low probability), it is the best fit model. When [RS][YS][RY] is not significant, we tested the difference between test statistics for [RS][YS][RY] and [RS][YS]. When the difference is significant, [RS][YS][RY] is still the best model. If not, we considered the significance of [RS][YS]. The decision rule is to stop partitioning the interactions when either the model or the difference between models is significant at the 10 percent level and to choose as the best model the model in the previous step (Fienberg, 1980).

We considered the hypothesis that SSR ratings were independent from ungulate damage by using standard 2x2 chi-square analysis (Fienberg, 1980) with data pooled from all three reaches for only the grazed year, 1990.

SSR variables may be correlated, and, because we were interested in knowing which combination best explained variations of the stream morphologic variables, we used a multiple regression indicator

TABLE 1. Definition of Aquatic Habitat and Stream Morphologic Variables.

Variable	Definition
Pool* Percent	Percent of total stream width classified as pools.
Pool Quality	Percent of pools rated as high quality pools.
Percent Cobble-Gravel	Percent of stream bottom classified as cobble or gravel (2 to 302 mm).
Stability	Percent of banks rated as stable.
COVER	Percent desirable bank vegetation. Assumes that shrubs are most desirable and that tree, grass and forbs, and exposed banks are 75, 50, and 25 percent, respectively, as desirable.
Water Width/Depth	Ratio of the water width to the average water depth.

*A pool is a reach of stream with surface velocity less than 0.3 mps (USFS, 1985).

Note: A stable bank has no signs of erosion or recent deposition and generally is well protected by vegetation or rock.

TABLE 2. Description of SSR Variables. Ratings are scaled so that the lowest values are the best and the highest values are the poorest. We divided the scores at their median value into good and fair categories (see Myers and Swanson, 1992; Pfankuch, 1978; or USFS, 1992, for detailed description of the ratings).

No. SSR	Name	Rating	Description
1	Landform Slope	1-8	Steepness of the land adjacent to the stream channel.
2	Mass Wasting	1-12	Existing or potential detachment of and downslope movement of large soil clods.
3	Debris Jam Potential	1-8	Presence of floatable objects on bank. Rating considers size and amount.
4	Vegetation Bank Protection	1-12	Percent cover of trees, shrubs, grass and forbs.
5	Channel Capacity	1-4	Rating of channel width/depth ratio with smallest being best.
6	Bank Rock Content	1-8	Size and amount of bank rock.
7	Obstructions and Flow Detectors	1-8	Rating of stability of objects which deflect flow and whether they cause stable pool-riffle sequences.
8	Cutting	1-16	Bank scour leading to degradation.
9	Deposition	1-16	Amount and size of material deposited on lower banks.
10	Rock	1-4	Amount of sediment rounding due to transport.
11	Brightness	1-4	Amount of staining.
12	Consolidation and Particle Packing	1-8	Degree of packing in the substrate.
13	Bottom Size Distribution and Stable Materials	1-16	Changes from natural size distribution and the percent of substrate judged to be stable (not abnormally transporting).
14	Scouring and Deposition	1-24	Evidence of scour or deposition on the stream bottom leading to stable pool-riffle sequences.
15	Clinging Vegetation	1-4	Amount of vegetation clinging to rocks.
16	Upper Bank	4-40	Sum of SSR Variables 1 to 4.
17	Lower Bank	5-52	Sum of SSR Variables 5 to 9.
18	Channel Bottom	6-60	Sum of SSR Variables 10 to 15.
19	Total SSR	15-152	Sum of all SSR variables.

variable design. We performed the following indicator variable analysis:

$$V = B_0 + B_1 \boldsymbol{SSR1} + B_2 \boldsymbol{SSR2} + \ldots + B_{15} \boldsymbol{SSR15} \quad (2)$$

Here, SSR* represented indicator variables of 14 individual SSR variables (excepting rock angularity, SSR10) and equaled 1 if good and 0 if fair according to the binary classification specified above.

We used indicator variable analysis to determine whether dependent variables varied among reaches, years, or a combination of both:

$$V = B_0 + B_1 \boldsymbol{Yr2} + B_2 \boldsymbol{Yr4} + B_3 \boldsymbol{R2} + B_4 \boldsymbol{R3}$$

$$+ B_5 \boldsymbol{R2Y2} + B_6 \boldsymbol{R2Y4} + B_7 \boldsymbol{R3Y2} + B_8 \boldsymbol{R3Y4} \quad (3)$$

In this relation, V represents a normally distributed dependent variable, Yr2 and Yr4 represent 1990 and 1992 while 1989 is the base year, R2 and R3 represent Reaches 2 and 3, respectively, while Reach 1 is the base, and the other terms are interaction terms defined as the product of its constituent parts. All independent indicator variables equal 1 if the observation is the given year or reach. Significant coefficients for the year or reach terms indicate variation from the base values. Significant interaction term coefficients indicate that variation from the base is limited to specific years and reaches.

We tested the variation of stream morphologic variables and aquatic habitat variables with vegetation type lumped over reach and year by using parametric or Kruskal-Wallis nonparametric one-way analysis of variance (Sokal and Rohlf, 1981). Correlations among the SSR variables were determined using Spearman rank correlations (Sokal and Rohlf, 1981). Percentile data is normally distributed if values cluster away from the range boundaries of 0 and 100. Pool quality and bank stability are not normally distributed because of many values on either boundary.

RESULTS

SSR Variable Correlation

Correlation between individual SSR variables ranged from near 0 (debris jam potential and brightness) to 0.88 (mass wasting and cutting) (Table 3). High correlation suggests processes occurring simultaneously or sequentially on different portions of the bank or similar variable definitions.

Variation of SSR Variables with Time and Reach

Table 4 presents selected log-linear models for variation of SSR with reach and year and significant relations among SSR variables and ungulate damage. An explanation of how we chose the model for interaction of reach and SSR for variable 1 (landform slope) provides an example of how we chose the best models throughout Table 4. Model [RY][RS][YS] has $\chi^2 = 2.29$ with P=0.68, and the difference with [YS][RS] is 1.09 with 4 degrees of freedom (the difference in df between models) and P=0.90, which is not significant. Similarly, neither [YS][RS] nor the difference with [RS][Y] is significant. However, the difference between [RS][Y] and [R][Y][S] is 10.2 with df=2 and P=0.006, which is significant. The rule described in the Method of Analysis section required that we choose [RS][Y] as the best model.

The model of complete independence best fits bank rock content, obstruction and flow deflectors, cutting, consolidation or particle packing, and the channel bottom sum. Bank rock content cannot change over short time periods and did not vary with reach; however, banks with higher rock content were not damaged by grazing in 1990. Obstructions and flow deflectors throughout this watershed are random boulders rather than coarse woody debris which had been previously removed. Undamaged sites in 1990 had better ratings, suggesting that stable obstructions and flow deflectors limited cattle access. Cutting is very light and randomly distributed throughout the watershed because the riparian vegetation is mostly recovering and banks are building due to sediment filtration and deposition (Myers and Swanson, in review). Consolidation had poorer ratings on damaged sites due to increased fine sediment. Independence of the channel bottom sum reflected the variety of best fit models for the individual variables. The significant variation of the channel bottom sum with ungulate damage reflected the significant variation of four of the six individual variables.

The model of interaction of reach and SSR variable fits landform slope, debris jam potential, channel capacity, rock angularity, and the upper bank sum. Landform slope and channel capacity varied with reach because stream type varied between Reach 1 and Reaches 2 and 3. Debris jam potential varied with reach because Reach 1 has mostly shrubs and grass, which produce very little large woody debris. The other reaches have predominately aspen riparian areas and therefore more debris in the channel. Rock angularity varied with reach because of the transport distance among reaches.

TABLE 3. Spearman Rank Correlations of Individual SSR Variables Grouped for All Years.

SSR	Landform Slope																
Mass Wasting	.55	Mass Wasting															
Debr. Jam Pot.	.45	.18	Debr. Jam Potential														
Veg. Bank Pr.	.54	.52	.31	Vegetative Bank Protection													
Chan. Capacity	–.20	–.37	–.37	–.28	Channel Capacity												
Bank Rock Content	–.22	.06	–.34	–.19	.11	Bank Rock Content											
Obs. and Flow Defl.	.39	.49	.34	.16	–.33	–.02	Obs. and Flow Defl.										
Cutting	.53	.88	.32	.48	–.53	.04	.58	Cutting									
Deposition	.21	.56	.03	.18	–.05	.03	.37	.46	Deposition								
Rock Angularity	–.35	–.19	–.34	–.19	–.04	.34	–.02	–.14	–.32	Rock Angularity							
Brightness	.27	.19	–.00	.07	.16	.21	.10	.13	.36	–.30	Brightness						
Cons. and Part. Packing	–.04	.10	.06	–.01	–.04	.48	.16	.07	.22	.16	.09	Cons. and Part. Packing					
Size Dist. and Percent Stable	–.14	–.01	.03	–.16	–.14	.41	.22	.01	–.14	.43	–.10	.65	Size Dist. and Percent Stable				
Scouring and Dep.	.35	.39	.20	.24	–.03	–.20	.16	.34	.64	–.62	.37	–.07	–.45	Scouring and Dep.			
Clinging Vegetation	.51	.31	.46	.42	–.19	–.34	.31	.35	.23	–.24	–.01	.27	–.02	.33	Clinging Veg.		
Upper Bank Sum	*	*	*	*	–.40	–.21	.46	.76	.38	–.37	.17	.01	–.11	.42	.55	Upper Bank	
Lower Bank Sum	.30	.77	.09	.26	*	*	*	*	*	–.14	.34	.34	.14	.45	.17	.52	L. Bank
Channel Bottom Sum	.21	.31	.17	.09	–.11	.33	.31	.28	.41	*	*	*	*	*	*	.25	.51

Note: Correlation between summation variables and their constituent parts are not performed.

Mass wasting, vegetative bank protection, deposition, brightness, scouring-deposition, aquatic vegetation, lower bank sum, and total SSR varied among reach and from year to year. Mass wasting improved substantially from 1989 to 1992 (Figure 2) on all reaches. However, the improvement was least on Reach 2, which had been grazed in 1990. Vegetative bank protection increased on all reaches reflecting continued riparian recovery. On Reach 3, the improvement was all in 1992 (Figure 3), suggesting that the aspen had finally reached sufficient density to protect the banks. Deposition improved substantially but variably on Reaches 1 and 3 and was stable on Reach 2 (Figure 4), reflecting improved watershed conditions (Debano and Schmidt, 1989 and 1990). Deposition on Reach 2 paralleled the lack of improvement of mass wasting. Brightness and aquatic vegetation improved most on Reach 1 and rated better on undamaged sites. Scouring and deposition improved on all reaches, reflecting a lack of scour during low flows. Substantial improvement of the overall lower bank term on Reach 1 reflected the combined effect of livestock removal and low flow allowing recovery (Figure 5). Variable or steady responses on Reaches 2 and 3 and variation with ungulate damage indicated that grazing limited recovery but that an upper limit to improvement may exist on these reaches.

Variation of Stream Morphologic and Aquatic Habitat Variables With SSR and Vegetation Type

Relations between stream morphologic or aquatic habitat variables and SSR variables as represented by Equation (2) coefficients suggested aspects of stability that affect or control the variables (Table 5). However, as discussed below, there must be a physical connection between the variables for a significant regression coefficient to represent cause and effect.

Pool percent varied negatively with landform slope, suggesting that it varied with entrenchment. Positive variation with scouring and deposition occurred because the increase in 1992 coincided with improvement of scouring and deposition. This indicated there are more pools in stable pool-riffle (scour-deposition) sequences. Pool percent varied with vegetative bank protection probably because it is much higher when banks are forbs or shrubs. This reflects a coincidental relationship because these vegetation types occur on the low-gradient, type C5 Reach 1. Tree-lined stations

TABLE 4. Selection of Log-Linear Models for SSR Variables and Variation of SSR Variables with Ungulate Damage. S is SSR, R is reach, and Y is year. The test statistic of the selected model is underlined. If no model is selected, then the model of complete interaction has been selected which is a complete lack of information. Underlined variables varied significantly with ungulate damage at the 10 percent significance level.

Model	**[RS] [YS] [RY]**		**[RS] [S]**		**[RS] [Y]**		**[R] [Y] [S]**	
Equation	**4**		**3**		**2**		**1**	
df	**4**		**8**		**10**		**12**	
SSR	χ^2	**Prob**	χ^2	**Prob**	χ^2	**Prob**	χ^2	**Prob**
Landford Slope	2.29	.68	3.38	.91	6.66	.76	16.9	.15
Mass Waste.	3.97	.41	4.46	.81	10.0	.44	14.8	.25
Debr. Jam Potential	1.46	.83	1.59	.99	2.78	.99	18.6	.10
Vegetative Bank Protection	2.17	.70	2.98	.94	7.80	.65	27.1	.01
Channel Capacity	6.29	.18	6.8	.56	8.10	.62	20.8	.05
Bank Rock Content	1.35	.85	1.77	.99	2.90	.98	4.95	.96
Obstructions and Flow Deflectors	3.65	.46	4.05	.85	5.60	.85	8.53	.74
Cutting	3.38	.50	3.72	.88	7.40	.68	14.4	.27
Deposition	2.30	.68	3.41	.91	25.0	.01	26.0	.01
Rock Angularity	0.0	1.00	0.46	.99	1.80	.99	9.46	.66
Brightness	2.32	.68	2.87	.94	9.50	.49	9.37	.67
Cons. and Particle Packing	3.94	.41	5.20	.52	5.90	.82	6.29	.90
Bottom Size Dist. and Percent Stable	7.80	.09	7.64	.47	16.2	.09	16.6	.16
Scouring and Dep.	.10	.99	1.26	.99	38.7	.00	39.7	.00
Clinging Vegetation	2.58	.63	8.55	.38	16.1	.10	26.3	.01
Upper Bank Sum	3.28	.51	3.74	.88	6.60	.76	19.7	.07
Lower Bank Sum	5.75	.22	6.21	.62	13.6	.19	14.2	.29
Channel Bottom Sum	5.07	.28	6.0	.42	6.60	.76	7.39	.83
Total SSR	4.55	.34	3.54	.89	11.5	.32	16.2	.18

are higher gradient portions of Reaches 2 and 3, which require rapids to dissipate energy.

Pool quality varied positively with consolidation, indicating that imbricated stream bottoms and stable features lead to quality pools. It varied negatively with bottom size distribution because stable, large-sized substrate leads to rapids and small pools. Due to sediment sorting, the largest pools have the largest distribution shift from the average for the reach (Milne, 1982), thus explaining the negative relation.

Gravel/cobble percent varied slightly with debris jam potential, vegetative bank protection, and vegetation type. Vegetative bank protection was highest on grassy, low gradient banks, where the substrate was sandy and gravel/cobble percent was low. Debris jam material is least on these banks; therefore, these relationships may be due to coincidental occurrence of different vegetation types on Reach 1 where the substrate is finer. Gravel/cobble percent is higher on steeper, tree-lined reaches because of the lack of sand. Embeddedness varied with scouring and deposition because high embeddedness resulted in low scouring and deposition ratings.

Good ratings of landform slope, obstructions and flow deflectors, and scouring and deposition all reduced COVER ratings. COVER varied negatively with landform slope because it paralleled variation of vegetation type with reach. Lower landform slopes,

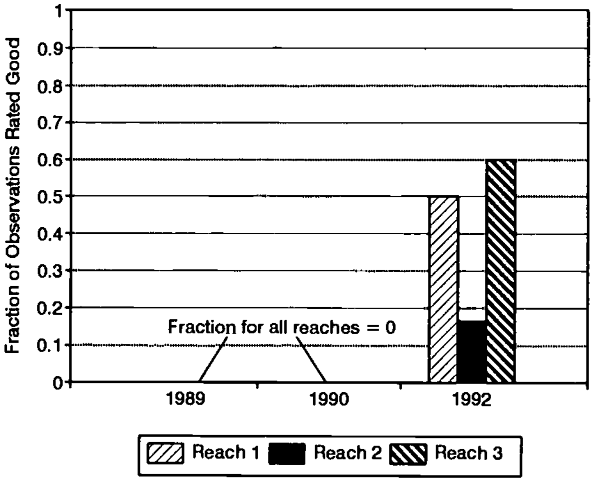

Figure 2. Variation of Mass Wasting With Year and Reach.

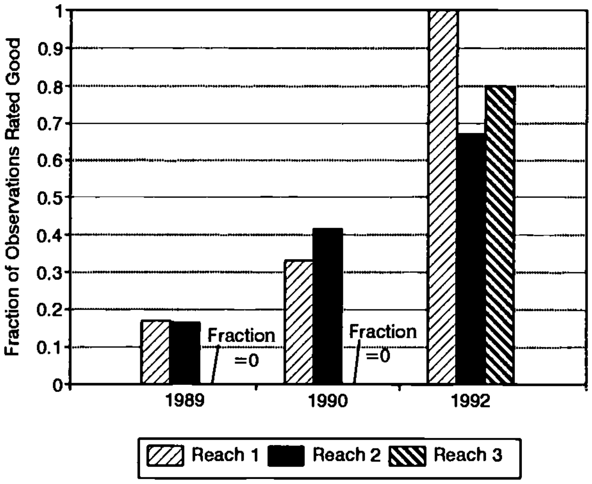

Figure 3. Variation of Vegetation Bank Protection With Year and Reach.

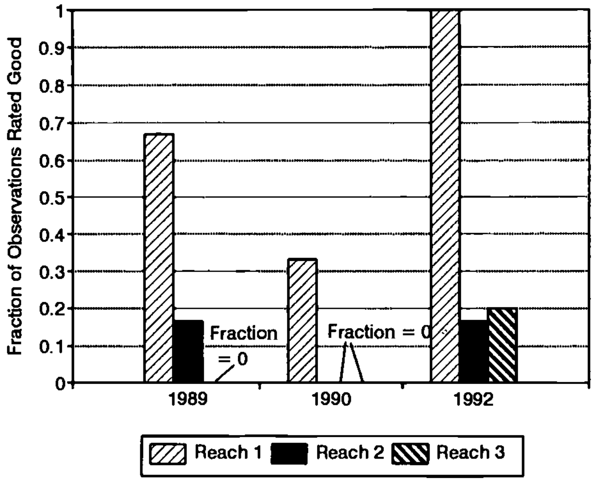

Figure 4 Variation of Deposition With Year and Reach.

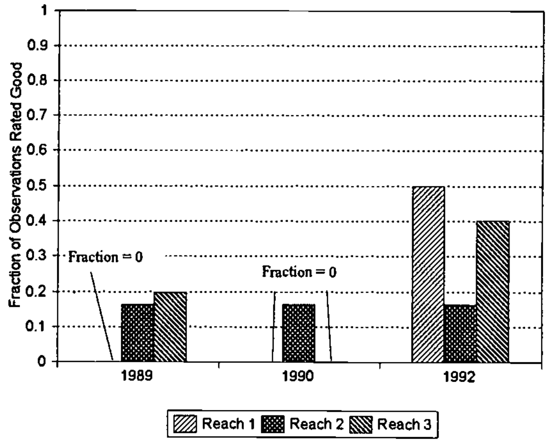

Figure 5. Variation of the Lower Bank Sum With Year and Reach.

TABLE 5. Significant ($p<0.1$) Coefficients from Least Squares Linear Regression of Stream Morphologic and Aquatic Habitat Variables With SSR Predictor Variables Described in Equation (2).

Dep. Var.	Ind. Var.	Coefficient	Error	Probability
Pool Percent	Landform Slope	–18.8	8.64	0.037
	Veg. Bank Protection	14.9	8.16	0.078
	Obs. and Flow Deflectors	15.8	8.70	0.088
	Scouring and Deposition	25.0	10.64	0.026
Pool Quality	Cons. and Part. Packing	33.1	12.24	0.011
	Bot. Size Dist. and Percent Stable	–38.2	15.74	0.021
Gravel/Cobble Percent	Debris Jam Potential	17.2	9.82	0.089
	Veg. Bank Protection	–14.9	8.77	0.099
Emb.	Scouring and Deposition	16.9	6.25	0.011
COVER	Landform Slope	–14.3	6.36	0.032
	Obs. and Flow Deflectors	–12.9	6.41	0.053
	Scouring and Deposition	–17.9	7.84	0.029
Stab.	Veg. Bank Protection	7.15	3.77	0.067
W/D	Veg. Bank Protection	–8.03	2.99	0.012

mostly on Reach 1, tended to be vegetated with grass. COVER also varied negatively with obstructions and flow deflectors because these items have had too little time to stabilize since the debris removal in the 1970s. The best scouring and deposition ratings occurred with grassy banks because the few pools formed by coarse woody debris on tree-lined reaches are less stable.

Stability varied only with vegetative bank protection. That neither cover varied with vegetative bank protection nor stability with vegetation type indicated that for these streams, grass, trees, and shrubs all provided adequate vegetative bank protection.

Finally, water width/depth ratio varied with vegetative bank protection. This agrees with other studies (Zimmerman *et al.*, 1967; Smith, 1976; Madej *et al.*, 1994), but its lack of variation with other variables, including vegetation type, is disturbing. Apparently, the narrow range of values did not provide sufficient variation of channel shapes to reflect trends.

Variation of Stream Morphologic and Aquatic Habitat Variables With Time and Reach

We used the Equation (3) model to test for variation with time and reach. Pool percent varied significantly with year and reach (p=0.000 and 0.035, respectively). There was a significant decrease between 1989 and 1990 on Reaches 1 and 2 and an increase between 1990 and 1992 on all reaches (Figure 6). Pools throughout tended to be of moderate quality in 1989 but poor in 1990 and 1992 (Figure 7) due to decreased depth resulting from infilling and drought. The increased area in 1992 resulted from low velocities.

Gravel/cobble percent and embeddedness varied among years (p=0.001 and 0.000, respectively). Trends with time were opposite (Figures 8 and 9), reflecting small increases in sedimentation with heavy grazing in 1990 and large increases with drought in 1992. Slight variation of cobble/gravel percent with reach (p=0.092) reflected differences between a sand bed in Reach 1 and gravel beds in Reaches 2 and 3.

Water width/depth ratio varied with year (p=0.058) because of a small increase from 1989 to 1990 (Figure 10), mostly on Reach 1. Slight variation among reaches reflected a decreasing width/depth ratio in Reach 1, possibly due to vegetative channel roughness that induced deposition and bank building (Table 6).

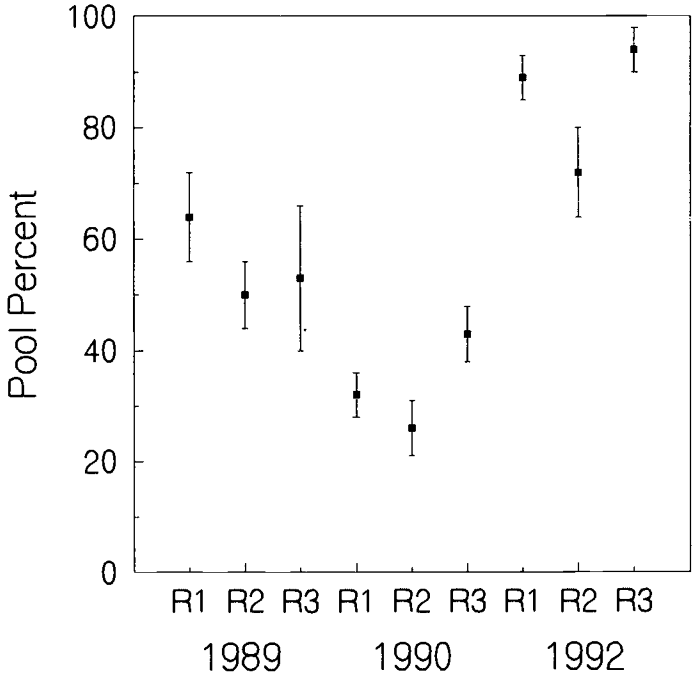

Figure 6. Variation of Pool Percent With Year and Reach (R1, R2, or R3). Lines represent the mean ± one standard error.

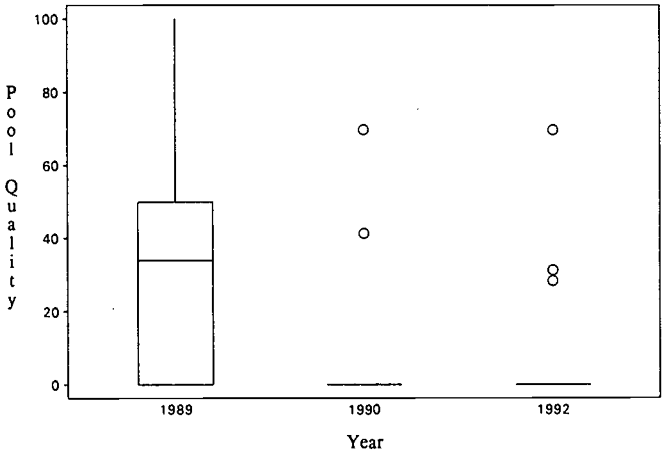

Figure 7. Variation of Pool Quality With Year. The box encloses the middle half of the data; the line bisecting the box represents the median; 0 represents probable outliers.

DISCUSSION

SSR Variables

Pfankuch (1978) SSR variables responded differently with time on different reaches. Different stream types responded differently to the grazing perturbation and will recover at different rates. The U.S. Forest Service identified critical elements from Pfankuch

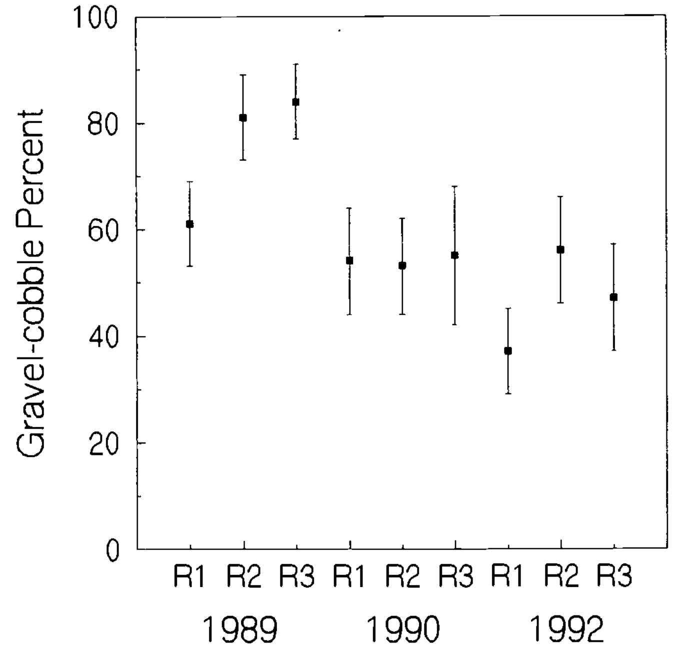

Figure 8. Variation of Gravel-Cobble Percent With Year and Reach (R1, R2, or R3). Lines represent means ± one standard error.

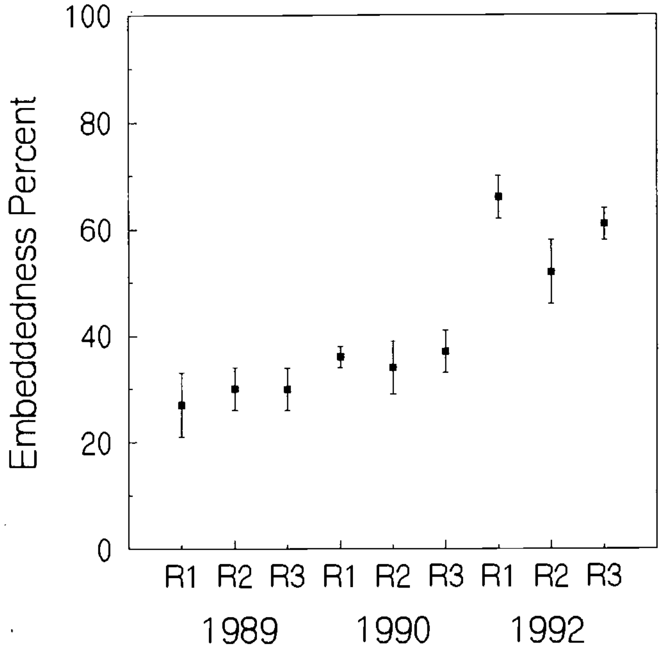

Figure 9. Variation of Embeddedness With Year and Reach (R1, R2, or R3). Lines represent means ± one standard error.

stability variables to best represent channel portions for various stream types (Kaplan-Henry *et al.,* 1994). Our identification of mass wasting, vegetative bank protection, deposition, and scouring and deposition agreed with Forest Service critical elements for temporal change on B4 streams. The relatively high correlation (Table 3) among all these variables suggested they represent similar processes affecting all three portions of the channel cross-section.

Landform slope and debris jam potential differed among reach (stream type) and did not change much with time. Channel capacity differed among reaches due to stream type differences. The negative correlation between channel capacity and upper bank sum suggested that narrow channels tended to be steep and erosive on their upper banks, reflecting stream type differences. We expect that bank rock content, consolidation, and bottom size distribution would distinguish reaches in differing geology. Obstructions and flow deflectors should distinguish riparian vegetation. These variables should be considered critical elements for distinguishing inherent differences among reaches.

Reach 3 had substantial improvements of mass wasting and vegetative bank protection (Figures 2 and 3) between 1990 and 1992. These variables have low observer variability (Myers and Swanson, 1992). Their continued improvement after 16 years of rest reflected the substantial time for recovery of tree vegetation (Myers and Swanson, in review) and the conditions of the upper bank. The improvement of the lower bank on Reach 3 (Figure 5) reflected changes allowed by the low flows such as vegetation of lower banks and no erosion.

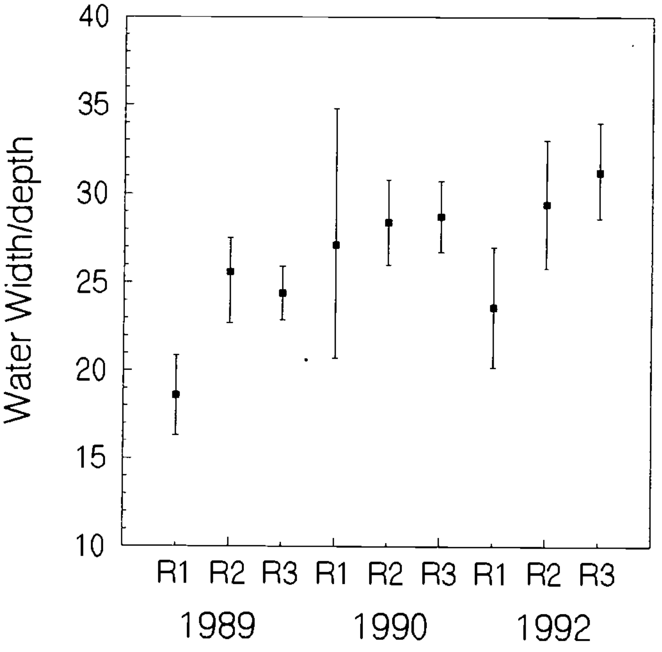

Figure 10. Variation of Water Width/Depth With Year and Reach (R1, R2, or R3). Lines represent means ± one standard error.

TABLE 6. Variation of Stream Morphologic Parameters With Vegetation Type.

Variable		Forbs	Trees	Shrubs	F	Prob.
One-Way Parametric Analysis of Variance						
Pool Percent	Mean	71.7A	45.5B	72.6A	7.21	0.002
	Standard Deviation	25.0	22.0	23.7		
Gravel/Cobble	Mean	54.1A	67.6B	50.2A	2.44	0.099
	Standard Deviation	22.2	24.1	23.0		
Embeddedness	Mean	46.0	35.8	48.0	2.41	0.101
	Standard Deviation	20.1	14.1	16.5		
W/D	Mean	25.7	27.8	23.2	1.35	0.270
	Standard Deviation	9.51	5.77	5.61		
Kruskal-Wallis One-Way Nonparametric Analysis of Variance						
Pool Quality Rank		22.8	21.8	28.2	2.32	0.31
Stability Rank		25.8	20.8	25.2	1.42	0.49

Stream Morphologic and Aquatic Habitat Variables

Variations in pool percent and quality reflected grazing impacts, the lack of stable coarse woody debris necessary for pool formation (Myers and Swanson, 1994; Smith *et al.*, 1993), gradient (Wohl *et al.*, 1993; Hubert and Kozel, 1993), substrate (Milne, 1982), and drought. Infilling during drought increased flatwater or low quality pools. During normal flows in 1990, pool percent ranged from 25 to 40 percent on Reaches 2 and 3, which may be near normal for B4 streams (Myers and Swanson, 1991). Values are high on Reach 1 in low flow years (1989 and 1992) because low-gradient C5 streams become one long, low-quality pool. Variation with obstructions and flow deflectors indicated dependence on structural components responsible for pool formation (Myers and Swanson, 1994). However, when boulders are small and random, they do not form significant pools (Zgheib, 1990) as is apparent on these streams. Just as a lack of boulders represents a geologic limit to stable pools, lack of coarse woody debris represents an anthropocentric limit to pools in the short run (Andrus *et al.*, 1988).

Trends in substrate parameters reflected sources of and ability to transport fine sediment. Pools accumulate fine sediment if the watershed provides a source (Lisle and Hilton, 1992) such as roads (Brown, 1994; Eaglin and Hubert, 1993) in this watershed (Myers and Swanson, 1996). The fine sediment does not flush during low flows (Hubert and Kozel, 1993). Grazing increased embeddedness much less than drought and road crossings. An apparent limitation to improvement in this watershed is the number of road crossings.

The decreasing width/depth ratio with time on Reach 1 and with vegetative bank protection while remaining constant on the rest of the watershed reflected inherent differential responses to similar inputs due to gradient, soils, vegetation, and geology (Kelson and Wells, 1989). As herbaceous and shrubby vegetation recovered due to exclosure (Platts *et al.*, 1983), Reach 1 became narrower as expected (Smith, 1976; Zimmerman *et al.*, 1967). The lack of confinement allows meandering (Howard and Knutson, 1984) such that active channels and floodplains can be reworked. In combination with establishing vegetation (Osterkamp and Hupp, 1984), this channel reworking may lead to type changes from C5 to E5 (Rosgen, 1994). However, as seen by increased width in 1990, sediment loading may limit narrowing and improvement of the downstream reach (Schumm, 1977; Kondolf, 1993) unless vegetation becomes established and causes accretion (Hupp and Simon, 1991) and channel narrowing (Smith, 1976; Graf, 1978). The ultimate fate of Reach 1 depends on management of the entire watershed (DeBano and Schmidt, 1990; Kondolf, 1993).

The lack of variation of width/depth ratio in Reaches 2 and 3 reflected the stability and slow recovery rate of B4 channels. These reaches should not narrow very much because of their moderate entrenchment, gravel bed load, and the prevalence of tree cover which will not filter much sediment. Tree cover also tends toward wider channels than grass or herb covered banks (Murgatroyd and Ternan, 1983; Zimmerman *et al.*, 1967).

CONCLUSION

The results of this research and Myers and Swanson (1996) illustrate how stream type limits the effectiveness of management because different stream types have different potential conditions and recovery rates. Land managers should set objectives based on the potential of the specific stream and its potential rate of change.

Significant variations of aquatic habitat and stream morphologic variables with SSR variables indicate that the ocular rating system provided an adequate means of monitoring habitat conditions. In addition to the link with habitat variables, managing agencies should continue to use these methods as supplements to more detailed surveys for three reasons. First, they are rapidly applied in the field. This is an important consideration to agencies responsible for many streams as they face negative budget pressures. Second, the methods force surveyors to observe attributes important to the hydrology and habitat of the system. Surveyors' field notes and photographs should focus on problems discovered using this methodology. Third, rapid ocular surveys focusing on critical SSR variables performed every one or two years would bridge longer time periods between more intensive surveys and help avoid major stream problems.

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